Instruction to Students:

Proposed Project Titles for Internal Assessment on Course Code:ENVSC-3031, Course type : Multidisciplinary Course -SEM-III : F.M.-10

Answer any one of the following (within 10 pages in Bengali or English):

1. Atmospheres of the Earth পৃথীবির বায়ুমন্ডল
2. Green House effects গ্রীন হাউস এফেক্ট
3. Global warming বিশ্ব উষ্ণায়ন

Project parameters for writing

1. Front Page-Title of the Project

Subject Code: ENVSC-3031

Name of the student :

Registration No.

Course: 4yr or 3yrs degree

Roll No.

Session

Next Page-

1) Introduction (ভূমিকা),

(From internet books, study materials or any other literature survey)

2) Objectives (উদ্দেশ্য)

3) Methodology (পদ্ধতি)

4) Causes (কারন) of Global warming/ Green house effects (if opts 2 /3); layers for atmosphere with important features (গুরুত্বপূর্ন বৈশিষ্ট্য) (if opt 1)

5) Effect (প্রভাব)of green house gasses and global warming on biodiversity (জীববৈচিত্র্য) (if opts 2 /3);in case of earth atmosphere-composition, and Significance (গুরুত্ব) of presence, etc).

6) How to solve the problems (কিভাবে সমস্যার সমাধান হবে)

7) Acknowledgement (কৃতজ্ঞতাস্বীকার)

2. Staple and Channel file-Submit within specific date as directed by Respective teacher.

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
1	202301035424	2023-24	230140340001	AFRIN KHATUN	afrinkhatun4839@gmail.com	8777450834	4-Year I	B.A.	Prof. Samik Dasgupta
2	202301035425	2023-24	230140340002	AFRIN KHATUN	afrin747777@gmail.com	7477771343	4-Year I	B.A.	
3	202301035426	2023-24	230140340003	AFRIN SULTANA	afrinsultana20041211@gmail.com	7047628120	4-Year I	B.A.	
4	202301035430	2023-24	230140340004	AFSANA KHATUN	tsk589054@gmail.com	6297744120	4-Year I	B.A.	
5	202301035436	2023-24	230140340005	AKAS CHATTERJEE	chatterjeeakash560@gmail.com	7864885289	4-Year I	B.A.	
6	202301035438	2023-24	230140340006	AKASH DHAK	akashdhak6@gmail.com	7439384908	4-Year I	B.A.	
7	202301035441	2023-24	230140340007	AKSHAY HALDAR	akshayhaldar51@gmail.com	9093283075	4-Year I	B.A.	
8	202301035451	2023-24	230140340008	ANAMIKA SARKAR	ayansarkar4896@gmail.com	9046114800	4-Year I	B.A.	
9	202301035452	2023-24	230140340009	ANANNYA KARMAKAR	anannyakarmakar17@gmail.com	8617453607	4-Year I	B.A.	
10	202301035453	2023-24	230140340010	ANANNYA MALIK	annamalik57755@gmail.com	9735641218	4-Year I	B.A.	
11	202301035455	2023-24	230140340011	ANIK BANERJEE	arunbanerjee158@gmail.com	8367801963	4-Year I	B.A.	
12	202001039688	2020-21	230140340012	ANIK DAS	anikdasdark@gmail.com	7718281852	4-Year I	B.A.	
13	202301035462	2023-24	230140340013	ANISA BEGUM	tutul712149@gmail.com	8116992676	4-Year I	B.A.	
14	202301035465	2023-24	230140340014	ANITA MONDAL	anitamondal12345609@gmail.com	9883313158	4-Year I	B.A.	
15	202301035472	2023-24	230140340015	ANKITA GANGULY	ankitaganguly552@gmail.com	8597426904	4-Year I	B.A.	
16	202301035474	2023-24	230140340016	ANKITA GHOSH	ag9234502@gmail.com	9647654899	4-Year I	B.A.	
17	202301035475	2023-24	230140340017	ANKITA MALIK	am3950937@gmail.com	9832773909	4-Year I	B.A.	
18	202301035477	2023-24	230140340018	ANKITA PAUL	anayaanuska355@gmail.com	8927274215	4-Year I	B.A.	
19	202301035481	2023-24	230140340019	ANSHIKA GHOSH	anshikaghosh98@gmail.com	9800134972	4-Year I	B.A.	
20	202301035482	2023-24	230140340020	ANTARA BHATTACHARJEE	bhattacharjeeantara882@gmail.com	9907977310	4-Year I	B.A.	
21	202301035485	2023-24	230140340021	ANUPA ROY	royanupa75@gmail.com	8767423671	4-Year I	B.A.	
22	202301035487	2023-24	230140340022	ANUSHREE LOHAR	anushreelohar194@gmail.com	7602518992	4-Year I	B.A.	
23	202301035492	2023-24	230140340023	ARCHITA MUKHERJEE	mukherjeeatishkumar@gmail.com	7602605090	4-Year I	B.A.	
24	202301035498	2023-24	230140340024	ARIJIT MUKHERJEE	arijit55625@gmail.com	7718271077	4-Year I	B.A.	
25	202301035501	2023-24	230140340025	ARINDAM SOREN	arindamsaren72@gmail.com	8101839464	4-Year I	B.A.	
26	202301035505	2023-24	230140340026	ARMIN SULTANA	arminsultana049@gmail.com	9800396785	4-Year I	B.A.	
27	202301035508	2023-24	230140340027	ARNAB SANTRA	ww.bidyutsantra12@gmail.com	9734036521	4-Year I	B.A.	
28	202301035525	2023-24	230140340028	ASHRITA THAKUR	ahsritathakur@gmail.com	7908234923	4-Year I	B.A.	
29	202301035526	2023-24	230140340029	ASIFA KHATUN	khatunasifa187@gmail.com	9641403481	4-Year I	B.A.	
30	202301035538	2023-24	230140340030	AVEEK ROY	aveekroy29@gmail.com	6297861913	4-Year I	B.A.	
31	202301035542	2023-24	230140340031	AVIPSA TRIBEDI	avipsatribedi@gmail.com	8910871039	4-Year I	B.A.	
32	202301035546	2023-24	230140340032	AYESHA KHATUN	arsenbiswas@gmail.com	9679671226	4-Year I	B.A.	
33	202301035547	2023-24	230140340033	BABAI KSHETRAPAL	babaikshetrapal447@gmail.com	7811863201	4-Year I	B.A.	
34	202301035555	2023-24	230140340034	BAPAN DAS	bdas66134@gmail.com	7439301905	4-Year I	B.A.	
1	202301035561	2023-24	230140340035	BARSHA AHIR	barshaahir24@gmail.com	8670908963	4-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
2	202301035562	2023-24	230140340036	BARSHA BHATTACHARYYA	barshabhattacharyya5@gmail.com	6295668531	4-Year I	B.A.	Prof. Anjan Dasgupta
3	202301035579	2023-24	230140340037	BINA HEMBRAM	binahembram2001@gmail.com	7074663586	4-Year I	B.A.	
4	202301035580	2023-24	230140340038	BINAY KUMAR DAS	binaykrdas029@gmail.com	6296268913	4-Year I	B.A.	
5	202301035581	2023-24	230140340039	BIPASHA BHATTACHARYA	bipashabhattacharya99@gmail.com	7431852955	4-Year I	B.A.	
6	202301035584	2023-24	230140340040	BIPASHA MONDAL	bipashamondal454@gmail.com	6294045637	4-Year I	B.A.	
7	202301035587	2023-24	230140340041	BISAKHA SOREN	bishakhasoren350@gmail.com	7872730313	4-Year I	B.A.	
8	202301035592	2023-24	230140340042	BITHIKA JANA	bithikajana067@gmail.com	7063279187	4-Year I	B.A.	
9	202301035598	2023-24	230140340043	BRISTI LOHAR	bristi712149@gmail.com	8016183047	4-Year I	B.A.	
10	202301035599	2023-24	230140340044	BRISTI MALIK	brishtimalik30@gmail.com	8391855306	4-Year I	B.A.	
11	202301035609	2023-24	230140340045	CHANDAN BAG	chandanbag566@gmail.com	6296920343	4-Year I	B.A.	
12	202301035625	2023-24	230140340046	DEBASMITA SARKAR	sarkardebasmita2005@gmail.com	9832850378	4-Year I	B.A.	
13	202301035630	2023-24	230140340047	DEBKALPO GHOSH	debkalpo2005@gmail.com	7003012213	4-Year I	B.A.	
14	202301035631	2023-24	230140340048	DEBOBRATA MURMU	mrxdebobrata01@gmail.com	8016115893	4-Year I	B.A.	
15	202301035633	2023-24	230140340049	DEBOLINA GHOSH	sonaighosh0212@gmail.com	9832311996	4-Year I	B.A.	
16	202301035635	2023-24	230140340050	DEBOPRIYA MAJI	majidebopriya22@gmail.com	7602030841	4-Year I	B.A.	
17	202301035658	2023-24	230140340052	FARHIN SULTANA	farhinsultana992@gmail.com	7363099501	4-Year I	B.A.	
18	202301035663	2023-24	230140340053	GARGI MAJUMDAR	gargimajumdar14012006@gmail.com	7044129002	4-Year I	B.A.	
19	202301035676	2023-24	230140340054	ISMATARA KHATUN	taniyask09@gmail.com	9883824750	4-Year I	B.A.	
20	202301035692	2023-24	230140340055	JESMIN SULTANA	jesminsk8899@gmail.com	9002928899	4-Year I	B.A.	
21	202301035693	2023-24	230140340056	JESMINA KHATUN	shaikhsamima032@gmail.com	8972357727	4-Year I	B.A.	
22	202301035703	2023-24	230140340057	JOBIDA RAHAMAN	monoararj@gmail.com	7908600286	4-Year I	B.A.	
23	202301035708	2023-24	230140340058	JUNAID HOSSAIN MOLLAH	junaid2005hoera@gmail.com	9046372741	4-Year I	B.A.	
24	202301035711	2023-24	230140340059	JYOTI HEMBRAM	hbapi5319@gmail.com	9932418203	4-Year I	B.A.	
25	202301035725	2023-24	230140340060	KHADIJA SULTANA	sksurab282@gmail.com	8642925491	4-Year I	B.A.	
26	202301035737	2023-24	230140340061	KOYEL RUIDAS	rakhiruidas5678@gmail.com	9832221668	4-Year I	B.A.	
27	202301035741	2023-24	230140340062	KOYEL THAKUR	koyelthakur54@gmail.com	8116692114	4-Year I	B.A.	
28	202301035749	2023-24	230140340063	KUNAL HANSDA	hansdak905@gmail.com	8617612826	4-Year I	B.A.	
29	202301035750	2023-24	230140340064	KUNAMI MURMU	kunamimurmu35@gmail.com	8293923838	4-Year I	B.A.	
30	202301035751	2023-24	230140340065	KUSHAL KARMAKAR	karmakarkushal33@gmail.com	7044328923	4-Year I	B.A.	
31	202301035753	2023-24	230140340066	KUSHAL SARKAR	ks6550515@gmail.com	9907492824	4-Year I	B.A.	
32	202301035758	2023-24	230140340067	LAKSHI SANDITA KSHETRAPA	kshetrapalmala818@gmail.com	7980799906	4-Year I	B.A.	
33	202301035775	2023-24	230140340068	MADHUMITA BISWAS	biswasmadhumita20@gmail.com	8609086488	4-Year I	B.A.	
34	202301035793	2023-24	230140340069	MANIK BAUL DAS	manikdas009099@gmail.com	9382970038	4-Year I	B.A.	
1	202301035797	2023-24	230140340070	MANISH DAS	khanyanhattala49@gmail.com	7047473745	4-Year I	B.A.	
2	202301035798	2023-24	230140340071	MANISHA CHOWDHURY	rimichowdhury2005@gmail.com	6297131871	4-Year I	B.A.	

Bejoy Narayan Mahavidyalaya
List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
3	202301035799	2023-24	230140340072	MANISHA KHATUN	manishakhatun7029@gmail.com	7029151703	4-Year I	B.A.	Prof. Anjan Das
4	202301035802	2023-24	230140340073	MANISHA NANDI	mn3166413@gmail.com	8918178451	4-Year I	B.A.	
5	202301035805	2023-24	230140340074	MARGIYA KHATUN	margiyamarjia@gmail.com	9883497347	4-Year I	B.A.	
6	202301035807	2023-24	230140340075	MARIYAM KHATUN	sknajim830@gmail.com	7699925903	4-Year I	B.A.	
7	202301035809	2023-24	230140340076	MAYMUNA SULTANA	maymunasultana49@gmail.com	9749109009	4-Year I	B.A.	
8	202301035811	2023-24	230140340077	MD ARIFUL ISLAM	mdariful7679@gmail.com	8653227950	4-Year I	B.A.	
9	202301035813	2023-24	230140340078	MD KAIF	mdkaif2770@gmail.com	7076372770	4-Year I	B.A.	
10	202301035814	2023-24	230140340079	MD MIZARUL ISLAM	mizarul44@gmail.com	8167855602	4-Year I	B.A.	
11	202301035817	2023-24	230140340080	MD SUHAIL	hectorsuhail931@gmail.com	9046269204	4-Year I	B.A.	
12	202301035821	2023-24	230140340081	MEGHNA CHAKRABORTY	suvojitturi95@gmail.com	9064247935	4-Year I	B.A.	
13	202301035823	2023-24	230140340082	MILI BARIK	julibarik91@gmail.com	9883808600	4-Year I	B.A.	
14	202301035830	2023-24	230140340083	MITALI BAULDAS	mbauldas2@gmail.com	8918816725	4-Year I	B.A.	
15	202301035835	2023-24	230140340085	MOLI MONDAL	mondalmoli98@gmail.com	8509021591	4-Year I	B.A.	
16	202301035836	2023-24	230140340086	MOMOTAJ BEGAM	momotajbegam754@gmail.com	9339945450	4-Year I	B.A.	
17	202301035840	2023-24	230140340087	MONIDIPA MAJUMDER	monidipamajumder1@gmail.com	8637023992	4-Year I	B.A.	
18	202301035844	2023-24	230140340088	MOUMITA BAULDAS	bauldasmoumita@gmail.com	7439328227	4-Year I	B.A.	
19	202301035845	2023-24	230140340089	MOUMITA GHOSH	mailtomoumitaghosh96@gmail.com	7063630398	4-Year I	B.A.	
20	202301035851	2023-24	230140340090	MRINMOY GAYEN	gayenmrinmoy03@gmail.com	9749949541	4-Year I	B.A.	
21	202301035855	2023-24	230140340091	MUKTA DEBNATH	debnathmukta81@gmail.com	6296016294	4-Year I	B.A.	
22	202301035860	2023-24	230140340092	NAFISA KHATUN	haquerabiul260@gmail.com	7699706650	4-Year I	B.A.	
23	202301035859	2023-24	230140340093	NAFISA KHATUN	nafisakh30@gmail.com	8116690655	4-Year I	B.A.	
24	202301035861	2023-24	230140340094	NAFISHA KHATUN	khatunnafisha876@gmail.com	7001124155	4-Year I	B.A.	
25	202301035862	2023-24	230140340095	NAJIYA KHATUN	naziyakhatunkhanyan@gmail.com	9883103931	4-Year I	B.A.	
26	202301035876	2023-24	230140340096	NASRIN KHATUN	khatunnasrin47227@gmail.com	9933434443	4-Year I	B.A.	
27	202301035878	2023-24	230140340097	NASRIN SULTANA	nasrinsultana4112005@gmail.com	9883320713	4-Year I	B.A.	
28	202301035880	2023-24	230140340098	NEHA KHATUN	nehakhatun595@gmail.com	9734733378	4-Year I	B.A.	
29	202301035887	2023-24	230140340099	NISHA PRAMANIK	nishapramanikpandua@gmail.com	8250259830	4-Year I	B.A.	
30	202301035889	2023-24	230140340101	NOURIN KHATUN	nourinkhatun515@gmail.com	7865877479	4-Year I	B.A.	
31	202301035892	2023-24	230140340102	NURZIYA KHATUN	khatunnurziya4@gmail.com	7797932349	4-Year I	B.A.	
32	202301035897	2023-24	230140340103	PALLAB ACHARYA	pallabacharya49@gmail.com	6289377972	4-Year I	B.A.	
33	202301035905	2023-24	230140340104	PAPRI DHALI	dhalit340@gmail.com	8670150661	4-Year I	B.A.	
34	202301035908	2023-24	230140340105	PARAMITA MALIK	paramitamalik09@gmail.com	8371098558	4-Year I	B.A.	
1	202301035919	2023-24	230140340106	PAYEL GAYEN	gainpayel04@gmail.com	8900212004	4-Year I	B.A.	
2	202301035933	2023-24	230140340107	PIYA DHARA	piyadhara07@gmail.com	8670819546	4-Year I	B.A.	
3	202301035951	2023-24	230140340108	PRITI DAS	daspriti1227@gmail.com	9475329519	4-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
4	202301035952	2023-24	230140340109	PRITI GHOSH	priti0405ghosh@gmail.com	7602034068	4-Year	B.A.	Prof. Ashok Howlader
5	202301035953	2023-24	230140340110	PRITI GHOSH	ghoshdipakkanti@gmail.com	7439807529	4-Year	B.A.	
6	202301035955	2023-24	230140340111	PRITI MUKHERJEE	00pritimukherjee@gmail.com	9641189805	4-Year	B.A.	
7	202301035969	2023-24	230140340112	PRIYANKA PAL	priyankapal9803@gmail.com	9679831852	4-Year	B.A.	
8	202301035970	2023-24	230140340113	PRIYANKA PRASAD GUPTA	pg4629268@gmail.com	9775800041	4-Year	B.A.	
9	202301035972	2023-24	230140340114	PRODIP BHATTACHARJEE	bhattacharyapradip939@gmail.com	9735109061	4-Year	B.A.	
10	202301035982	2023-24	230140340115	PURNIMA DAS	pudas2005@gmail.com	9800067532	4-Year	B.A.	
11	202301035984	2023-24	230140340116	PUTUL HALDER	subhajithaldar54@gmail.com	7029511042	4-Year	B.A.	
12	202301035985	2023-24	230140340117	PUTUL SARKAR	putulsarkar5960@gmail.com	7063583013	4-Year	B.A.	
13	202301036015	2023-24	230140340119	RAMITA KARMAKAR	ramitakarmakar1304@gmail.com	9748763449	4-Year	B.A.	
14	202301036016	2023-24	230140340120	RAMKANAI GHOSH	ramkanaighosh5@gmail.com	6291839456	4-Year	B.A.	
15	202301036018	2023-24	230140340121	RANA SING	rana8145710557@gmail.com	8101870322	4-Year	B.A.	
16	202301036027	2023-24	230140340122	RESMINARA KHATUN	muskankhatun74471@gmail.com	7477481718	4-Year	B.A.	
17	202301036030	2023-24	230140340123	RIKI MUKHERJEE	mukherjeeriki02@gmail.com	8972732100	4-Year	B.A.	
18	202301036035	2023-24	230140340124	RIMA MONDAL	mondalrima756@gmail.com	7319342095	4-Year	B.A.	
19	202301036039	2023-24	230140340125	RIMPA ADHIKARI	rimpaadhikari38@gmail.com	6297570522	4-Year	B.A.	
20	202301036044	2023-24	230140340126	RIMPA KSHETRAPAL	rimpaa0987654321@gmail.com	9907280558	4-Year	B.A.	
21	202301036047	2023-24	230140340127	RIMPA MAJHI	rimpamajhi025@gmail.com	9907395506	4-Year	B.A.	
22	202301036054	2023-24	230140340128	RINKI GHOSH	rinkighosh2306@gmail.com	7047614806	4-Year	B.A.	
23	202301036080	2023-24	230140340131	ROHIT KARMAKAR	rohit2006karmakar@gmail.com	6290265459	4-Year	B.A.	
24	202301036086	2023-24	230140340132	RONIT GHOSH	ranitghosh149@gmail.com	8777595237	4-Year	B.A.	
25	202301036100	2023-24	230140340133	RUMANA YEASMIN	khursidurrahaman@gmail.com	9933859697	4-Year	B.A.	
26	202301036113	2023-24	230140340134	RUPSA MALIK	malikrupsa755@gmail.com	9832056601	4-Year	B.A.	
27	202301036117	2023-24	230140340135	RUPSHA DESHMUKH	rupshadeshmukh334@gmail.com	9679758597	4-Year	B.A.	
28	202301036124	2023-24	230140340136	SABNAM YESMIN	shannanyeasmin7@gmail.com	9339448589	4-Year	B.A.	
29	202301036126	2023-24	230140340137	SADIA SULTANA	sadiasultana712134@gmail.com	9883228618	4-Year	B.A.	
30	202301036134	2023-24	230140340138	SAHABUDDIN SARKAR	kaifsarkar083@gmail.com	7063010620	4-Year	B.A.	
31	202301036136	2023-24	230140340139	SAHANAJ KHATUN	khatusahanaj332@gmail.com	8250163683	4-Year	B.A.	
32	202301036139	2023-24	230140340140	SAHEBA KHATUN	babysaheba6@gmail.com	7001222498	4-Year	B.A.	
33	202301036140	2023-24	230140340141	SAHELI GHOSH	sahelighosh713@gmail.com	7384152080	4-Year	B.A.	
34	202301036149	2023-24	230140340142	SALUNIHAR YASMIN	saluniharyasmin@gmail.com	6295880057	4-Year	B.A.	
1	202301036150	2023-24	230140340143	SAMATA DAS	haraprasaddas609@gmail.com	9907323471	4-Year	B.A.	
2	202301036159	2023-24	230140340144	SAMRIN SULTANA	samrinsultana333@gmail.com	6295682730	4-Year	B.A.	
3	202301036165	2023-24	230140340145	SANCHITA MAJHI	majhisanchita5@gmail.com	8167853861	4-Year	B.A.	
4	202301036166	2023-24	230140340146	SANCHITA ROY	roysanchita200421@gmail.com	9641788945	4-Year	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
5	202301036178	2023-24	230140340147	SANIA KHATUN	saniakhatun453@gmail.com	9907793562	4-Year I	B.A.	Smt. Moumita Mukherjee
6	202301036180	2023-24	230140340148	SANIA PARVIN	blackheart0687@gmail.com	8653796181	4-Year I	B.A.	
7	202301036183	2023-24	230140340149	SANIA SULTANA	saniasultana67890@gmail.com	8250569230	4-Year I	B.A.	
8	202301036182	2023-24	230140340150	SANIA SULTANA	saniasultana396@gmail.com	9883965778	4-Year I	B.A.	
9	202301036192	2023-24	230140340151	SAPTAMI SANTRA	saptamisantara@gmail.com	7477879297	4-Year I	B.A.	
10	202301036200	2023-24	230140340152	SARMIN SULTANA	sarminsultana4464@gmail.com	9641450076	4-Year I	B.A.	
11	202301036209	2023-24	230140340154	SATYAJIT KONHAR	satyajitkonhar0@gmail.com	9933824784	4-Year I	B.A.	
12	202301036210	2023-24	230140340155	SAYAK NANDY	sayaknandy8@gmail.com	8509630191	4-Year I	B.A.	
13	202301036218	2023-24	230140340156	SAYANI RAY BARMAN	sayaniroybarman0@gmail.com	8597012442	4-Year I	B.A.	
14	202301036226	2023-24	230140340157	SHAHNAJ KHATUN	kshahnaj923@gmail.com	9800725999	4-Year I	B.A.	
15	202301036233	2023-24	230140340158	SHARMILA ACHARYA	sharmilaacharya873@gmail.com	8617868452	4-Year I	B.A.	
16	202301036237	2023-24	230140340159	SHARMISTHA ADHIKARI	adhikarisanat6@gmail.com	9832808907	4-Year I	B.A.	
17	202301036242	2023-24	230140340160	SHIBSANKAR MURMU	shibsankarmurmu554@gmail.com	7478431657	4-Year I	B.A.	
18	202301036247	2023-24	230140340162	SHRABANI BAG	rinkubag279@gmail.com	7319096013	4-Year I	B.A.	
19	202301036256	2023-24	230140340163	SHREYA GHOSH	bablighosh003@gmail.com	8159942150	4-Year I	B.A.	
20	202301036259	2023-24	230140340164	SHREYA NANDY	shreyanandy946@gmail.com	9153017862	4-Year I	B.A.	
21	202301036262	2023-24	230140340165	SHUKDEB BAULDAS	bosssukdebdas123@gmail.com	9907623949	4-Year I	B.A.	
22	202301036269	2023-24	230140340166	SHYAMAY BANDOPADHYAY	Shyamaybandhopadhyay@gmail.com	7439758844	4-Year I	B.A.	
23	202301036280	2023-24	230140340167	SIMRAN KHATUN	simransekh29@gmail.com	9339725089	4-Year I	B.A.	
24	202301036298	2023-24	230140340169	SK SUMAITA	sksumaita46@gmail.com	9800276335	4-Year I	B.A.	
25	202301036299	2023-24	230140340170	SNEHA DAS	001tapasdas@gmail.com	9883612366	4-Year I	B.A.	
26	202301036302	2023-24	230140340171	SNEHA GHOSH	ghosh.sneha7sg@gmail.com	6295854383	4-Year I	B.A.	
27	202301036304	2023-24	230140340172	SNEHA GUPTA	ng59971@gmail.com	8617370357	4-Year I	B.A.	
28	202301036306	2023-24	230140340173	SNEHA MONDAL	mondalsneha3504@gmail.com	8609532426	4-Year I	B.A.	
29	202301036314	2023-24	230140340174	SOHINI SETH	sethsohini233@gmail.com	9749207233	4-Year I	B.A.	
30	202301036322	2023-24	230140340175	SONALI HAZRA	sonalihazra325@gmail.com	8293781281	4-Year I	B.A.	
31	202301036333	2023-24	230140340177	SOUMI DEBNATH	soumidebnath63@gmail.com	7501334782	4-Year I	B.A.	
32	202301036353	2023-24	230140340179	SRAGDHARA DEY	bandanadey167@gmail.com	7439751721	4-Year I	B.A.	
33	202301036367	2023-24	230140340180	SUCHARITA BANDYOPADHYA	sucharitabandyopadhyay757@gmail.com	8597198020	4-Year I	B.A.	
34	202301036368	2023-24	230140340181	SUCHARITA POREL	sucharitaporel768@gmail.com	8116850503	4-Year I	B.A.	
1	202101013574	2021-22	230140340182	SUDIPTA CHOWDHURY	sudiptachowdhury268@gmail.com	8653224619	4-Year I	B.A.	
2	202301036374	2023-24	230140340183	SUDIPTA SADHUKHAN	sudiptasadhukhan333@gmail.com	8167722898	4-Year I	B.A.	
3	202301036376	2023-24	230140340184	SUHANA KHATUN	faiyazsarkar7@gmail.com	9635972031	4-Year I	B.A.	
4	202301036377	2023-24	230140340185	SUHANA SULTANA	bosssuhanasultana123@gmail.com	9749614346	4-Year I	B.A.	
5	202301036386	2023-24	230140340186	SUKANTA BASKEY	2021sukanta23august@gmail.com	9907816340	4-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
6	202301036390	2023-24	230140340187	SULTANA KHATUN	sultana01khatun7@gmail.com	8597460453	4-Year I	B.A.	Smt. Soma Bandhyopadhyay
7	202301036394	2023-24	230140340189	SUMAN ROY	sr8817259@gmail.com	9907281477	4-Year I	B.A.	
8	202301036400	2023-24	230140340190	SUMANA MALLICK	sumanamallickrinky@gmail.com	9635238289	4-Year I	B.A.	
9	202301036407	2023-24	230140340191	SUMIT SHAW	shawsumit115@gmail.com	7047579695	4-Year I	B.A.	
10	202301036411	2023-24	230140340192	SUMITRA HEMBRAM	sumitrahembram986@gmail.com	7384459551	4-Year I	B.A.	
11	202301036413	2023-24	230140340193	SUPARNA BAULDAS	suparnabauldas50@gmail.com	9038210644	4-Year I	B.A.	
12	202301036415	2023-24	230140340194	SUPARNA MAJUMDER	chinmoymajumdar52@gmail.com	8670381479	4-Year I	B.A.	
13	202301036416	2023-24	230140340195	SUPRITI GHOSH	supritighosh344@gmail.com	9064670772	4-Year I	B.A.	
14	202301036419	2023-24	230140340196	SUPRIYA SAHA	supriyasaha658@gmail.com	8653113723	4-Year I	B.A.	
15	202301036421	2023-24	230140340197	SUPRIYO SARKAR	supriyopiku402@gmail.com	8392059084	4-Year I	B.A.	
16	202301036439	2023-24	230140340198	SUVAM ADHIKARI	suvy2604@gmail.com	9831919023	4-Year I	B.A.	
17	202301036442	2023-24	230140340199	SWAPNA MANDI	swapnamandi487@gmail.com	8250346687	4-Year I	B.A.	
18	202301036449	2023-24	230140340200	TAMANNA SULTANA	tamannasultana1330@gmail.com	7044641733	4-Year I	B.A.	
19	202301036464	2023-24	230140340202	TASLINA KHATUN	taslinakhatun1107@gmail.com	9775083718	4-Year I	B.A.	
20	202301036469	2023-24	230140340203	TITAS GHOSH	titasghosh2005@gmail.com	7063366909	4-Year I	B.A.	
21	202301036471	2023-24	230140340204	TITHI KHETO	tithikheto7@gmail.com	9614354969	4-Year I	B.A.	
22	202301036472	2023-24	230140340205	TITHI MONDAL	tithimondal8270@gmail.com	8207010655	4-Year I	B.A.	
23	202301036474	2023-24	230140340206	TITLY POLLEY	polleytitly@gmail.com	8240374624	4-Year I	B.A.	
24	202301036477	2023-24	230140340207	TRISHA GHOSH	gtrisha237@gmail.com	8159968291	4-Year I	B.A.	
25	202201045470	2022-23	230140340208	TRISHA PAUL	trishapaul2303@gmail.com	6291502975	4-Year I	B.A.	
26	202301036484	2023-24	230140340209	TUSU SOREN	tususoren1@gmail.com	6295737293	4-Year I	B.A.	
27	202301036488	2023-24	230140340210	UNMESABNUR SARKAR	sabnursarkar144@gmail.com	7063399970	4-Year I	B.A.	
28	202301036497	2023-24	230340340001	AFTAD HOSSAIN MONDAL	aftadhossainmondal710@gmail.com	7583902500	4-Year I	B.Sc.	
29	202301036499	2023-24	230340340002	AMRITA SENGUPTA	amitava0105@gmail.com	7501062901	4-Year I	B.Sc.	
30	202301036500	2023-24	230340340003	ANANYA CHAKRABARTY	anathbandhuchakrabarty0@gmail.com	8016488206	4-Year I	B.Sc.	
31	202301036502	2023-24	230340340004	ANIK MUKHERJEE	a28041244@gmail.com	9163848491	4-Year I	B.Sc.	
32	202301036503	2023-24	230340340005	ANKAN MALAKAR	ankanmalakar1432@gmail.com	7384721101	4-Year I	B.Sc.	
33	202201042609	2023-24	230340340006	ANKUR SINGHA ROY	ankursingharoy98@gmail.com	8637043382	4-Year I	B.Sc.	
34	202301036504	2023-24	230340340007	ANWESHA GHOSH	anweshaghosh4321@gmail.com	8207013186	4-Year I	B.Sc.	
1	202301036506	2023-24	230340340008	ARPITA KARMAKAR	purnimakarmakar075@gmail.com	9804026723	4-Year I	B.Sc.	
2	202301036508	2023-24	230340340010	AYESA KHATUN	ayesakhatun0786786@gmail.com	9641739141	4-Year I	B.Sc.	
3	202201042615	2022-23	230340340011	BIDISHA GOSWAMI	bidishagswm@gmail.com	6294323271	4-Year I	B.Sc.	
4	202301036511	2023-24	230340340012	DIPAYAN NAYEK	roopdipayan@gmail.com	9734940523	4-Year I	B.Sc.	
5	202301036514	2023-24	230340340013	JESHMINA KHATUN	kjeshmina56@gmail.com	8388011882	4-Year I	B.Sc.	
6	202301036515	2023-24	230340340014	JINITA GHOSH	jinitaghosh@gmail.com	7501535253	4-Year I	B.Sc.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
7	202301036516	2023-24	230340340015	KRISHNA MONDAL	krishnamondal84261@gmail.com	6297847418	4-Year I	B.Sc.	Sri Sampad Dey
8	202301036517	2023-24	230340340016	MADHUSRI KAYAL	madhusrikayal11223344@gmail.com	8250002783	4-Year I	B.Sc.	
9	202301036518	2023-24	230340340017	MANJIMA BISWAS	manjimabiswas90@gmail.com	8391034810	4-Year I	B.Sc.	
10	202301036519	2023-24	230340340018	MARYUM FIROZ	maryum1300@gmail.com	8927968353	4-Year I	B.Sc.	
11	202301036525	2023-24	230340340019	RODDUR CHATTOPADHYAY	roddur2023@gmail.com	6289857619	4-Year I	B.Sc.	
12	202301036526	2023-24	230340340020	RUPSHA MAZUMDAR	rupshamajumder007@gmail.com	8343087345	4-Year I	B.Sc.	
13	202301036527	2023-24	230340340021	SABNAM KHATUN	ranirani44899@gmail.com	8388873460	4-Year I	B.Sc.	
14	202301036528	2023-24	230340340022	SAMPRITI DEBNATH	sabitadebnath92@gmail.com	7585889022	4-Year I	B.Sc.	
15	202301036530	2023-24	230340340023	SANCHARI MUKHERJEE	mukherjeesanchari7@gmail.com	9641038916	4-Year I	B.Sc.	
16	202301036531	2023-24	230340340024	SANCHITA HEMBROM	hembromsanchita48@gmail.com	8167853925	4-Year I	B.Sc.	
17	202301036534	2023-24	230340340025	SATYAJEET ROY	roysatyajeet11@gmail.com	7318814251	4-Year I	B.Sc.	
18	202301036535	2023-24	230340340026	SATYAKI SARKAR	satyakis699@gmail.com	8972999652	4-Year I	B.Sc.	
19	202301036536	2023-24	230340340027	SAYAN BHATTACHARJEE	bhattacharjee000000@gmail.com	9883592558	4-Year I	B.Sc.	
20	202301036537	2023-24	230340340028	SHOVANDEB GHOSH	shovan2006ghosh@gmail.com	8391054411	4-Year I	B.Sc.	
21	202301036539	2023-24	230340340029	SHUBHAM DEBNATH	debnath.shubham04@gmail.com	9339519570	4-Year I	B.Sc.	
22	202301036540	2023-24	230340340030	SK NADIM	sknadim01012005@gmail.com	7679924036	4-Year I	B.Sc.	
23	202301036542	2023-24	230340340031	SOHEL SARKAR	sohel123456sarkar@gmail.com	9883346463	4-Year I	B.Sc.	
24	202301036546	2023-24	230340340033	SUMALYA GHOSH	sumalyarosna712149@gmail.com	7384513657	4-Year I	B.Sc.	
25	202301036549	2023-24	230340340035	SUSMITA TIKADAR	tikadarsubal2@gmail.com	8481812050	4-Year I	B.Sc.	
26	202301036550	2023-24	230340340036	SUSNIGDHA HAZRA	susnigdha9205@gmail.com	9339335702	4-Year I	B.Sc.	
27	202301036553	2023-24	230340340037	TRINANKUR MONDAL	mondaltrinankur@gmail.com	7044457119	4-Year I	B.Sc.	
28	202301036554	2023-24	230340340038	TRISHA GHOSH	trishaghosh346@gmail.com	6297276782	4-Year I	B.Sc.	
29	202301036555	2023-24	230340340039	TRISHA MONDAL	trisha82506@gmail.com	8250695948	4-Year I	B.Sc.	
30	202301035414	2023-24	230440330001	ABDUL SAJID MONDAL	sajidmondal7337@gmail.com	8972556475	3-Year I	B.A.	
31	202301035416	2023-24	230440330002	ABDUL WASIM MOLLAH	wasimmollahpandua@gmail.com	7003917473	3-Year I	B.A.	
32	202301035417	2023-24	230440330003	ABHIJIT MURMU	avijitmurmu2703@gmail.com	9679746381	3-Year I	B.A.	
33	202301035419	2023-24	230440330004	ABHIJIT TUDU	avijittudu22@gmail.com	9883166169	3-Year I	B.A.	
34	202301035420	2023-24	230440330005	ABIDA SULTANA	abidasultana4291@gmail.com	9907177443	3-Year I	B.A.	
1	202301035422	2023-24	230440330007	AFREEN KHATUN	sonalikhatun55116@gmail.com	6295620275	3-Year I	B.A.	
2	202301035423	2023-24	230440330008	AFRIN KHATUN	khatunaffrin61@gmail.com	7083043739	3-Year I	B.A.	
3	202301035428	2023-24	230440330010	AFROZA NASRIN	aliskafsar9@gmail.com	8348348814	3-Year I	B.A.	
4	202301035429	2023-24	230440330011	AFROZA TABASSUM	afrozatabassum2005@gmail.com	8900570312	3-Year I	B.A.	
5	202301035432	2023-24	230440330012	AFSANA SULTANA	asultana0205@gmail.com	7001208511	3-Year I	B.A.	
6	202301035434	2023-24	230440330013	AGNI GHOSH	agnig5930@gmail.com	7478432520	3-Year I	B.A.	
7	202301035435	2023-24	230440330014	AJIT SAREN	ajitsoren710@gmail.com	9832534270	3-Year I	B.A.	

Bejoy Narayan Mahavidyalaya
List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
8	202301035443	2023-24	230440330015	AKSHOY MURMU	murmuakshay9@gmail.com	7797613580	3-Year I	B.A.	Sri Soumyojit Chowdhury
9	202301035445	2023-24	230440330017	ALOKA MURMU	sanjaymurmu1165@gmail.com	8509873003	3-Year I	B.A.	
10	202301035447	2023-24	230440330018	AMENA KHATUN	ska58139@gmail.com	6295468839	3-Year I	B.A.	
11	202301035448	2023-24	230440330019	AMIT KORA	amitkora860@gmail.com	8649828811	3-Year I	B.A.	
12	202301035454	2023-24	230440330020	ANANYA MONDAL	ananyamondol56@gmail.com	8101407826	3-Year I	B.A.	
13	202301035456	2023-24	230440330021	ANIKET SIKDER	aniketsikder@gmail.com	9002328405	3-Year I	B.A.	
14	202301035457	2023-24	230440330022	ANIMA BAULDAS	animadasanimadas520@gmail.com	7866836626	3-Year I	B.A.	
15	202301035458	2023-24	230440330023	ANIMA KISKU	animakisku70@gmail.com	7076174450	3-Year I	B.A.	
16	202301035460	2023-24	230440330024	ANIMESH ROY	animeshroy272@gmail.com	6296812767	3-Year I	B.A.	
17	202301035461	2023-24	230440330025	ANIRBAN RAHA	iamanirban.raha@gmail.com	7001876272	3-Year I	B.A.	
18	202301035463	2023-24	230440330026	ANISHA DAS	adas37069@gmail.com	8927385783	3-Year I	B.A.	
19	202301035466	2023-24	230440330028	ANITA PANDIT	anitapandit.khanyan@gmail.com	7602458777	3-Year I	B.A.	
20	202301035467	2023-24	230440330029	ANJALI MURMU	murmuanjali426@gmail.com	9064345771	3-Year I	B.A.	
21	202301035469	2023-24	230440330031	ANJANA SINGH	shinganjana45@gmail.com	7063385880	3-Year I	B.A.	
22	202301035470	2023-24	230440330032	ANJU MANDI	mandimanju67@gmail.com	9933153413	3-Year I	B.A.	
23	202301035471	2023-24	230440330033	ANKIT SUR	ankitsurankit@gmail.com	9382933495	3-Year I	B.A.	
24	202301035473	2023-24	230440330034	ANKITA GHOSH	ghoshankita2812@gmail.com	8653517204	3-Year I	B.A.	
25	202301035476	2023-24	230440330035	ANKITA MISTRY	riyamistri8436@gmail.com	8116692300	3-Year I	B.A.	
26	202301035479	2023-24	230440330036	ANNABI DAS	annabidas28@gmail.com	9647073796	3-Year I	B.A.	
27	202301035480	2023-24	230440330037	ANNABI SINGH	mampisinghpandua003@gmail.com	9907301669	3-Year I	B.A.	
28	202301035488	2023-24	230440330040	ANUSHUA PAL	anushuapal6@gmail.com	8293924126	3-Year I	B.A.	
29	202301035489	2023-24	230440330041	APARAJITA MODAK	modakaparajita8@gmail.com	7478690602	3-Year I	B.A.	
30	202301035491	2023-24	230440330042	APSONA SULTANA	apsonasultana51@gmail.com	9064071447	3-Year I	B.A.	
31	202101048430	2021-22	230440330044	ARGHYA HALDER	arghya331h@gmail.com	8653227968	3-Year I	B.A.	
32	202301035494	2023-24	230440330045	ARIAN MALLICK	arian786mallick@gmail.com	6296760187	3-Year I	B.A.	
33	202301035495	2023-24	230440330046	ARIFA KHATUN	khatunarifa18469@gmail.com	9883610353	3-Year I	B.A.	
34	202301035496	2023-24	230440330047	ARIFA KHATUN	ak3003482@gmail.com	8388993656	3-Year I	B.A.	
1	202301035497	2023-24	230440330048	ARIJIT KHANRA	arijitkhanra916@gmail.com	7076007730	3-Year I	B.A.	
2	202301035500	2023-24	230440330050	ARINDAM SAREN	arindamsaren4@gmail.com	9339130459	3-Year I	B.A.	
3	202301035502	2023-24	230440330051	ARISBA YESMIN	arisbayasmin39@gmail.com	9163902981	3-Year I	B.A.	
4	202301035504	2023-24	230440330052	ARKO GHOSH	arkoghospandua2006@gmail.com	9907308835	3-Year I	B.A.	
5	202301035507	2023-24	230440330053	ARNAB GHOSH	ghosharnab240@gmail.com	9832152256	3-Year I	B.A.	
6	202301035509	2023-24	230440330055	ARPAN DEBNATH	arpandebnath376@gmail.com	8509027510	3-Year I	B.A.	
7	202301035512	2023-24	230440330056	ARPAN SINGH	siddarthsingh712146@gmail.com	9339952489	3-Year I	B.A.	
8	202301035513	2023-24	230440330057	ARPITA DAS	ad270332@gmail.com	9051455207	3-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
9	202301035515	2023-24	230440330058	ARPITA KOLEY	arpitakoley7000@gmail.com	7872237022	3-Year I	B.A.	Prof. Pritwis Biswas
10	202301035516	2023-24	230440330059	ARPITA MANDI	arpitamandi418@gmail.com	9800345049	3-Year I	B.A.	
11	202301035517	2023-24	230440330060	ARPITA MOL	molarpita434@gmail.com	8927280372	3-Year I	B.A.	
12	202301035518	2023-24	230440330062	ARPITA SARKAR	arpitasarkarpandua@gmail.com	8509365165	3-Year I	B.A.	
13	202301035519	2023-24	230440330063	ARPITA SINGH	arpitasingh85298@gmail.com	7908956248	3-Year I	B.A.	
14	202301035520	2023-24	230440330064	ARPITA SOREN	arpitasoren11@gmail.com	9832450692	3-Year I	B.A.	
15	202301035524	2023-24	230440330066	ASHIS CHANDRA MURMU	ashischandramurmu@gmail.com	7029607640	3-Year I	B.A.	
16	202301035527	2023-24	230440330067	ASIFA KHATUN	khatunasifa2649@gmail.com	8945553391	3-Year I	B.A.	
17	202301035530	2023-24	230440330069	ASMA KHATUN	asmakhatun3810@gmail.com	8250517144	3-Year I	B.A.	
18	202301035532	2023-24	230440330071	ASMIRA KHATUN	alfak8583@gmail.com	6294239044	3-Year I	B.A.	
19	202301035533	2023-24	230440330072	ATANU GHOSH	atanu.ag2002@gmail.com	7319137763	3-Year I	B.A.	
20	202301035535	2023-24	230440330073	ATANU SHIL	atanu2726@gmail.com	8670153077	3-Year I	B.A.	
21	202301035536	2023-24	230440330074	ATIKA RIMA MOLLAH	atikamollah4@gmail.com	6294110585	3-Year I	B.A.	
22	202301035539	2023-24	230440330076	AVIJIT HEMBRAM	avijithembram56@gmail.com	6297427253	3-Year I	B.A.	
23	202301035540	2023-24	230440330077	AVIJIT LOHAR	avijitlohar83178@gmail.com	8961508452	3-Year I	B.A.	
24	202301035541	2023-24	230440330078	AVIK GHOSH	avikghoshbhaira@gmail.com	7679582367	3-Year I	B.A.	
25	202301035543	2023-24	230440330079	AYANTANI SINGH	singhruma709@gmail.com	8670160937	3-Year I	B.A.	
26	202301035544	2023-24	230440330080	AYESA KHATUN	ayeshakhatun13152@gmail.com	9339424525	3-Year I	B.A.	
27	202301035548	2023-24	230440330081	BABITA MAJHI	babitamajhi148@gmail.com	8927032538	3-Year I	B.A.	
28	202301035549	2023-24	230440330082	BABY MAJHI	babymajhi2006@gmail.com	9091265180	3-Year I	B.A.	
29	202301035550	2023-24	230440330083	BAISHAKHI BISWAS	swapanbiswastanba77@gmail.com	6296402952	3-Year I	B.A.	
30	202301035551	2023-24	230440330084	BAISHAKHI SINGH	baishakhis314@gmail.com	7407812289	3-Year I	B.A.	
31	202301035553	2023-24	230440330085	BANDANA HANSDA	hansdabandana767@gmail.com	8250577587	3-Year I	B.A.	
32	202301035554	2023-24	230440330086	BANDITA MURMU	murmubandita48@gmail.com	7439498791	3-Year I	B.A.	
33	202301035557	2023-24	230440330087	BARNALI KISKU	kiskubarnali61@gmail.com	9932684715	3-Year I	B.A.	
34	202301035558	2023-24	230440330088	BARNALI MAJHI	barnalimajhi0101@gmail.com	8670759842	3-Year I	B.A.	
1	202301035560	2023-24	230440330089	BARSA SARKAR	sarkarbarsha705@gmail.com	8972782662	3-Year I	B.A.	
2	202301035564	2023-24	230440330090	BARSHA MALIK	mampimalik884@gmail.com	8509219075	3-Year I	B.A.	
3	202301035567	2023-24	230440330091	BASANTI BAULDAS	bamabauldas71@gmail.com	7477859852	3-Year I	B.A.	
4	202301035569	2023-24	230440330093	BEAUTY MURMU	murmubeauty1335@gmail.com	6296197973	3-Year I	B.A.	
5	202301035571	2023-24	230440330094	BEUTI PANDIT	tiyam1537@gmail.com	8509682494	3-Year I	B.A.	
6	202301035574	2023-24	230440330095	BIDISHA SULTANA	bidishasultana27@gmail.com	8509523851	3-Year I	B.A.	
7	202301035576	2023-24	230440330096	BIKASH HANSDA	bikashhansda551@gmail.com	6295726170	3-Year I	B.A.	
8	202301035578	2023-24	230440330097	BIKRAM MONDAL	bikrammondal0707@gmail.com	6294083604	3-Year I	B.A.	
9	202301035582	2023-24	230440330098	BIPASHA DEBNATH	bd0830255@gmail.com	9330969743	3-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
10	202301035583	2023-24	230440330099	BIPASHA DUTTA	bipashaduttapandua@gmail.com	9907979294	3-Year	B.A.	Prof. Abir Bandopadhyay
11	202301035585	2023-24	230440330100	BIRAJ DAS	das787960@gmail.com	6296725724	3-Year	B.A.	
12	202301035593	2023-24	230440330103	BITHIKA PAL	palbithika28@gmail.com	7602224290	3-Year	B.A.	
13	202301035594	2023-24	230440330104	BRATATI DAS	bratatidas141@gmail.com	6294632909	3-Year	B.A.	
14	202301035596	2023-24	230440330105	BRISHTI MONDAL	brishtimondal800@gmail.com	8116597173	3-Year	B.A.	
15	202301035602	2023-24	230440330108	BRISTI MURMU	bristimurmu59@gmail.com	9564849738	3-Year	B.A.	
16	202301035603	2023-24	230440330109	BRISTI PAUL	palbristy9@gmail.com	9679752332	3-Year	B.A.	
17	202301035604	2023-24	230440330110	BROJESH HEMBRAM	brojeshhembram00@gmail.com	8016287530	3-Year	B.A.	
18	202301035606	2023-24	230440330111	CHAITALI HALDER	halderchaitali52@gmail.com	8167860247	3-Year	B.A.	
19	202301035607	2023-24	230440330112	CHAITALI ROY	mitu1234bijoy@gmail.com	8597012041	3-Year	B.A.	
20	202301035611	2023-24	230440330115	CHANDANA HANSDA	chandanahasda4@gmail.com	8918393399	3-Year	B.A.	
21	202301035612	2023-24	230440330116	CHANDMONI SAREN	chandmonisaren71@gmail.com	7699717599	3-Year	B.A.	
22	202301035613	2023-24	230440330117	CHANDRA PAL	chandra1752005@gmail.com	6294110544	3-Year	B.A.	
23	202301035615	2023-24	230440330118	CHANDRANI SHEE	chandranishee62@gmail.com	7719200226	3-Year	B.A.	
24	202301035616	2023-24	230440330119	CHANDRIMA CHAKRABORTY	chakrabortychandrima294@gmail.com	8100452226	3-Year	B.A.	
25	202301035617	2023-24	230440330120	CHANDU HEMBRAM	chanduhembram063@gmail.com	8637854700	3-Year	B.A.	
26	202301035618	2023-24	230440330121	CHAPA DAS	arjundas6247@gmail.com	9734340576	3-Year	B.A.	
27	202301035620	2023-24	230440330122	DALIA KOLEY	koleydalia556@gmail.com	8637561711	3-Year	B.A.	
28	202301035621	2023-24	230440330123	DEBAPRATIM CHAKRABORTY	debapratimchakraborty3@gmail.com	7602904160	3-Year	B.A.	
29	202301035622	2023-24	230440330124	DEBARATI MITRA	debaratimitra001@gmail.com	9907177226	3-Year	B.A.	
30	202301035623	2023-24	230440330125	DEBASHIS KORA	ganeshkora554@gmail.com	9093422362	3-Year	B.A.	
31	202301035626	2023-24	230440330126	DEBDAITA SEN	sendebdaita@gmail.com	9547628462	3-Year	B.A.	
32	202301035627	2023-24	230440330127	DEBIKA HEMRAM	hemramdebika91@gmail.com	8710077385	3-Year	B.A.	
33	202301035628	2023-24	230440330128	DEBIKA MURMU	dbkmurmu@gmail.com	8172071061	3-Year	B.A.	
34	202301035632	2023-24	230440330130	DEBOJIT GHOSH	debojitghosh589@gmail.com	8670155317	3-Year	B.A.	
1	202301035634	2023-24	230440330131	DEBOLINA KSHETRAPAL	debolinapal66@gmail.com	9883259782	3-Year	B.A.	
2	202301035639	2023-24	230440330133	DEEP DAS	alodas289@gmail.com	8509892883	3-Year	B.A.	
3	202301035643	2023-24	230440330136	DHRUBO MONDAL	mondaldhrubo333@gmail.com	9883832987	3-Year	B.A.	
4	202301035644	2023-24	230440330137	DIP PATRA	patradip137@gmail.com	9907227518	3-Year	B.A.	
5	202301035646	2023-24	230440330138	DIPAK LOHAR	dipaklohar191@gmail.com	9832334982	3-Year	B.A.	
6	202301035647	2023-24	230440330139	DIPANKAR BAULDAS	dipankarbauldas7@gmail.com	7679308964	3-Year	B.A.	
7	202301035649	2023-24	230440330140	DIPU POREL	bipul0029y@gmail.com	9083218568	3-Year	B.A.	
8	202301035650	2023-24	230440330141	DISHA BAULDAS	bauldasdisha9@gmail.com	7602294459	3-Year	B.A.	
9	202301035651	2023-24	230440330142	DISHA DAS	ddas77850@gmail.com	7872738713	3-Year	B.A.	
10	202301035652	2023-24	230440330143	DISHA DAS	dishadas472@gmail.com	9609189137	3-Year	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
11	202301035653	2023-24	230440330144	DISHA SANTRA	santradisha673@gmail.com	9547990638	3-Year I	B.A.	Sri Suprasanya Chatterjee
12	202301035654	2023-24	230440330145	DONA BEPARI	donabepari0@gmail.com	8583928623	3-Year I	B.A.	
13	202301035655	2023-24	230440330146	DONA SHEE	she60529@gmail.com	9064704924	3-Year I	B.A.	
14	202301035657	2023-24	230440330147	FALGUNI DEY	deysebasish2@gmail.com	9083244290	3-Year I	B.A.	
15	202301035659	2023-24	230440330148	FATEMA ANSARI	fatemaansari817@gmail.com	7501538342	3-Year I	B.A.	
16	202301035660	2023-24	230440330149	FERDOUSI SULTANA	sahera9268@gmail.com	9093121476	3-Year I	B.A.	
17	202301035661	2023-24	230440330150	FIRDOUSI KHATUN	ss5471640@gmail.com	9123786068	3-Year I	B.A.	
18	202301035662	2023-24	230440330151	FULMONI HEMBRAM	fulmonihembram95@gmail.com	7501031574	3-Year I	B.A.	
19	202301035664	2023-24	230440330152	GAYATRI MUKHERJEE	gayatrimukherjee73@gmail.com	6289888296	3-Year I	B.A.	
20	202301035665	2023-24	230440330153	GOPAL DHARA	dharagopal691@gmail.com	8388991960	3-Year I	B.A.	
21	202301035668	2023-24	230440330155	GURU DAS PANDIT	gurud9288@gmail.com	8670131215	3-Year I	B.A.	
22	202301035669	2023-24	230440330156	HASINA BANU	hasinakhatun5868@gmail.com	6295453506	3-Year I	B.A.	
23	202301035671	2023-24	230440330157	HASMANTARA KHATUN	hasmontarakhatun@gmail.com	8653224548	3-Year I	B.A.	
24	202301035672	2023-24	230440330158	HIRANMOY MURMU	murmuhiranmoy5@gmail.com	9907610736	3-Year I	B.A.	
25	202301035674	2023-24	230440330160	INDRAJIT GHOSH	indrajitg319@gmail.com	7029359310	3-Year I	B.A.	
26	202301035675	2023-24	230440330161	INDRAJIT MURMU	murmusukumani9@gmail.com	8512902145	3-Year I	B.A.	
27	202301035677	2023-24	230440330162	ITI BESRA	itibesra@gmail.com	8927459608	3-Year I	B.A.	
28	202301035679	2023-24	230440330164	JABA SAREN	jabasaren36@gmail.com	8617352224	3-Year I	B.A.	
29	202301035681	2023-24	230440330166	JANAM AFRIN	khatunafrin816@gmail.com	9339256707	3-Year I	B.A.	
30	202301035683	2023-24	230440330168	JAYANTA MURMU	jayantamurmu031@gmail.com	9382470220	3-Year I	B.A.	
31	202301035686	2023-24	230440330170	JAYSHREE HALDER	ajh712135@gmail.com	9339949727	3-Year I	B.A.	
32	202301035688	2023-24	230440330171	JEET HALDAR	jeethaldar835@gmail.com	7584823025	3-Year I	B.A.	
33	202301035689	2023-24	230440330172	JEMIMA SARKAR	khatunalisha378@gmail.com	9932510614	3-Year I	B.A.	
34	202301035690	2023-24	230440330173	JESHMIN KHATUN	chotosarsa036@gmail.com	7738969477	3-Year I	B.A.	
1	202301035691	2023-24	230440330174	JESMIN KHATUN	mmahjabi267@gmail.com	6296313722	3-Year I	B.A.	
2	202301035694	2023-24	230440330175	JHANTU PAUL	rp737944@gmail.com	9635924354	3-Year I	B.A.	
3	202301035695	2023-24	230440330176	JHARNA MAJUMDER	majumderjharna7@gmail.com	8512904071	3-Year I	B.A.	
4	202301035696	2023-24	230440330177	JHUMA MANDI	jhumamandi8@gmail.com	7602042543	3-Year I	B.A.	
5	202301035699	2023-24	230440330179	JHUMPA SINHA	jhumpasinha2004@gmail.com	7029187075	3-Year I	B.A.	
6	202301035700	2023-24	230440330180	JIT MONDAL	jitmondal040@gmail.com	9933944043	3-Year I	B.A.	
7	202301035705	2023-24	230440330183	JOYEETA BARUI	baruijayeeta04@gmail.com	9883812982	3-Year I	B.A.	
8	202301035709	2023-24	230440330185	JUTHIKA SAREN	jhutikasaren@gmail.com	9907304032	3-Year I	B.A.	
9	202301035710	2023-24	230440330186	JYOTI GHOSH	ghoshashokkumar14@gmail.com	9002103596	3-Year I	B.A.	
10	202301035713	2023-24	230440330187	JYOTI SAHANI	sahanijyoti32@gmail.com	9339227142	3-Year I	B.A.	
11	202301035716	2023-24	230440330189	KAJAL HANSDA	anamikaanamika2329@gmail.com	7478339592	3-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
12	202301035715	2023-24	230440330190	KAJAL HANSDA	kajalhansda54@gmail.com	8918129152	3-Year I	B.A.	Sri Bibhas Howlader
13	202301035717	2023-24	230440330191	KAJAL KUNDU	kajalkundu2005@gmail.com	7074330710	3-Year I	B.A.	
14	202301035718	2023-24	230440330192	KAMALA HANSDA	hansdakamala45@gmail.com	7319370246	3-Year I	B.A.	
15	202301035719	2023-24	230440330193	KANAK DHARA	dharak300@gmail.com	9932907549	3-Year I	B.A.	
16	202301035721	2023-24	230440330194	KARUN BALA	bittubala61@gmail.com	9907602027	3-Year I	B.A.	
17	202301035723	2023-24	230440330195	KEYA DAS	keyad840@gmail.com	7076807155	3-Year I	B.A.	
18	202301035726	2023-24	230440330196	KOHELI MALIK	sahelimalik5@gmail.com	7602309536	3-Year I	B.A.	
19	202301035728	2023-24	230440330197	KOUSHIK SAJJAL	koushiksajjal50@gmail.com	8250092726	3-Year I	B.A.	
20	202301035729	2023-24	230440330198	KOUSIK BAIRAGYA	kousikbairagya5@gmail.com	9382250439	3-Year I	B.A.	
21	202301035730	2023-24	230440330199	KOYEL BAG	bagk31965@gmail.com	9883706412	3-Year I	B.A.	
22	202301035731	2023-24	230440330200	KOYEL BALA	koyelbala05@gmail.com	7076884367	3-Year I	B.A.	
23	202301035732	2023-24	230440330201	KOYEL BISWAS	kb0832385@gmail.com	7688064276	3-Year I	B.A.	
24	202301035733	2023-24	230440330202	KOYEL DAS	koyeldaspandua@gmail.com	7501519679	3-Year I	B.A.	
25	202301035734	2023-24	230440330203	KOYEL DEBNATH	debnathkoyel919@gmail.com	8016311473	3-Year I	B.A.	
26	202301035738	2023-24	230440330204	KOYEL SAMANTA	koyelsamanta073@gmail.com	7001126510	3-Year I	B.A.	
27	202301035740	2023-24	230440330206	KOYEL SHARMA	koyelsharma722@gmail.com	9907401648	3-Year I	B.A.	
28	202301035742	2023-24	230440330207	KRISHNA GOPAL BAULDAS	krishnagopalbauldas@gmail.com	8637852311	3-Year I	B.A.	
29	202301035747	2023-24	230440330208	KULSUM KHATUN	skmuard@gmail.com	6295902030	3-Year I	B.A.	
30	202301035748	2023-24	230440330210	KULSUM KHATUN	kulsumkhatun710@gmail.com	9134490262	3-Year I	B.A.	
31	202301035752	2023-24	230440330211	KUSHAL NANDY	nandykushal9@gmail.com	9907489364	3-Year I	B.A.	
32	202301035754	2023-24	230440330212	LABANI KSHETRAPAL	labanikshetra286@gmail.com	8345016647	3-Year I	B.A.	
33	202301035759	2023-24	230440330215	LAKSHIMONI MURMU	murmulakshimoni0@gmail.com	8972473576	3-Year I	B.A.	
34	202301035762	2023-24	230440330216	LALITA HANSDA	lalitahansda499@gmail.com	7863901052	3-Year I	B.A.	
1	202301035769	2023-24	230440330219	LAZINA KHATUN	lazina748@gmail.com	6297266054	3-Year I	B.A.	
2	202301035770	2023-24	230440330220	LIMPIA DAS	limpiyadas@gmail.com	7364035749	3-Year I	B.A.	
3	202301035771	2023-24	230440330221	LIPIKA KISKU	lipikakisku42@gmail.com	7810907972	3-Year I	B.A.	
4	202301035772	2023-24	230440330222	LISA PAUL	paullisa804@gmail.com	7501718173	3-Year I	B.A.	
5	202301035774	2023-24	230440330224	LOVELY KHATUN	khatunlovly76@gmail.com	8293094304	3-Year I	B.A.	
6	202301035776	2023-24	230440330225	MADHUMITA GHOSH	madhumitaghosh8827@gmail.com	8927125694	3-Year I	B.A.	
7	202301035777	2023-24	230440330226	MADHUMITA HEMBRAM	bristehembram@gmail.com	9883012520	3-Year I	B.A.	
8	202301035778	2023-24	230440330227	MADHUMITA MONDAL	mmadhumita809@gmail.com	9679746187	3-Year I	B.A.	
9	202301035779	2023-24	230440330228	MADHUMITA SOREN	sorenmadhumita538@gmail.com	9679748920	3-Year I	B.A.	
10	202301035780	2023-24	230440330229	MAFIJA KHATUN	khatunmofija4@gmail.com	9832793229	3-Year I	B.A.	
11	202301035782	2023-24	230440330231	MAHINA KHATUN	nasrinparvin36000@gmail.com	9609477253	3-Year I	B.A.	
12	202301035784	2023-24	230440330232	MALLIKA SING	mallikasing147@gmail.com	8101451116	3-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
13	202301035785	2023-24	230440330233	MAMPI BARUI	mampibarui639@gmail.com	7865904413	3-Year	B.A.	Sri Kaushik Chatterjee
14	202301035789	2023-24	230440330236	MANDIRA MURMU	mandiram719@gmail.com	6297655792	3-Year	B.A.	
15	202301035790	2023-24	230440330237	MANGALDEEP KOTAL	mongolkotal6@gmail.com	8617525095	3-Year	B.A.	
16	202301035791	2023-24	230440330238	MANGALDIP HEMBRAM	m83085634@gmail.com	7477712714	3-Year	B.A.	
17	202301035795	2023-24	230440330240	MANIKA DAS	dasmonika6534@gmail.com	9732834096	3-Year	B.A.	
18	202301035796	2023-24	230440330241	MANIKA HANSDA	manikahansda17@gmail.com	7363992071	3-Year	B.A.	
19	202301035800	2023-24	230440330242	MANISHA KSHETRAPAL	mkshetrapal546@gmail.com	7439263497	3-Year	B.A.	
20	202301035804	2023-24	230440330243	MANOSHI ADHIKARY	manoshiadhikari2@gmail.com	9907548759	3-Year	B.A.	
21	202301035806	2023-24	230440330244	MARIA SULTANA	monirhossain9145@gmail.com	9131231996	3-Year	B.A.	
22	202301035810	2023-24	230440330245	MD ABDUL KALAM	mdabbas1006197232@gmail.com	7063147372	3-Year	B.A.	
23	202301035812	2023-24	230440330246	MD HABIB HOSSAIN	hossainmdhabib27@gmail.com	7029603198	3-Year	B.A.	
24	202301035816	2023-24	230440330248	MD SAMIULLAH	mdsamiullah11072005@gmail.com	9046396054	3-Year	B.A.	
25	202301035824	2023-24	230440330249	MILI DAS	s12430409@gmail.com	6294348763	3-Year	B.A.	
26	202301035826	2023-24	230440330250	MINAXI SARKAR	sarkarminakhsi@gmail.com	7384154234	3-Year	B.A.	
27	202301035827	2023-24	230440330251	MIR RAFIKUL RAHAMAN	mirrafikul14@gmail.com	8509086814	3-Year	B.A.	
28	202301035829	2023-24	230440330252	MITA MALIK	srikantom133@gmail.com	7363955913	3-Year	B.A.	
29	202301035831	2023-24	230440330253	MITALI DAS	dasmitali4507@gmail.com	6289173953	3-Year	B.A.	
30	202301035833	2023-24	230440330254	MOFIJA KHATUN	skarajul2@gmail.com	6294582461	3-Year	B.A.	
31	202301035834	2023-24	230440330255	MOHAMMAD JUNAID	m49557934@gmail.com	9046372035	3-Year	B.A.	
32	202301035837	2023-24	230440330256	MONALIKA MONDAL	monalikamondal9@gmail.com	7074065584	3-Year	B.A.	
33	202301035838	2023-24	230440330257	MONALISA BARIK	barikmonalisa545@gmail.com	8670109673	3-Year	B.A.	
34	202301035839	2023-24	230440330258	MONDIRA MALIK	mandiramalik04466@gmail.com	9641726110	3-Year	B.A.	
1	202301035841	2023-24	230440330259	MONISHA PAL	palmonisha04@gmail.com	6295641800	3-Year	B.A.	
2	202301035842	2023-24	230440330260	MOU SINGH	singhmou64@gmail.com	9641083034	3-Year	B.A.	
3	202301035843	2023-24	230440330261	MOULI SHARMA	mouli781098@gmail.com	7810981356	3-Year	B.A.	
4	202301035846	2023-24	230440330263	MOUPRIYA MURMU	moupriyamurmu86@gmail.com	8509616902	3-Year	B.A.	
5	202301035847	2023-24	230440330264	MOUSAMI DAS	dmousami159@gmail.com	8293095254	3-Year	B.A.	
6	202301035850	2023-24	230440330266	MOUSUMI MURMU	murmumahadev68@gmail.com	9002780260	3-Year	B.A.	
7	202301035852	2023-24	230440330267	MST AFSANA KHATUN	mstafsanakhatun578@gmail.com	7811079076	3-Year	B.A.	
8	202301035853	2023-24	230440330268	MST SAHEBA KHATUN	ksahaba03@gmail.com	7478464153	3-Year	B.A.	
9	202301035857	2023-24	230440330269	NABANITA KUNDU	nabanitakundu2005@gmail.com	7584899970	3-Year	B.A.	
10	202301035858	2023-24	230440330270	NABANITA SANTRA	sona.dey141990@gmail.com	8101519735	3-Year	B.A.	
11	202301035864	2023-24	230440330271	NAMITA MURMU	numitamurmu52@gmail.com	9547285791	3-Year	B.A.	
12	202301035866	2023-24	230440330272	NANDINI SOREN	nandinisoren4@gmail.com	8967573810	3-Year	B.A.	
13	202301035867	2023-24	230440330273	NANDITA GARAI	ngarai055@gmail.com	9339316848	3-Year	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
14	202301035869	2023-24	230440330275	NANDITA MONDAL	mondalnandita038@gmail.com	9339882850	3-Year	B.A.	Prof. Dipak Garai
15	202301035870	2023-24	230440330276	NANDITA ROY	nanditasuvankar4@gmail.com	8101108343	3-Year	B.A.	
16	202101048153	2021-22	230440330277	NARGIS MEHAZABIN AHMAD	nargis2002khanyan@gmail.com	7047807210	3-Year	B.A.	
17	202301035873	2023-24	230440330278	NASIBAH KHATUN	n9394581@gmail.com	9609506807	3-Year	B.A.	
18	202301035874	2023-24	230440330279	NASMIN KHATUN	nasmin094@gmail.com	9883327637	3-Year	B.A.	
19	202301035875	2023-24	230440330280	NASRIFA KHATUN	pk2812407@gmail.com	7601957357	3-Year	B.A.	
20	202301035881	2023-24	230440330281	NEHA PAL	nehapal712146@gmail.com	9476195383	3-Year	B.A.	
21	202301035882	2023-24	230440330282	NEHA ROY	neharoy20911@gmail.com	8167618100	3-Year	B.A.	
22	202301035883	2023-24	230440330283	NEHA SARDAR	nehasardar57@gmail.com	9679265079	3-Year	B.A.	
23	202301035885	2023-24	230440330284	NIHA MONDAL	nihatanumondal2005@gmail.com	9064633985	3-Year	B.A.	
24	202301035890	2023-24	230440330285	NURE MODINA	khatunalisha037@gmail.com	8250948931	3-Year	B.A.	
25	202301035891	2023-24	230440330286	NURUNNAHAR KHATUN	sknurulhuda369@gmail.com	9474196084	3-Year	B.A.	
26	202301035893	2023-24	230440330287	ORMITA MURMU	murmuormita@gmail.com	7797473182	3-Year	B.A.	
27	202301035895	2023-24	230440330288	PABITRA GHOSH	pabitrag338@gmail.com	6297270626	3-Year	B.A.	
28	202301035896	2023-24	230440330289	PALASH SARKAR	iampalashsarkar01@gmail.com	8637853610	3-Year	B.A.	
29	202301035898	2023-24	230440330290	PALLABI SHIKARI	pallabishiakri@gmail.com	8918528120	3-Year	B.A.	
30	202301035900	2023-24	230440330291	PAMELA ROY	milonroy6137@gmail.com	8617492503	3-Year	B.A.	
31	202301035901	2023-24	230440330292	PAMELI GHOSH	pamelighosh287@gmail.com	9907329903	3-Year	B.A.	
32	202301035909	2023-24	230440330295	PARBATI HALDER	halderparboti35@gmail.com	7679191300	3-Year	B.A.	
33	202301035910	2023-24	230440330296	PARBIN SULTANA	parbin56789100@gmail.com	7063200245	3-Year	B.A.	
34	202301035913	2023-24	230440330298	PARUL SAREN	parulsaren75@gmail.com	8597182951	3-Year	B.A.	
1	202301035915	2023-24	230440330299	PARVIN SULTANA	parvinsultana771962@gmail.com	9775330809	3-Year	B.A.	
2	202301035916	2023-24	230440330300	PAYEL BAG	payelpb544@gmail.com	7601835929	3-Year	B.A.	
3	202301035918	2023-24	230440330301	PAYEL DEBNATH	d85441631@gmail.com	8927084288	3-Year	B.A.	
4	202301035920	2023-24	230440330302	PAYEL GHOSH	payelg037@gmail.com	9093994131	3-Year	B.A.	
5	202301035921	2023-24	230440330303	PAYEL MANDI	mandipayel9@gmail.com	9339293165	3-Year	B.A.	
6	202301035922	2023-24	230440330304	PAYEL MUKHERJEE	pm709415@gmail.com	8900362498	3-Year	B.A.	
7	202301035926	2023-24	230440330307	PAYEL ROY	payelroy.khanyan@gmail.com	8972990560	3-Year	B.A.	
8	202301035927	2023-24	230440330308	PINKI MAN	manpinki440@gmail.com	9609732346	3-Year	B.A.	
9	202301035928	2023-24	230440330309	PIU GHOSH	piughosh374@gmail.com	9339031439	3-Year	B.A.	
10	202301035929	2023-24	230440330310	PIU MALLICK	mallickpiu6@gmail.com	9907887332	3-Year	B.A.	
11	202301035935	2023-24	230440330312	PIYA SARDAR	piya69738@gmail.com	9832837780	3-Year	B.A.	
12	202301035937	2023-24	230440330313	POMI GHOSH	ghoshpomi982@gmail.com	9832858494	3-Year	B.A.	
13	202301035938	2023-24	230440330314	POUSALI GHOSH	pousalighosh62@gmail.com	8670547969	3-Year	B.A.	
14	202301035940	2023-24	230440330316	PRADIP KONRA	Pradipkonra17@gmail.com	9088072554	3-Year	B.A.	ia

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
15	202301035942	2023-24	230440330317	PRAMIT GHOSH	pramitg736@gmail.com	8927971740	3-Year	B.A.	Prof. Pranab Kirtuni
16	202301035943	2023-24	230440330318	PRANAB HEMBRAM	pradiph743@gmail.com	6291273581	3-Year	B.A.	
17	202301035946	2023-24	230440330320	PRATIMA MANDI	pratimamandi000@gmail.com	9907829181	3-Year	B.A.	
18	202301035948	2023-24	230440330321	PREYASI GHOSH	preyasighosh30@gmail.com	8509812644	3-Year	B.A.	
19	202301035949	2023-24	230440330322	PRINKA BARMAN	priyankabarmon283@gmail.com	7718527228	3-Year	B.A.	
20	202301035950	2023-24	230440330323	PRITAM KARMAKAR	itzsonu2004@gmail.com	8597188909	3-Year	B.A.	
21	202301035956	2023-24	230440330325	PRITI NANDI	pritinandi563@gmail.com	7364053218	3-Year	B.A.	
22	202301035958	2023-24	230440330326	PRIYA MANDI	priya9046372967@gmail.com	9046372967	3-Year	B.A.	
23	202301035959	2023-24	230440330327	PRIYA MONDAL	priyqmondal@gmail.com	6294905812	3-Year	B.A.	
24	202301035961	2023-24	230440330328	PRIYANKA BISWAS	pb7736724@gmail.com	7384200939	3-Year	B.A.	
25	202301035962	2023-24	230440330329	PRIYANKA HANSDA	P78869672@gmail.com	7980492424	3-Year	B.A.	
26	202301035964	2023-24	230440330331	PRIYANKA HAZRA	priyankahazra712149@gmail.com	9339159861	3-Year	B.A.	
27	202301035968	2023-24	230440330334	PRIYANKA PAL	ppal632145987@gmail.com	9339760197	3-Year	B.A.	
28	202301035974	2023-24	230440330337	PROMITA MALIK	promitamalik059@gmail.com	7501127245	3-Year	B.A.	
29	202301035975	2023-24	230440330338	PROTIMA DHARA	bivashdharabivashdhara5964@gmail.com	6290935454	3-Year	B.A.	
30	202301035976	2023-24	230440330339	PUJA ADHIKARY	adhikarypuja911@gmail.com	7478456935	3-Year	B.A.	
31	202301035977	2023-24	230440330340	PUJA BAULDAS	pujabauldas853@gmail.com	9547437203	3-Year	B.A.	
32	202301035978	2023-24	230440330341	PUJA HEMBRAM	mabdiajit@gmail.com	9907305997	3-Year	B.A.	
33	202301035980	2023-24	230440330343	PUJA MALLICK	pujamallick428@gmail.com	8250512521	3-Year	B.A.	
34	202301035981	2023-24	230440330344	PURBASHA MONDAL	purbashamondal597@gmail.com	8649834770	3-Year	B.A.	
1	202301035983	2023-24	230440330345	PURNIMA MURMU	purnimamurmu9955@gmail.com	8637515067	3-Year	B.A.	nerjee
2	202301035987	2023-24	230440330346	RACHANA DAS	dasbasanti7126@gmail.com	8101817126	3-Year	B.A.	
3	202301035989	2023-24	230440330347	RACHANA GHOSH	grachana043@gmail.com	9002204824	3-Year	B.A.	
4	202301035988	2023-24	230440330348	RACHANA GHOSH	rimi222005@gmail.com	7602518862	3-Year	B.A.	
5	202301035990	2023-24	230440330349	RACHANA MONDAL	rachanamondal2105@gmail.com	9339926769	3-Year	B.A.	
6	202301035996	2023-24	230440330352	RAHIMA KHATUN	mdb686522@gmail.com	7810803226	3-Year	B.A.	
7	202301035997	2023-24	230440330353	RAJ HAZRA	rh6178610@gmail.com	9382213259	3-Year	B.A.	
8	202301036001	2023-24	230440330355	RAJA MALIK	rajamalik9768@gmail.com	8972657733	3-Year	B.A.	
9	202301036003	2023-24	230440330356	RAJA MANNA	rajamanna859@gmail.com	8167777183	3-Year	B.A.	
10	202301036004	2023-24	230440330357	RAJDIP SAHA	rajdeepsaha2122@gmail.com	8100408950	3-Year	B.A.	
11	202301036006	2023-24	230440330358	RAJIB KISKU	kisku0017@gmail.com	8100051260	3-Year	B.A.	
12	202301036008	2023-24	230440330359	RAKHI BISWAS	rajughosh2097@gmail.com	9933585012	3-Year	B.A.	
13	202301036010	2023-24	230440330360	RAKHI MURMU	rakhimurmu.somragori007@gmail.com	8116999648	3-Year	B.A.	
14	202301036011	2023-24	230440330361	RAKHI SOREN	rakhisoren560@gmail.com	8710065818	3-Year	B.A.	
15	202301036013	2023-24	230440330363	RAMAIJIT SOREN	ramaijitsoren@gmail.com	8016500340	3-Year	B.A.	

Bejoy Narayan Mahavidyalaya
List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration No	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
16	202301036014	2023-24	230440330364	RAMEN TURI	swapanturi5399@gmail.com	8336077130	3-Year I	B.A.	Prof. Sanchali Bar
17	202301036017	2023-24	230440330365	RANA MALIK	malikrana199@gmail.com	9883313953	3-Year I	B.A.	
18	202301036021	2023-24	230440330367	RANI TUDU	rani5436tudu@gmail.com	9073469082	3-Year I	B.A.	
19	202301036022	2023-24	230440330368	RANJIT SHOW	shawranjit81406@gmail.com	7362984929	3-Year I	B.A.	
20	202301036024	2023-24	230440330369	RAYA MODAK	rayamodak3@gmail.com	7810974347	3-Year I	B.A.	
21	202301036025	2023-24	230440330370	REKHA MAJHI	sagarrekha915@gmail.com	9547284913	3-Year I	B.A.	
22	202301036029	2023-24	230440330371	RIA SAHA	sahariya827@gmail.com	7384046087	3-Year I	B.A.	
23	202301036031	2023-24	230440330372	RIMA DAS	rimadas292006@gmail.com	8653996714	3-Year I	B.A.	
24	202301036036	2023-24	230440330373	RIMA SAMADDAR	rimasamaddar2@gmail.com	8389809579	3-Year I	B.A.	
25	202301036037	2023-24	230440330374	RIMI MONDAL	sumanamondal0728@gmail.com	9735220728	3-Year I	B.A.	
26	202301036042	2023-24	230440330377	RIMPA CHAKRABARTY	rimachakraborty394@gmail.com	9679650273	3-Year I	B.A.	
27	202301036048	2023-24	230440330380	RIMPA MALIK	rimpamalik621@gmail.com	8918188688	3-Year I	B.A.	
28	202301036049	2023-24	230440330381	RIMPA ROY	royrimpa211@gmail.com	7679590589	3-Year I	B.A.	
29	202301036051	2023-24	230440330382	RIMPA SANTRA	santrarimpa980@gmail.com	8617043521	3-Year I	B.A.	
30	202301036052	2023-24	230440330383	RIMPRIYA GHOSH	rimpriyaghosh098@gmail.com	9832106838	3-Year I	B.A.	
31	202301036053	2023-24	230440330384	RINA TUDU	tudurina09@gmail.com	7601876391	3-Year I	B.A.	
32	202301036058	2023-24	230440330385	RIPTA MURMU	riptamurmu@gmail.com	7029017088	3-Year I	B.A.	
33	202301036059	2023-24	230440330386	RISHOV SHARMA	sharmarick057@gmail.com	9749586105	3-Year I	B.A.	
34	202301036060	2023-24	230440330387	RISUM DAS	rishomdas90@gmail.com	6289839580	3-Year I	B.A.	
1	202301036061	2023-24	230440330388	RITA JANA	rjana9252@gmail.com	8100677042	3-Year I	B.A.	i Talukder
2	202301036062	2023-24	230440330389	RITA MALIK	malikrita123456@gmail.com	7029219121	3-Year I	B.A.	
3	202301036063	2023-24	230440330390	RITA MONDAL	ritachampta2006@gmail.com	6294764588	3-Year I	B.A.	
4	202301036064	2023-24	230440330391	RITA PAL	pal806749@gmail.com	9339728956	3-Year I	B.A.	
5	202301036065	2023-24	230440330392	RITAM GHOSH	ritamghosh979@gmail.com	7430044474	3-Year I	B.A.	
6	202301036066	2023-24	230440330393	RITAM NANDY	ritamnandy8@gmail.com	8116076432	3-Year I	B.A.	
7	202301036068	2023-24	230440330394	RITIKA MURMU	pareshmurmu61@gmail.com	7029180128	3-Year I	B.A.	
8	202301036069	2023-24	230440330395	RITIKA SARKAR	sarkarritika275@gmail.com	9609724543	3-Year I	B.A.	
9	202301036075	2023-24	230440330397	RIYA ROY	riyaroy99807@gmail.com	9883935847	3-Year I	B.A.	
10	202301036079	2023-24	230440330400	ROHIT DAS	rohitd2501@gmail.com	9641901560	3-Year I	B.A.	
11	202301036082	2023-24	230440330401	ROJINA PARBHIN	alanowarakhatun@gmail.com	8637344726	3-Year I	B.A.	
12	202301036085	2023-24	230440330402	ROKSAR KHATUN	roksarkhatun410@gmail.com	9339241060	3-Year I	B.A.	
13	202301036087	2023-24	230440330403	ROSHNI GHOSH	roshnighosh2005@gmail.com	7001032626	3-Year I	B.A.	
14	202301036088	2023-24	230440330404	ROSHNI KHATUN	redmi9apandua@gmail.com	8167859287	3-Year I	B.A.	
15	202301036092	2023-24	230440330405	RUDRA GHOSH	rudraghosh135@gmail.com	8927410169	3-Year I	B.A.	
16	202301036093	2023-24	230440330406	RUKHSANA KHATUN	mohammadanwar93452@gmail.com	7501695712	3-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
17	202301036097	2023-24	230440330407	RUMA MURMU	mruma5080@gmail.com	8927852717	3-Year	B.A.	Prof. Khukuman
18	202301036099	2023-24	230440330408	RUMANA SULTANA	sultanarumana82@gmail.com	8670763734	3-Year	B.A.	
19	202301036101	2023-24	230440330409	RUMI MONDAL	rumimondal2105@gmail.com	8768953079	3-Year	B.A.	
20	202301036105	2023-24	230440330412	RUPALI DAS	rupalidas4168@gmail.com	8250704168	3-Year	B.A.	
21	202301036107	2023-24	230440330413	RUPALI MANDI	mandirupali86@gmail.com	6297847720	3-Year	B.A.	
22	202301036108	2023-24	230440330414	RUPALI MURMU	RUPALIMURMU250@GMAIL.COM	7866094188	3-Year	B.A.	
23	202301036109	2023-24	230440330415	RUPAM BISWAS	rupambiswas613@gmail.com	6295020815	3-Year	B.A.	
24	202301036110	2023-24	230440330416	RUPAM MONDAL	rupamm355@gmail.com	9062399074	3-Year	B.A.	
25	202301036111	2023-24	230440330417	RUPREKHA BANERJEE	mistibanerjer@gmail.com	9339718769	3-Year	B.A.	
26	202301036114	2023-24	230440330418	RUPSA MIR	rupsamir428@gmail.com	9382994546	3-Year	B.A.	
27	202301036115	2023-24	230440330419	RUPSA ROY	rupsaroy983@gmail.com	9831441627	3-Year	B.A.	
28	202301036116	2023-24	230440330420	RUPSANA KHATUN	krupsana786@gmail.com	8670146618	3-Year	B.A.	
29	202301036118	2023-24	230440330421	RUPSHA GHOSH	rupshaghosh030@gmail.com	7602518907	3-Year	B.A.	
30	202301036121	2023-24	230440330423	SABINA KHATUN	khatunminu45@gmail.com	9002315850	3-Year	B.A.	
31	202301036122	2023-24	230440330424	SABITA HEMBRAM	hembrambidhan618@gmail.com	7363023935	3-Year	B.A.	
32	202301036125	2023-24	230440330426	SABUJ BAULDAS	sabujbauldas8@gmail.com	9002156385	3-Year	B.A.	
33	202301036127	2023-24	230440330427	SAFIKA PERVIN	safikapervin9876@gmail.com	9339872207	3-Year	B.A.	
34	202301036128	2023-24	230440330428	SAFIYA KHATUN	khatunsapiya43@gmail.com	7557806162	3-Year	B.A.	
1	202301036130	2023-24	230440330429	SAGAR BISWAS	sagarbiswaswb@gmail.com	9339684702	3-Year	B.A.	
2	202301036129	2023-24	230440330430	SAGAR BISWAS	sagarbiswas35697@gmail.com	8609535697	3-Year	B.A.	
3	202301036131	2023-24	230440330431	SAGAR GHOSH	sagarghosh2576@gmail.com	7063757207	3-Year	B.A.	
4	202301036132	2023-24	230440330432	SAGAR MURMU	sagarmurmu641@gmail.com	7679704611	3-Year	B.A.	
5	202301036137	2023-24	230440330433	SAHANAJ KHATUN	sahanajkhatun289@gmail.com	7319123773	3-Year	B.A.	
6	202301036141	2023-24	230440330435	SAHINA SULTANA	sahinakhatun1467@gmail.com	9123394549	3-Year	B.A.	
7	202301036142	2023-24	230440330436	SAHINUR KHATUN	Sahinurk786@gmail.com	8348481960	3-Year	B.A.	
8	202301036145	2023-24	230440330438	SAJIYA KHATUN	kureshisajia@gmail.com	7872604952	3-Year	B.A.	
9	202301036146	2023-24	230440330439	SALEHA KHATUN	saleha7112004@gmail.com	9641689368	3-Year	B.A.	
10	202301036153	2023-24	230440330440	SAMIMA KHATUN	khatunsamima31077@gmail.com	9339059253	3-Year	B.A.	
11	202301036152	2023-24	230440330441	SAMIMA KHATUN	sajidakh2021@gmail.com	9732314931	3-Year	B.A.	
12	202301036156	2023-24	230440330443	SAMRAT KADAMBANSHI	samratkadambanshi@gmail.com	8389910385	3-Year	B.A.	
13	202301036160	2023-24	230440330444	SANATAN HANSDA	sanatanhansda2005@gmail.com	9907681685	3-Year	B.A.	
14	202301036161	2023-24	230440330445	SANATAN HEMBRAM	sanatanh792@gmail.com	8967995107	3-Year	B.A.	
15	202301036162	2023-24	230440330446	SANCHITA DAS	sanchita8584@gmail.com	9679388584	3-Year	B.A.	
16	202301036167	2023-24	230440330448	SANCHITA SAREN	sarensanchita75@gmail.com	9749426258	3-Year	B.A.	
17	202301036168	2023-24	230440330449	SANDHYA MISTRI	sandhyamistry719@gmail.com	9547279607	3-Year	B.A.	raj Deb

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
18	202301036170	2023-24	230440330450	SANGITA CHOUHAN	chauhansangita266@gmail.com	7584807318	3-Year	B.A.	Sri Deb
19	202301036171	2023-24	230440330451	SANGITA GHOSH	moumita712139@gmail.com	8100076274	3-Year	B.A.	
20	202301036173	2023-24	230440330452	SANGITA LAYEK	goutmlayek@gmail.com	9883770933	3-Year	B.A.	
21	202301036174	2023-24	230440330453	SANGITA MONDAL	shilpa712146@gmail.com	9647547669	3-Year	B.A.	
22	202301036175	2023-24	230440330454	SANGITA SAREN	sanjitsoren354@gmail.com	8927919558	3-Year	B.A.	
23	202301036176	2023-24	230440330455	SANIA KHATOON	saniakhatunpandua@gmail.com	9083325948	3-Year	B.A.	
24	202301036177	2023-24	230440330456	SANIA KHATUN	mrriyazali303@gmail.com	7001940210	3-Year	B.A.	
25	202301036184	2023-24	230440330457	SANIA SULTANA	4764sania@gmail.com	9339788244	3-Year	B.A.	
26	202301036181	2023-24	230440330458	SANIA SULTANA	saniasultana988@gmail.com	9547577523	3-Year	B.A.	
27	202301036187	2023-24	230440330459	SANIYA KHATUN	saniyakhatun12868@gmail.com	8670763904	3-Year	B.A.	
28	202301036185	2023-24	230440330460	SANIYA KHATUN	www.saniyakhan762@gmail.com	7363082873	3-Year	B.A.	
29	202301036188	2023-24	230440330461	SANJU MONDAL	sanjumondal8962@gmail.com	8910867953	3-Year	B.A.	
30	202301036189	2023-24	230440330462	SANKHADWIP SHARMA	rintu1990sharma@gmail.com	8101219366	3-Year	B.A.	
31	202301036193	2023-24	230440330465	SAPTARSHI GHOSH	ghoshsaptarshi289@gmail.com	8927115263	3-Year	B.A.	
32	202301036194	2023-24	230440330466	SARA YASMIN	ysara8115@gmail.com	9641590996	3-Year	B.A.	
33	202301036197	2023-24	230440330467	SARASWATI SOREN	mantu.bnm@gmail.com	9883935755	3-Year	B.A.	
34	202301036198	2023-24	230440330468	SARASWATI TUDU	studu8242@gmail.com	7063897287	3-Year	B.A.	
1	202301036201	2023-24	230440330469	SARNA KISKU	sarnakisku117@gmail.com	9679746638	3-Year	B.A.	
2	202301036203	2023-24	230440330470	SATHI BAGCHI	sathibagchi05@gmail.com	7364034773	3-Year	B.A.	
3	202301036204	2023-24	230440330471	SATHI BARAI	sathibarai051@gmail.com	9614975304	3-Year	B.A.	
4	202301036208	2023-24	230440330475	SATHI MAL	malgopal787@gmail.com	8371951365	3-Year	B.A.	
5	202301036211	2023-24	230440330476	SAYAN DAS	sd6166365@gmail.com	9883947280	3-Year	B.A.	
6	202301036212	2023-24	230440330477	SAYAN DUTTA	duttasayan995@gmail.com	9382532931	3-Year	B.A.	
7	202301036214	2023-24	230440330479	SAYANI DAS	dsayani797@gmail.com	9907549008	3-Year	B.A.	
8	202301036215	2023-24	230440330480	SAYANI DEY	sayaniday8116@gmail.com	8116994661	3-Year	B.A.	
9	202301036216	2023-24	230440330481	SAYANI GHOSH	sayanighosh1708@gmail.com	8981279707	3-Year	B.A.	
10	202301036217	2023-24	230440330482	SAYANI MANNA	mannagopla2022@gmail.com	8017778509	3-Year	B.A.	
11	202301036221	2023-24	230440330484	SEAUTI SARDAR	sardarseauti@gmail.com	8293835046	3-Year	B.A.	
12	202301036222	2023-24	230440330485	SEHENAZ KHATUN	sehenazkhatun737@gmail.com	9679310691	3-Year	B.A.	
13	202301036223	2023-24	230440330486	SEKH ARIYEN ISLAM	ariyensk034@gmail.com	8158853705	3-Year	B.A.	
14	202301036224	2023-24	230440330487	SERINA KHATUN	sonakhatun12341234@gmail.com	8116757897	3-Year	B.A.	
15	202301036228	2023-24	230440330488	SHAKHI MANDI	shakimandi94@gmail.com	9732235536	3-Year	B.A.	
16	202301036231	2023-24	230440330489	SHAMPA MUKHERJEE	shampa9601@gmail.com	8293009601	3-Year	B.A.	
17	202301036232	2023-24	230440330490	SHAMPA SAREN	shampasaren86@gmail.com	7980489930	3-Year	B.A.	
18	202301036234	2023-24	230440330491	SHARMILA BANERJEE	sharmilabanerjee2005@gmail.com	6296094201	3-Year	B.A.	Bani Patua

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
19	202301036236	2023-24	230440330492	SHARMIN SULTANA	sultanasarmin856@gmail.com	7001220901	3-Year	B.A.	Prof.
20	202301036238	2023-24	230440330493	SHARMISTHA DEBNATH	puchkudebnath3@gmail.com	9046083540	3-Year	B.A.	
21	202301036245	2023-24	230440330495	SHNEHA MANDI	mandishenha@gmail.com	7384716651	3-Year	B.A.	
22	202301036246	2023-24	230440330496	SHOAIB SARKAR	sarkarshoaib06@gmail.com	8927717443	3-Year	B.A.	
23	202301036248	2023-24	230440330497	SHRABANI MAJUMDAR	shrabanimajumdar774@gmail.com	7477703779	3-Year	B.A.	
24	202301036249	2023-24	230440330498	SHRABANI MALIK	malikajay5868@gmail.com	8670755079	3-Year	B.A.	
25	202301036250	2023-24	230440330499	SHRABANI MISTRI	shrabanimistri1234@gmail.com	9679750291	3-Year	B.A.	
26	202301036253	2023-24	230440330500	SHRABANI TUDU	abhijittudu136@gmail.com	7810833828	3-Year	B.A.	
27	202301036255	2023-24	230440330501	SHRESTHA HALDER	rimi20399@gmail.com	8972657585	3-Year	B.A.	
28	202301036257	2023-24	230440330502	SHREYA MAJUMDAR	shreyamajumdar85@gmail.com	9800135963	3-Year	B.A.	
29	202301036258	2023-24	230440330503	SHREYA MONDAL	shreyamondal8116@gmail.com	9046132247	3-Year	B.A.	
30	202301036260	2023-24	230440330504	SHUBHANA GHOSH	bidishaghosh198@gmail.com	6295481749	3-Year	B.A.	
31	202301036261	2023-24	230440330505	SHUBHASHIS KHAN	shubhashiskhan@gmail.com	8972980115	3-Year	B.A.	
32	202301036263	2023-24	230440330506	SHULI SINGH	anilmandi704@gmail.com	7872850328	3-Year	B.A.	
33	202301036265	2023-24	230440330507	SHUVANKAR ROY	suvs0177@gmail.com	7439207974	3-Year	B.A.	
34	202301036267	2023-24	230440330509	SHYAMALI SAREN	shyamalisaren91@gmail.com	9749315601	3-Year	B.A.	
1	202301036270	2023-24	230440330510	SIDDHARTHA MAJHI	siddharthamajhi27102005@gmail.com	9907720287	3-Year	B.A.	of. Ishita Aditya
2	202301036271	2023-24	230440330511	SIMA BAG	simabag121@gmail.com	8514930314	3-Year	B.A.	
3	202301036272	2023-24	230440330512	SIMA HANSDA	asimahansda36@gmail.com	7363013695	3-Year	B.A.	
4	202301036273	2023-24	230440330513	SIMA KORA	simakorasis@gmail.com	9832969338	3-Year	B.A.	
5	202301036274	2023-24	230440330514	SIMA MALIK	simamalik098@gmail.com	8617866093	3-Year	B.A.	
6	202301036276	2023-24	230440330515	SIMA ORANG	simaorang1243@gmail.com	8670340194	3-Year	B.A.	
7	202301036277	2023-24	230440330516	SIMA SULTANA	simasultanasultanasima@gmail.com	7601829891	3-Year	B.A.	
8	202301036281	2023-24	230440330519	SINGRAI TUDU	singrai1324@gmail.com	7439597007	3-Year	B.A.	
9	202301036282	2023-24	230440330520	SITU MONDAL	situmandal630@gmail.com	8945052477	3-Year	B.A.	
10	202301036283	2023-24	230440330521	SK ABU TAUSIF	skabutausif@gmail.com	8972656127	3-Year	B.A.	
11	202301036291	2023-24	230440330525	SK IMRAN ALI	skimranali34098@gmail.com	7699471886	3-Year	B.A.	
12	202301036293	2023-24	230440330527	SK NASIM ALI	sknasim5987@gmail.com	9641757334	3-Year	B.A.	
13	202301036297	2023-24	230440330530	SK SOHEL ABBAS	sksohelabbas50@gmail.com	8116005476	3-Year	B.A.	
14	202301036301	2023-24	230440330532	SNEHA GHOSH	snehaghosh1123@gmail.com	8116670947	3-Year	B.A.	
15	202301036303	2023-24	230440330533	SNEHA GHOSH	myself1432two@gmail.com	9339278110	3-Year	B.A.	
16	202301036305	2023-24	230440330534	SNEHA KSHETRAPAL	purnimakshetrapal66@gmail.com	9093479725	3-Year	B.A.	
17	202301036307	2023-24	230440330535	SNEHA PAL	sneha712146@gmail.com	7363020427	3-Year	B.A.	
18	202301036308	2023-24	230440330536	SNEHA SAHANI	sahanisneha36@gmail.com	9800069598	3-Year	B.A.	
19	202301036309	2023-24	230440330537	SNEHA SAMANTA	snehasamanta081@gmail.com	7602408912	3-Year	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
20	202301036310	2023-24	230440330538	SNEHA SHARMA	sharmaa83695@gmail.com	9735016966	3-Year I	B.A.	Pro
21	202301036312	2023-24	230440330539	SOBIA KHATUN	sobiasorkar@gmail.com	9339153576	3-Year I	B.A.	
22	202301036313	2023-24	230440330541	SOHANA SULTANA	sksahid95999@gmail.com	9775876768	3-Year I	B.A.	
23	202301036316	2023-24	230440330543	SOMA GHOSH	somaghosh1314225@gmail.com	8116730120	3-Year I	B.A.	
24	202301036317	2023-24	230440330544	SOMA MIDDAY	middaysoma2@gmail.com	6290769382	3-Year I	B.A.	
25	202301036318	2023-24	230440330545	SOMA ROY	somaroy9311@gmail.com	9907296667	3-Year I	B.A.	
26	202301036320	2023-24	230440330546	SONALI BARAI	baraisonali963@gmail.com	8653184080	3-Year I	B.A.	
27	202301036323	2023-24	230440330547	SONALI MAJHI	majhisonali811@gmail.com	9330645197	3-Year I	B.A.	
28	202301036326	2023-24	230440330548	SONALI ROY	roy2005sonali@gmail.com	9093277486	3-Year I	B.A.	
29	202301036330	2023-24	230440330550	SOUMAJIT SINGHA ROY	soumajitsingharoy07@gmail.com	8101313818	3-Year I	B.A.	
30	202301036336	2023-24	230440330552	SOUMI KUMAR	ksoumi736@gmail.com	8649821320	3-Year I	B.A.	
31	202301036338	2023-24	230440330553	SOUMI ROY	rsoumi563@gmail.com	7001203550	3-Year I	B.A.	
32	202301036337	2023-24	230440330554	SOUMI ROY	soumiroy435@gmail.com	8101748313	3-Year I	B.A.	
33	202301036339	2023-24	230440330555	SOUMIK DAS	soumikdas0077@gmail.com	9875374420	3-Year I	B.A.	
34	202301036340	2023-24	230440330556	SOUMIK GHOSH	soumikghosh9474@gmail.com	8670541571	3-Year I	B.A.	
1	202301036342	2023-24	230440330558	SOUMYA DAS	s7217897@gmail.com	6297465436	3-Year I	B.A.	mt. Shampa Singha
2	202301036343	2023-24	230440330559	SOUMYADIPTA MUKHERJEE	mukherjeesoumyadipta630@gmail.com	8918809908	3-Year I	B.A.	
3	202301036344	2023-24	230440330560	SOUMYAJIT SANTRA	santrasoumyajit791@gmail.com	8609544634	3-Year I	B.A.	
4	202301036345	2023-24	230440330561	SOURAV ADHIKARY	souravadhikari864@gmail.com	8327835245	3-Year I	B.A.	
5	202301036347	2023-24	230440330562	SOURAV DAS	sd1808732@gmail.com	8670405638	3-Year I	B.A.	
6	202301036348	2023-24	230440330563	SOURAV GHOSH	souravmbghosh@gmail.com	9883511824	3-Year I	B.A.	
7	202301036352	2023-24	230440330565	SRABANI LOHAR	srabanilohar3@gmail.com	8972654591	3-Year I	B.A.	
8	202301036354	2023-24	230440330566	SREEJA GHOSH	sreejaghosh596@gmail.com	7001414099	3-Year I	B.A.	
9	202301036355	2023-24	230440330567	SRIMANTA BASKEY	baskeysrimanta65@gmail.com	9749869950	3-Year I	B.A.	
10	202301036357	2023-24	230440330568	SUBHAJIT DAS	dmukta940@gmail.com	9547284932	3-Year I	B.A.	
11	202301036360	2023-24	230440330570	SUBHANKAR GHOSHAL	sghoshal814@gmail.com	9123865226	3-Year I	B.A.	
12	202301036363	2023-24	230440330571	SUBRATA DAS	daspakri@gmail.com	6296895524	3-Year I	B.A.	
13	202301036365	2023-24	230440330572	SUBRATA MURMU	murmusubrata384@gmail.com	7047191272	3-Year I	B.A.	
14	202301036366	2023-24	230440330573	SUCHANA DAS	das.haradhan0022@gmail.com	8172000202	3-Year I	B.A.	
15	202301036369	2023-24	230440330574	SUDIP BISWAS	sb8146737@gmail.com	8509566797	3-Year I	B.A.	
16	202301036371	2023-24	230440330576	SUDIPA MAN	sudipaman123@gmail.com	8145533060	3-Year I	B.A.	
17	202301036372	2023-24	230440330577	SUDIPTA KAORA	sudiptakaora@gmail.com	7001157091	3-Year I	B.A.	
18	202301036373	2023-24	230440330578	SUDIPTA MISTRI	dulalmistri88@gmail.com	8617643164	3-Year I	B.A.	
19	202301036379	2023-24	230440330579	SUJATA GHOSH	ghoshsujata1504@gmail.com	9046372115	3-Year I	B.A.	
20	202301036380	2023-24	230440330580	SUJATA MAJHI	tukmukimajhi569@gmail.com	8927304230	3-Year I	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
21	202301036381	2023-24	230440330581	SUJATA MISTRY	mistrypriya2207@gmail.com	8538814280	3-Year	B.A.	S
22	202301036383	2023-24	230440330583	SUJAY BISWAS	biswassujay218@gmail.com	9933171701	3-Year	B.A.	
23	202301036387	2023-24	230440330584	SUKDEB SAREN	saransukdeb@gmail.com	7602304617	3-Year	B.A.	
24	202301036389	2023-24	230440330585	SUKLAL TUDU	studu2523@gmail.com	7364978183	3-Year	B.A.	
25	202301036392	2023-24	230440330586	SUMAN GHOSH	sumanghosh2137221@gmail.com	6296327431	3-Year	B.A.	
26	202301036393	2023-24	230440330587	SUMAN KHETRAPAL	sumankhetrapal97@gmail.com	8159931581	3-Year	B.A.	
27	202301036396	2023-24	230440330588	SUMANA BAULDAS	supriyobauldas@gmail.com	9046628266	3-Year	B.A.	
28	202301036397	2023-24	230440330589	SUMANA BISWAS	sb9751462@gmail.com	8972736325	3-Year	B.A.	
29	202301036398	2023-24	230440330590	SUMANA DAS	sumanadas7797690736@gmail.com	8967595047	3-Year	B.A.	
30	202301036401	2023-24	230440330591	SUMANA SAHANI	sahanisumana385@gmail.com	8101289420	3-Year	B.A.	
31	202301036404	2023-24	230440330593	SUMI BISWAS	sumi.biswas412@gmail.com	9339001616	3-Year	B.A.	
32	202301036405	2023-24	230440330594	SUMIT MISTRI	smistri022@gmail.com	6297995406	3-Year	B.A.	
33	202301036410	2023-24	230440330596	SUMITA TURI	sumitaturi6@gmail.com	7479049585	3-Year	B.A.	
34	202301036412	2023-24	230440330597	SUNITA JADAV	sy4407163@gmail.com	8670762347	3-Year	B.A.	
1	202301036414	2023-24	230440330598	SUPARNA BISWAS	bsuparna329@gmail.com	9907609631	3-Year	B.A.	Smt. Kankana Nandi
2	202301036424	2023-24	230440330600	SURAJIT HEMBROM	hemramsekhar@gmail.com	9883171518	3-Year	B.A.	
3	202301036425	2023-24	230440330601	SURANJAN DAS	suranjandas465@gmail.com	8972811909	3-Year	B.A.	
4	202301036429	2023-24	230440330602	SUSHMITA KONRA	korasubhas20@gmail.com	7047646593	3-Year	B.A.	
5	202301036430	2023-24	230440330603	SUSMITA MALIK	rajesmalik224@gmail.com	9002742334	3-Year	B.A.	
6	202301036431	2023-24	230440330604	SUSMITA PAL	susmitapal2484@gmail.com	9330183103	3-Year	B.A.	
7	202301036432	2023-24	230440330605	SUSMITA SAMADDAR	samaddersusmita04@gmail.com	7384491037	3-Year	B.A.	
8	202301036433	2023-24	230440330606	SUSMITA SARKAR	sapnasarkar672@gmail.com	7501092459	3-Year	B.A.	
9	202301036434	2023-24	230440330607	SUSMITA TURI	susmitaturi666@gmail.com	7601992833	3-Year	B.A.	
10	202301036435	2023-24	230440330608	SUSUMA BAGANI	susumabagani101@gmail.com	8670707930	3-Year	B.A.	
11	202301036437	2023-24	230440330609	SUTISHNA MALIK	sutishnamalik@gmail.com	9735048891	3-Year	B.A.	
12	202301036441	2023-24	230440330611	SWAPNA LOHAR	swapnalohar9382@gmail.com	7679155686	3-Year	B.A.	
13	202301036446	2023-24	230440330614	TAINU KHATOON	sunalik155@gmail.com	9831108413	3-Year	B.A.	
14	202301036448	2023-24	230440330615	TAJSADIKA SULTANA	tajsadikasultana4@gmail.com	9339875653	3-Year	B.A.	
15	202301036450	2023-24	230440330616	TAMASA MALIK	tamasamalik2005@gmail.com	8945037651	3-Year	B.A.	
16	202301036452	2023-24	230440330617	TANIYA DAS	akash795633@gmail.com	9875360829	3-Year	B.A.	
17	202301036454	2023-24	230440330618	TANU HAOLADAR	7063tanu01@gmail.com	9064051954	3-Year	B.A.	
18	202301036456	2023-24	230440330619	TANUSHREE BAULDAS	tanushreebauldas418@gmail.com	8670484894	3-Year	B.A.	
19	202301036457	2023-24	230440330620	TANUSHRI BAG	tanushribag929@gmail.com	9932912512	3-Year	B.A.	
20	202301036458	2023-24	230440330621	TANUSRI DAS	rinadaspandua20@gmail.com	9932583788	3-Year	B.A.	
21	202301036459	2023-24	230440330622	TANUSRI TUDU	tapantudu169@gmail.com	8670154235	3-Year	B.A.	

Bejoy Narayan Mahavidyalaya

List of Students for Internal Assesment of Sem-III Multi dis. 2024-2025 Code-ENVSC-3031

Sl.No.	Registration N	Registrat	Roll No	Student Name	Email ID	Mobile Numb	NEP p	Cours	Assigned Teacher
22	202301036460	2023-24	230440330623	TANUTRA SETH	tanutraseth585@gmail.com	9476445465	3-Year	B.A.	
23	202301036462	2023-24	230440330624	TAPASI PANDIT	pandittapasi045@gmail.com	8250197065	3-Year	B.A.	
24	202301036463	2023-24	230440330625	TARANNUM PARVEEN	ptarannum892@gmail.com	7439597997	3-Year	B.A.	
25	202301036465	2023-24	230440330626	TASMINA KHATUN	tasminak988@gmail.com	9883069818	3-Year	B.A.	
26	202301036466	2023-24	230440330627	THAKURMANI MURMU	animamurmu69@gmail.com	8617510620	3-Year	B.A.	
27	202301036468	2023-24	230440330628	TIRTHA BACHAR	tirthabarmon@gmail.com	9088589064	3-Year	B.A.	
28	202301036476	2023-24	230440330630	TRIPTI SINGH	ts763994@gmail.com	9635174696	3-Year	B.A.	
29	202301036478	2023-24	230440330631	TUHIN MALLICK	tuhinmallick338@gmail.com	9002150259	3-Year	B.A.	
30	202301036479	2023-24	230440330632	TUHINA KHATUN	tuhinakp@gmail.com	9609977088	3-Year	B.A.	
31	202301036481	2023-24	230440330633	TUMPA PRAMANIK	tumpaparamanik60@gmail.com	7679482484	3-Year	B.A.	
32	202301036482	2023-24	230440330634	TUSHAR DURLAV	tushardurlav85@gmail.com	7679538730	3-Year	B.A.	
33	202301036486	2023-24	230440330636	UMA BHAWAL	umabhawal2@gmail.com	8653152233	3-Year	B.A.	
34	202301036487	2023-24	230440330637	UMA GHOSH	umaghosh9635@gmail.com	8145298472	3-Year	B.A.	
1	202301036489	2023-24	230440330638	URBITA MANDI	urbitamandi@gmail.com	8710061583	3-Year	B.A.	Prof. Kaushik Sarkar
2	202301036490	2023-24	230440330639	UTTAM SARDAR	uttamssrdar@gmail.com	7602313786	3-Year	B.A.	
3	202301035450	2023-24	230440330644	ANAKN MAJUMDAR	ankanmajumdar2005@gmail.com	8695703436	3-Year	B.A.	
4	202301035570	2023-24	230440330647	BEAUTY ROY	br4355180@gmail.com	8637805654	3-Year	B.A.	
5	202301035724	2023-24	230440330648	KEYA DAS	keyadas621@gmail.com	9475470601	3-Year	B.A.	
6	202301036112	2023-24	230440330654	RUPSA KHATUN	khatunrupsa737@gmail.com	9733399227	3-Year	B.A.	
7	202301036151	2023-24	230440330655	SAMIHA RAHAMAN	khatunsahanara26@gmail.com	9046461079	3-Year	B.A.	
8	202301036461	2023-24	230440330659	TAPAS KUMBHAKAR	tapaskumbhakar70@gmail.com	7407670992	3-Year	B.A.	
9	202301036496	2023-24	230640330001	ADITI KARMAKAR	karmakaraditi43@gmail.com	9476160158	3-Year	B.Sc.	
10	202301036510	2023-24	230640330005	DEBANJAN DEY	debanjan.dey858@gmail.com	8653403440	3-Year	B.Sc.	
11	202101049892	2023-24	230640330006	DEEPKUMAR GUIN	deepkumarguin79@gmail.com	9064719525	3-Year	B.Sc.	
12	202301036512	2023-24	230640330007	FARHINA KHATUN	khatunfarhina2004@gmail.com	7501284647	3-Year	B.Sc.	
13	202301036521	2023-24	230640330008	MOU MONDAL	moum89996@gmail.com	7501142455	3-Year	B.Sc.	
14	202301036522	2023-24	230640330009	POULOMI BHATTACHARYA	poulomibhattacharya357@gmail.com	8250803391	3-Year	B.Sc.	
15	202301036523	2023-24	230640330010	RIMPA MISTRI	rimpamistri2005@gmail.com	7363995012	3-Year	B.Sc.	
16	202301036529	2023-24	230640330011	SANA MONDAL	mondalsana84@gmail.com	9883225027	3-Year	B.Sc.	
17	202301036538	2023-24	230640330013	SHRABONI MONDAL	mondalshraboni.2007@gmail.com	9064985980	3-Year	B.Sc.	
18	202301036541	2023-24	230640330014	SOHAN ALI SHA	alishasohan50@gmail.com	8250130260	3-Year	B.Sc.	

List of teachers assigned for Sem-III Multi disciplinary Subject ENVS (2024-			
Sl No	Name of the Teacher	Department	Phone No
1	Sri Samik Dasgupta	English	9051394899
2	Sri Anjan Dasgupta	English	9733050582
3	Sri Anjan Das	English	9434251423
4	Sri Ashok Howlader	English	9332395609
5	Smt. Moumita Mukherjee	English	9836516061
6	Smt. Soma Bandopadhyay	English	9477435705
7	Sri Sampad Dey	Bengali	8116013057
8	Sri Soumyojit Chowdhury	Bengali	8900251218
9	Sri Pritwis Biswas	History	8335950752
10	Sri Abir Bandopadhyay	History	9830604131
11	Sri Suprasanya Chatterjee	History	9874395127
12	Sri Bibhas Howlader	History	9046934542
13	Sri Kaushik Chatterjee	History	7699920052
14	Sri Dipak Garai	Sanskrit	7908032998
15	Sri Pranab Kirtunia	Philosophy	9093580028
16	Smt. Sanchali Banerjee	Philosophy	9830320470
17	Smt. Khukumani Talukder	Philosophy	9679723979
18	Sri Debraj Deb	Philosophy	7679867395
19	Sri Bani Patua	History	9434348343
20	Smt. Ishita Aditya	Political Science	9474391738
21	Smt. Shampa Singha	Philosophy	8981335060
22	Smt. Kankana Nandi	Philosophy	9474697305
23	Sri Kaushik Sarkar	Sanskrit	7501480660

-2025)
Email ID
samikdasgupta7@gmail.com
tellanjan@yahoo.com
anjanenglis@gmail.com
asokeeng.21.hooghly@gmail.com
moumitamandal85@gmail.com
soma5790@gmail.com
sampadcooldey@gmail.com
soumyajit050@gmail.com
prithwis16ts@gmail.com
abirbondo85@gmail.com
chatterjeesuprasanna@gmail.com
bivashhowlader2014@gmail.com
kchatterjee417@gmail.com
dgorai756@gmail.com
pranabkirtunia10@gmail.com
sanchali15@gmail.com
khukumani.talukdar@gmail.com
debdebraj6@gmail.com
banibrata1910@gmail.com
ishitaaditya@ymail.com
shampasingha1983@gmail.com
kankana.asl@gmail.com
kaushiksarkar.blg@gmail.com

SEMESTER- III

PAPER CODE: ENVSC 3031 [ENVSC Multidisciplinary: COURSE NO. 3]
CLIMATE CHANGE & CLIMATE ACTION
TOTAL CREDITS: 3

TIME: 2 Hours | **MARKS: 40**
Lecture: 50

Learning objectives

- Explain the fundamentals of climate change science
- Present the international climate change legal and policy framework and explain key issues under negotiation
- Describe the expected consequences of climate change and the role of adaptation
- Provide a rational for climate change mitigation and propose actions in key sectors
- Outline basic elements of planning processes to deliver climate change action

The Science of climate change: Atmosphere of the Earth; Global temperature – Past and present trend, Green house effects; Global energy balance: Greenhouse gases and aerosols; its effects on global warming **15**

Climate change and its effects: Impact of climate change on the perspective of biodiversity, ocean, natural hazards, health risk, food supply, poverty, environmental refugee **10**

Climate action: Climate change - adoption, Vulnerability assessment-IPCC Framework (AR5 and AR6); Identifying and selecting adaptation option, linking adaptation and development Planning **10**

Policy and mitigation: Policy approaches for mitigation and Low Carbon Development; Role of National and Sectorial Institutions in climate change planning, National Action Plan on Climate **15**

Learning outcome

After completion of this course students should learn about -

Fundaments of climate change science as well as know-how of the equipment with techniques for adaptation and vulnerability assessment

Knowledge and understanding on future implementation of low carbon development policy

Proposed faculty involvement

Unit 1 & 2: Social Science/ Botany/Zoology
Unit3: Geography/Botany/ Zoology/ History
Unit4: Geography/ Social Science/ Physics
Unit 5: Political Science/Social Science

Bengali
- History
, Pol Sc.
, Economics
, Philosophy
, Santali
, Sanskrit

The Science of climate change

ATMOSPHERE OF THE EARTH:

What Is Atmosphere?

An atmosphere is a blanket of gases that surrounds Earth. It is held near the surface of the planet by Earth's gravitational attraction. Argon, oxygen and nitrogen from the three main constituents of the atmosphere.

Definition

"Atmosphere is a protective layer of gases that shelters all life on Earth, keeping temperatures within a relatively small range and blocking out harmful rays of sunlight."

Features of the Atmosphere:

- Helps retain the sun's heat and prevents it from escaping back into space.
- Protects life from harmful radiation from the sun.
- Plays a major role in Earth's water cycle.
- Helps keep the climate on Earth moderate.

There is no boundary between the atmosphere and outer space. The atmosphere gets less dense and denser until it "blends" into outer space.

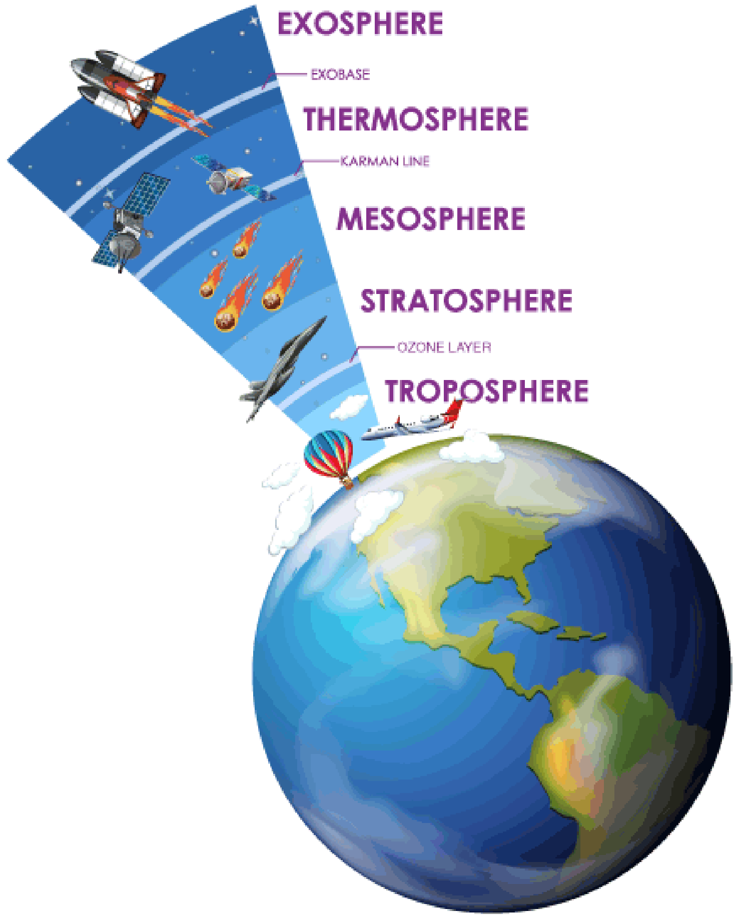
Layers of Atmosphere

What do you see when you stand outside and look up? A blue sky? A group of clouds? At night you might see a crescent moon, stars, a satellite. What you are not seeing, however, is the complexity of our atmosphere.

The atmosphere has five distinct layers that are determined by the changes in temperature that happen with increasing altitude. Layers of Earth's atmosphere are divided into five different layers as:

- Exosphere
- Thermosphere
- Mesosphere
- Stratosphere
- Troposphere

Let us find out more about the layers of atmosphere and their importance.



The hierarchical arrangement of various layers of the Earth's atmosphere

Troposphere

The troposphere is the lowest layer in the atmosphere. It extends upward to about 10 km above sea level starting from ground level. The lowest part of the troposphere is called the boundary layer and the topmost layer is called the tropopause. The troposphere contains 75% of all air in the atmosphere. Most clouds appear in this layer because 99% of the water vapour in the atmosphere is found here. Temperature and air pressure drop as you go higher in the troposphere. When a parcel of air moves upwards it expands. When air expands it cools. Due to this reason, the base of the troposphere is warmer than its base because the air in the surface of the Earth absorbs the sun's energy, gets heated up and moves upward as a result of which it cools down.

Stratosphere

Above the troposphere lies the stratosphere which extends from the top of the troposphere to about 50 km (31 miles) above the ground. The ozone layer lies within the stratosphere. Ozone molecules in this layer absorb high-energy ultraviolet (UV) light from the Sun and convert it into heat. Because of this, unlike the troposphere, the stratosphere gets warmer the higher you go!

Mesosphere

Above the stratosphere is the mesosphere and it extends to a height of about 85 km (53 miles) from the ground. Here, the temperature grows colder as you rise up through the mesosphere. The coldest parts of our atmosphere are located in this layer and can reach –90°C.

Thermosphere

Thermosphere lies above the mesosphere and this is a region where the temperature increases as you go higher up. The temperature increase is caused due to the absorption of energetic ultraviolet and X-ray radiation from the sun. However, the air in this layer is so thin that it would feel freezing cold to us! Satellites orbit Earth within the thermosphere. Temperatures in the upper thermosphere can range from about 500° C to 2,000° C or higher. The aurora, the Northern Lights and Southern Lights, occur in the thermosphere.

Exosphere

Exosphere is the final frontier of the Earth's gaseous envelope. The air in the exosphere is constantly but gradually leaking out of the Earth's atmosphere into outer space. There is no clear cut upper boundary where the exosphere finally fades away into space.

Ionosphere

The ionosphere isn't a distinct layer unlike other layers in the atmosphere. The ionosphere is a series of regions in parts of the mesosphere and thermosphere where high-energy radiation from the Sun has knocked electrons loose from their parent atoms and molecules.

Summary of Layers of Atmosphere			
Region	**Altitude Range (km)**	**Temperature Range(0°C)**	**Important Characteristics**
Troposphere	**0-11**	**15 to -56**	**Weather occurs here**
Stratosphere	**11-50**	**-56 to -2**	**The ozone layer is present here**
Mesosphere	**50-85**	**-2 to -92**	**Meteors burn in this layer**
Thermosphere	**85-800**	**-92 to 1200**	**Auroras occur here**

Watch this video to know everything about the air around us. Although, technically we call it the atmosphere – the circle of air. Learn how this atmosphere arranges itself in 4 layers above earth – troposphere, stratosphere, mesosphere, thermosphere, how the ozone layer protects us from the harmful UV rays of the sun, and why it feels cold when we go up high in the air.

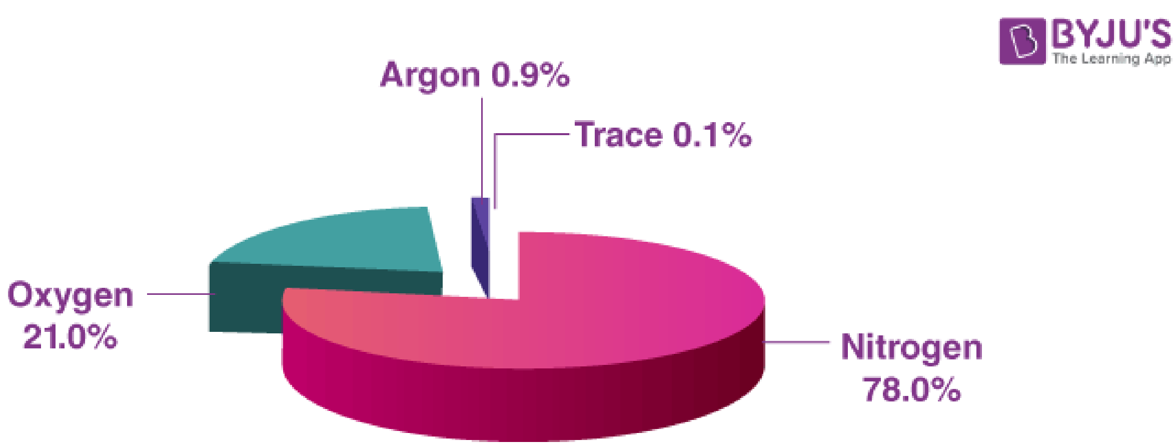
What Would Happen if the Earth's Atmosphere Disappeared?

Have you ever wondered what would happen if the Earth lost its atmosphere? Here is a breakdown of what could happen:

- Birds and planes would fall from the sky. Although we can't see air, it has a mass that supports flying objects.
- The sky would turn black. The sky gets its colour blue due to the atmosphere. Gases and particles in Earth's atmosphere scatter sunlight in all directions. Blue light is scattered more than other colours because it travels as shorter, smaller waves. This is why we see a blue sky most of the time.
- There would be no sensation of sound. Although you could feel vibrations from the ground you wouldn't hear anything. Sound requires a medium to travel.
- All the water bodies such as rivers, lakes and oceans would boil away. Boiling occurs when the vapour pressure of a liquid exceeds external pressure. In a vacuum, the water readily boils.
- Organisms that breathe air to survive would die.

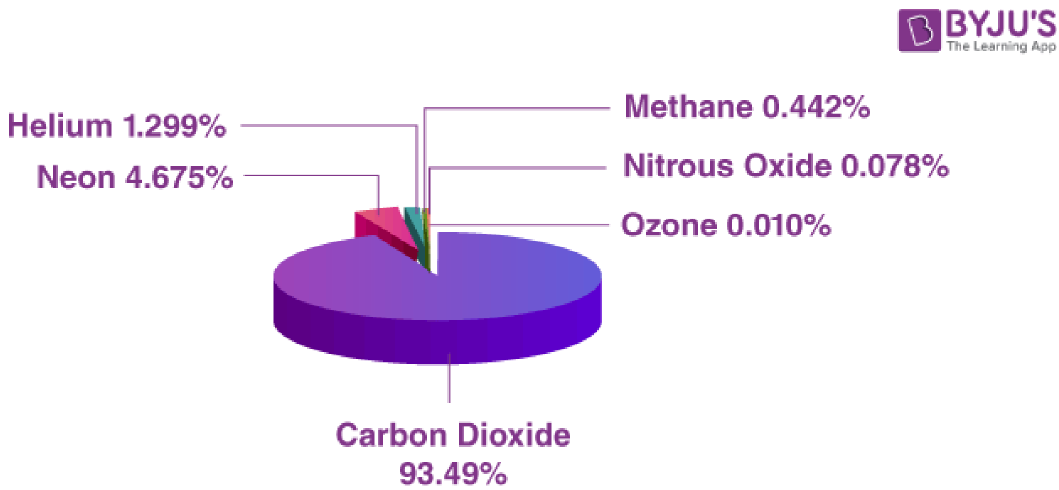
Composition of Atmosphere – Gases in the Atmosphere

The atmospheric composition of gas on Earth is largely conducted by the by-products of the life that it nurtures.



Dry air from earth's atmosphere contains 0.038% of carbon dioxide, 20.95% of oxygen, 78.08% of nitrogen and 0.93% of argon.

Traces of hydrogen, neon, helium, nitrous oxide, ozone and other “noble” gases, but generally a variable amount of water vapour is also present, on average about 1% at sea level.



GLOBAL TEMPERATURE-PAST AND PRESENT TREND:

Climate Change: Global Temperature

BY REBECCA LINDSEY AND LUANN DAHLMAN REVIEWED BY JESSICA BLUNDEN

PUBLISHED JANUARY 18, 2024

HIGHLIGHTS

- Earth’s temperature has risen by an average of 0.11° Fahrenheit (0.06° Celsius) per decade since 1850, or about 2° F in total.
  - The rate of warming since 1982 is more than three times as fast: 0.36° F (0.20° C) per decade.
- 2023 was the warmest year since global records began in 1850 by a wide margin.
  - It was 2.12 °F (1.18 °C) above the 20th-century average of 57.0°F (13.9°C).
  - It was 2.43 °F (1.35 °C) above the pre-industrial average (1850-1900).
- The 10 warmest years in the historical record have all occurred in the past decade (2014-2023).
- 2023 global summary

Related Content

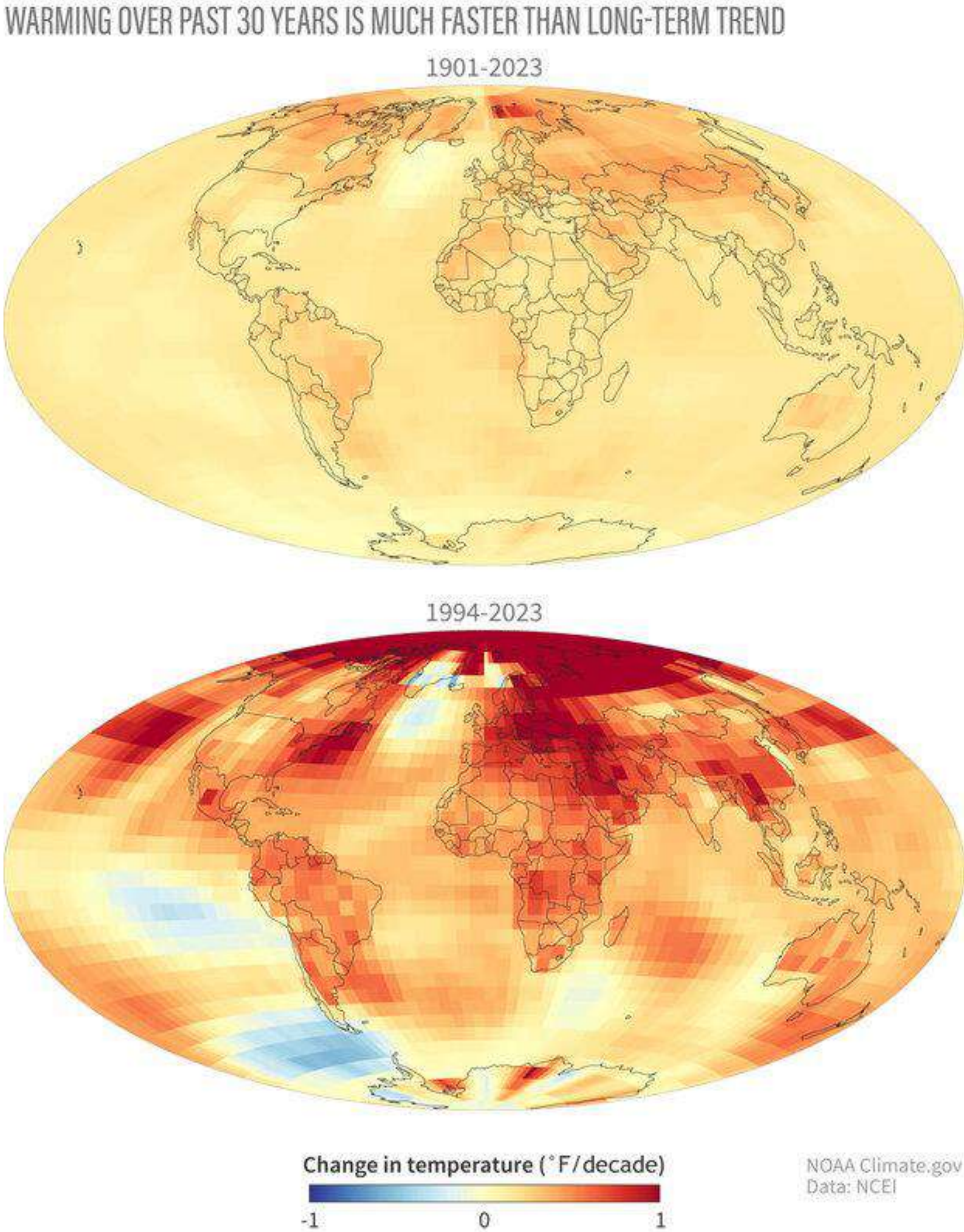
1880190019201940196019802000202 0−1.2−0.8−0.400.40.81.2

GLOBAL AVERAGE SURFACE TEMPERATUREYearDifference from 1901-2000 average (°C)

Yearly surface temperature from 1880–2023 compared to the 20th-century average (1901-2000). Blue bars indicate cooler-than-average years; red bars show warmer-than-average years. NOAA Climate.gov graph, based on data from the National Centers for Environmental Information.

Given the tremendous size and heat capacity of the global oceans, it takes a massive amount of added heat energy to raise Earth’s average yearly surface temperature even a small amount. The roughly 2-degree Fahrenheit (1 degrees Celsius) increase in global average surface temperature that has occurred since the pre-industrial era (1850-1900 in NOAA's record) might seem small, but it means a significant increase in accumulated heat.

That extra heat is driving regional and seasonal temperature extremes, reducing snow cover and sea ice, intensifying heavy rainfall, and changing habitat ranges for plants and animals—expanding some and shrinking others. As the map below shows, most land areas have warmed faster than most ocean areas, and the Arctic is warming faster than most other regions. In addition, it's clear that the rate of warming over the past few decades is much faster than the average rate since the start of the 20th century.



Trends in annual surface temperature in the past few decades (1994-2023, bottom) compared to the trend since the start of the 20th century (1901-2023, top). Recent warming is much faster than the longer-term average, with some locations warming by 1 degree Fahrenheit or more per decade. Differences are most dramatic in the Arctic, where the loss of reflective ice and snow amplifies the rate of warming. NOAA Climate.gov, based on data provided by NOAA National Centers for Environmental Information.

About surface temperature

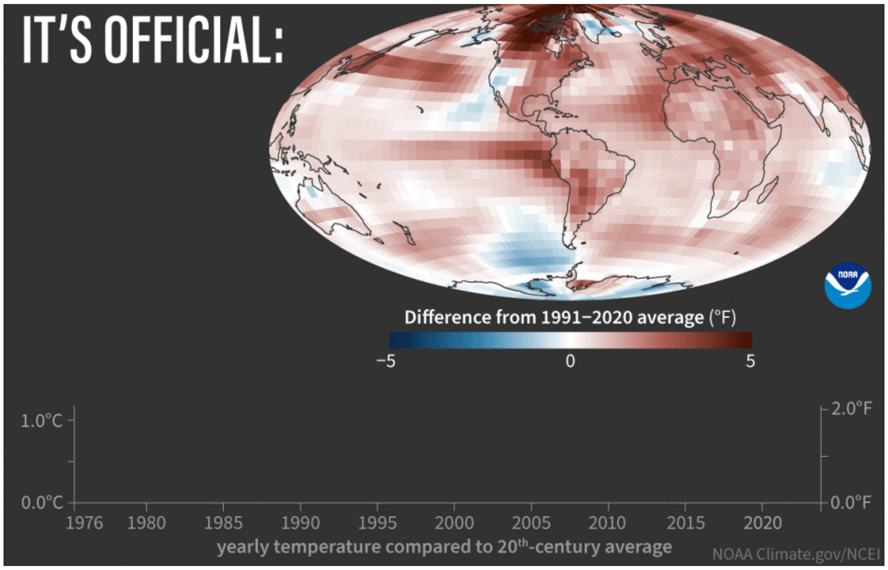
The concept of an average temperature for the entire globe may seem odd. After all, at this very moment, the highest and lowest temperatures on Earth are likely more than 100°F (55°C) apart. Temperatures vary from night to day and between seasonal extremes in the Northern and Southern Hemispheres. This means that some parts of Earth are quite cold while other parts are downright hot. To speak of the "average" temperature, then, may seem like nonsense. However, the concept of a global average temperature is convenient for detecting and tracking changes in Earth's energy budget—how much sunlight Earth absorbs minus how much it radiates to space as heat—over time.

To calculate a global average temperature, scientists begin with temperature measurements taken at locations around the globe. Because their goal is to track *changes* in temperature, measurements are converted from absolute temperature readings to temperature anomalies—the difference between the observed temperature and the long-term average temperature for each location and date. Multiple independent research groups across the world perform their own analysis of the surface temperature data, and they all show a similar upward trend.

Across inaccessible areas that have few measurements, scientists use surrounding temperatures and other information to estimate the missing values. Each value is then used to calculate a global temperature average. This process provides a consistent, reliable method for monitoring changes in Earth's surface temperature over time. Read more about how the global surface temperature record is built in our Climate Data Primer.

Global temperature in 2023

According to the 2023 Global Climate Report from NOAA National Centers for Environmental Information, every month of 2023 ranked among the 7 warmest for that month, and the months in the second half of the year (June-December) were each their hottest on record. In July, August, and September, global temperatures were more than 1.0°C (1.8°F) above the long-term average—the first time in NOAA's record any month has breached that threshold.



Map of global average surface temperature in 2023 compared to the 1991-2020 average. Warmer-than-average areas are shades of red, and cooler-than-average areas are shades of blue. The darker the color, the bigger the difference from average. The animated bar graph shows global temperatures each year from 1976 (left) to 2023 (right) compared to the 1901-2000 average. 1976 (blue bar at far left) was the last time a year was cooler than the 20th-century average. 2023 (far right) set a new record for warmest year. NOAA Climate.gov image, based on data provided by NOAA National Centers for Environmental Information.

Other 2023 rankings included...

- warmest year on record for land and ocean areas individually;

- warmest year on record for both the Northern and Southern Hemispheres (land and ocean areas combined),
    - warmest year for land and ocean individually in the North,
    - 2nd-warmest year for land and warmest year for ocean in the South;
- 40th-warmest year for the Antarctic,
- 4th-warmest year for the Arctic.

For more regional details and 2023 climate statistics, see the 2023 Global Climate Report from NOAA's National Centers for Environmental Information.

Past and future change in global temperature

Though warming has not been uniform across the planet, the upward trend in the globally averaged temperature shows that more areas are warming than cooling. According to NOAA's 2023 Annual Climate Report the combined land and ocean temperature has increased at an average rate of 0.11° Fahrenheit (0.06° Celsius) per decade since 1850, or about 2° F in total. The rate of warming since 1982 is more than three times as fast: 0.36° F (0.20° C) per decade.

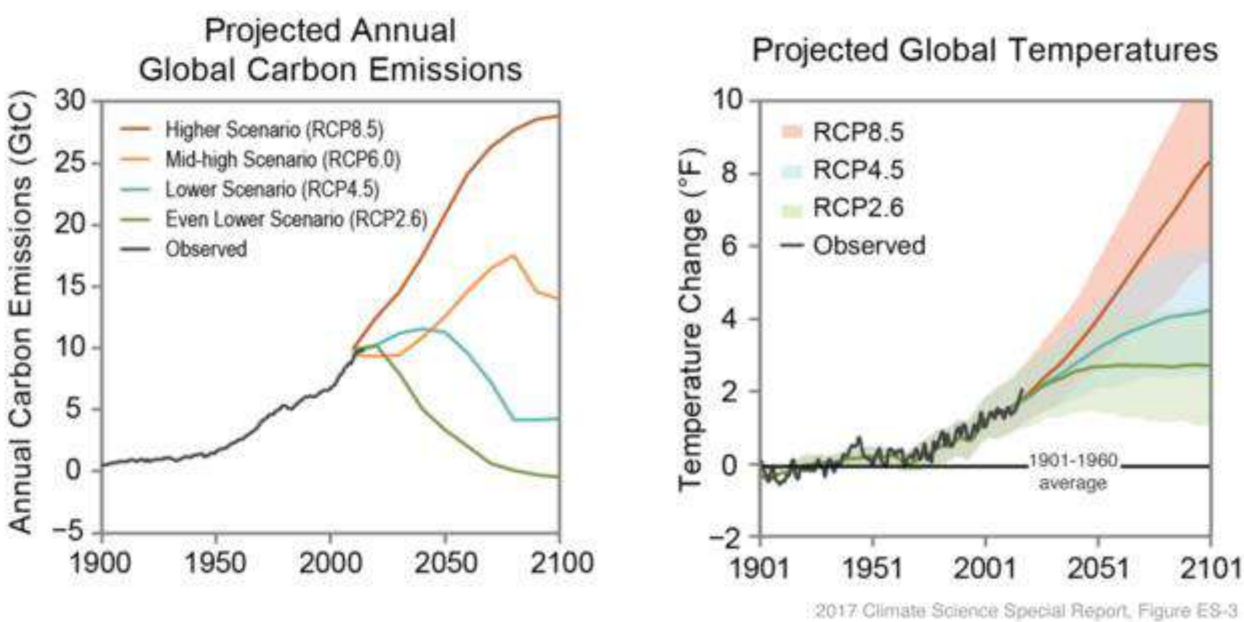
According to the latest Synthesis Report (pdf) from the Intergovernmental Panel on Climate Change, there is no debate about the cause of this warming trend:

Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020.

In the IPCC's Sixth Assessment Report on the Physical Basis of Climate Change, experts summarized the relative influence of all things known to affect Earth's average surface temperature:

The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C [2.01 ˚F]. Over this period, it is *likely* that well-mixed greenhouse gases (GHGs) contributed a warming of 1.0°C to 2.0°C, and other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural (solar and volcanic) drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C.

The amount of future warming Earth will experience depends on how much carbon dioxide and other greenhouse gases we emit in coming decades. Today, our activities—burning fossil fuels and to a lesser extent clearing forests—add about 11 billion metric tons of carbon (equivalent to a little over 40 billion metric tons of carbon dioxide) to the atmosphere each year. Because that is more carbon than natural processes can remove, atmospheric carbon dioxide amounts increase each year.



(**left**) Hypothetical pathways of carbon emissions ("representative concentration pathways," or RCPs) throughout the twenty-first century based on different possible energy policies and economic growth patterns. (**right**) Projected temperature increase relative to the 1901-1960 average depending on which RCP we eventually follow. Image by Katharine Hayhoe, from the *2017 Climate Science Special Report* by the U.S. Global Change Research Program.

According to the 2017 U.S. Climate Science Special Report, if yearly emissions continue to increase rapidly, as they have since 2000, models project that by the end of this century, global temperature will be at least 5 degrees Fahrenheit warmer than the 1901-1960 average, and possibly as much as 10.2 degrees warmer. If annual emissions increase more slowly and begin to decline significantly by 2050, models project temperatures would still be at least 2.4 degrees warmer than the first half of the 20th century, and possibly up to 5.9 degrees warmer.

GREEN HOUSE EFFECTS ,GREEN HOUSE GASSES AND AEROSOLS:

Greenhouse gases (GHGs) control energy flows in the atmosphere by absorbing infra–red radiation. These trace gases comprise less than 1% of the atmosphere. Their levels are determined by a balance between "sources" and "sinks". Sources are processes that generate greenhouse gases; sinks are processes that destroy or remove them. Humans affect greenhouse gas levels by introducing new sources or by interfering with natural sinks.

- **The largest contributor to the natural greenhouse effect is water vapour.** Its presence in the atmosphere is not directly affected by human activity. Nevertheless, water vapour matters for climate change because of an important "positive feedback". Warmer air can hold more moisture, and models predict that a small global warming would lead to a rise in global water vapour levels, further adding to the enhanced greenhouse effect. On the other hand, it is possible that some regions may become drier. Because modelling climate processes involving clouds and rainfall is particularly difficult, the exact size of this crucial feedback remains unknown.
- **Carbon dioxide is currently responsible for over 60% of the "enhanced" greenhouse effect, which is responsible for climate change.** This gas occurs naturally in the atmosphere, but burning coal, oil, and natural gas is releasing the carbon stored in these "fossil fuels" at an unprecedented rate. Likewise, deforestation releases carbon stored in trees. Current annual emissions amount to over 7 billion tonnes of carbon, or almost 1% of the total mass of carbon dioxide in the atmosphere.
- **Carbon dioxide produced by human activity enters the natural carbon cycle.** Many billions of tonnes of carbon are exchanged naturally each year between the atmosphere, the oceans, and land vegetation. The exchanges in this massive and complex natural system are precisely balanced; carbon dioxide levels appear to have varied by less than 10% during the 10,000 years before industrialization. In the 200 years since 1800, however, levels have risen by almost 30%. Even with half of humanity's carbon dioxide emissions being absorbed by the oceans and land vegetation, atmospheric levels continue to rise by over 10% every 20 years.
- **A second important human influence on climate is aerosols.** These clouds of microscopic particles are *not* a greenhouse gas. In addition to various natural sources, they are produced from sulphur dioxide emitted mainly by power stations, and by the smoke from deforestation and the burning of crop wastes. Aerosols settle out of the air after only a few days, but they are emitted in such massive quantities that they have a substantial impact on climate.
- **Aerosols cool the climate locally by scattering sunlight back into space.** Aerosol particles block sunlight directly and also provide "seeds" for clouds to form, and often these clouds also have a cooling effect. Over heavily industrialized regions, aerosol cooling may counteract nearly all of the warming effect of greenhouse gas increases to date.

- **Methane is a powerful greenhouse gas whose levels have already doubled.** The main "new" sources of methane are agricultural, notably flooded rice paddies and expanding herds of cattle. Emissions from waste dumps and leaks from coal mining and natural gas production also contribute. The main sink for methane is chemical reactions in the atmosphere, which are very difficult to model and predict.
- **Methane from past emissions currently contributes 15–20% of the enhanced greenhouse effect.** The rapid rise in methane started more recently than the rise in carbon dioxide, but methane's contribution has been catching up fast. However, methane has an effective atmospheric lifetime of only 12 years, whereas carbon dioxide survives much longer. This means that the relative importance of methane versus carbon dioxide emissions depends on the "time horizon". For example, methane emitted during the 1980s is expected to have about 80% of the impact of that decade's carbon dioxide emissions over the 20–year period 1990–2010, but only 30% over the 100–year period 1990–2090 (see figure).
- **Nitrous oxide, chlorofluorocarbons (CFCs), and ozone contribute the remaining 20% of the enhanced greenhouse effect.** Nitrous oxide levels have risen by 15%, mainly due to more intensive agriculture. CFCs increased rapidly until the early 1990s, but levels of key CFCs have since stabilised due to tough emission controls introduced under the Montreal Protocol to protect the stratospheric ozone layer. Ozone is another naturally-occurring greenhouse gas whose levels are rising in some regions in the lower atmosphere due to air pollution, even as they decline in the stratosphere.
- **Humanity's greenhouse gas emissions have already disturbed the global energy budget by about 2.5 Watts per square metre.** This equals about one percent of the net incoming solar energy that drives the climate system. One percent may not sound like much, but added up over the earth's entire surface, it amounts to the energy content of 1.8 million tonnes of oil every minute, or over 100 times the world's current rate of commercial energy consumption. Since greenhouse gases are only a by-product of energy consumption, it is ironic that the amount of energy humanity actually uses is tiny compared to the impact of greenhouse gases on natural energy flows in the climate system.

EFFECT ON GLOBAL WARMING:

Greenhouse gases primarily contribute to warming the environment by trapping heat from the sun in the atmosphere, while aerosols can either cool or warm the planet depending on their composition, with most types of aerosols generally having a cooling effect by reflecting sunlight back into space; essentially, greenhouse gases cause warming while many aerosols counteract this warming to a degree by reflecting sunlight.

Explanation:

- **Greenhouse gases:**

  These gases, like carbon dioxide and methane, absorb infrared radiation emitted from the Earth's surface, preventing it from escaping into space and thus warming the planet.

- **Aerosols:**

  These are tiny particles suspended in the air, which can either absorb or reflect sunlight depending on their characteristics.

- **Cooling effect of aerosols:**

  Many types of aerosols, like sulfate particles from burning coal, reflect sunlight back into space, creating a cooling effect.

- **Warming effect of aerosols:**

  Some aerosols, like black carbon (soot), can absorb sunlight, contributing to warming.

  Key points to remember:

- **Overall impact:** While greenhouse gases generally have a warming effect, aerosols can partially offset this warming by reflecting sunlight.
- **Type matters:** The impact of aerosols on climate depends on their composition and size.
- **Cloud interactions:** Aerosols can also influence cloud formation, further impacting the Earth's energy balance.
- 3. Greenhouse gases and aerosols - UNFCCC
  18 Jul 2000 — Warmer air can hold more moisture, and models predict that a small global warming would lead to a rise in global water ...
  UNFCCC
- Basics of Climate Change | US EPA
  7 Nov 2024 — Unlike greenhouse gases, the climate effects of aerosols vary depending on what they are made of and where they are emit...
  U.S. Environmental Protection Agency (.gov)
- Aerosols: Small Particles with Big Climate Effects
  12 Jun 2023 — Aerosol air pollution has made the planet about 0.7° F (0.4 °C) cooler than it otherwise would be, according to the 202...

Aerosols can also be produced naturally from a number of natural processes e.g. forest fires, volcanoes and isoprene emitted from plants. We know that greenhouse gases provide a warming effect to Earth's surface, but aerosol pollution in the atmosphere can counteract this warming effect

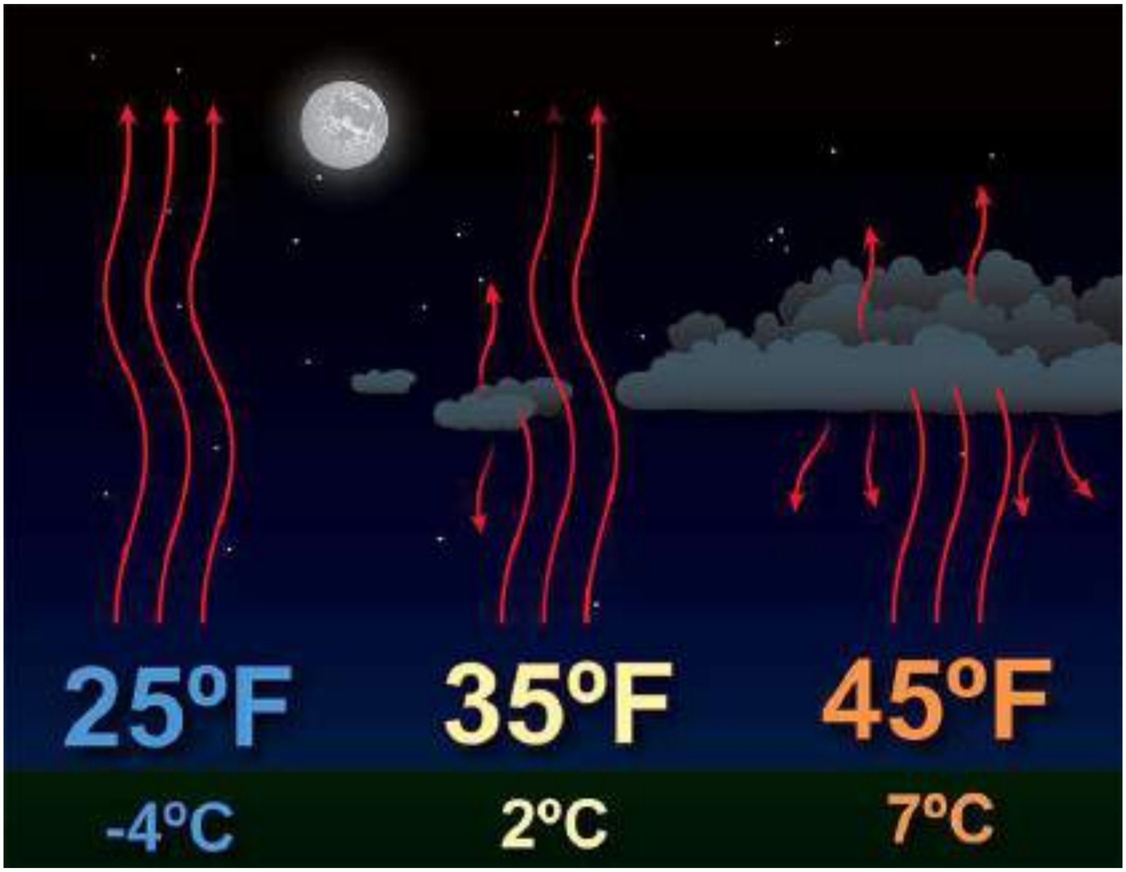
GLOBAL ENERGY BALANCE:

The Earth-Atmosphere Energy Balance

The earth-atmosphere energy balance is the balance between incoming energy from the Sun and outgoing energy from the Earth. Energy released from the Sun is emitted as shortwave light and ultraviolet energy. When it reaches the Earth, some is reflected back to space by clouds, some is absorbed by the atmosphere, and some is absorbed at the Earth's surface.

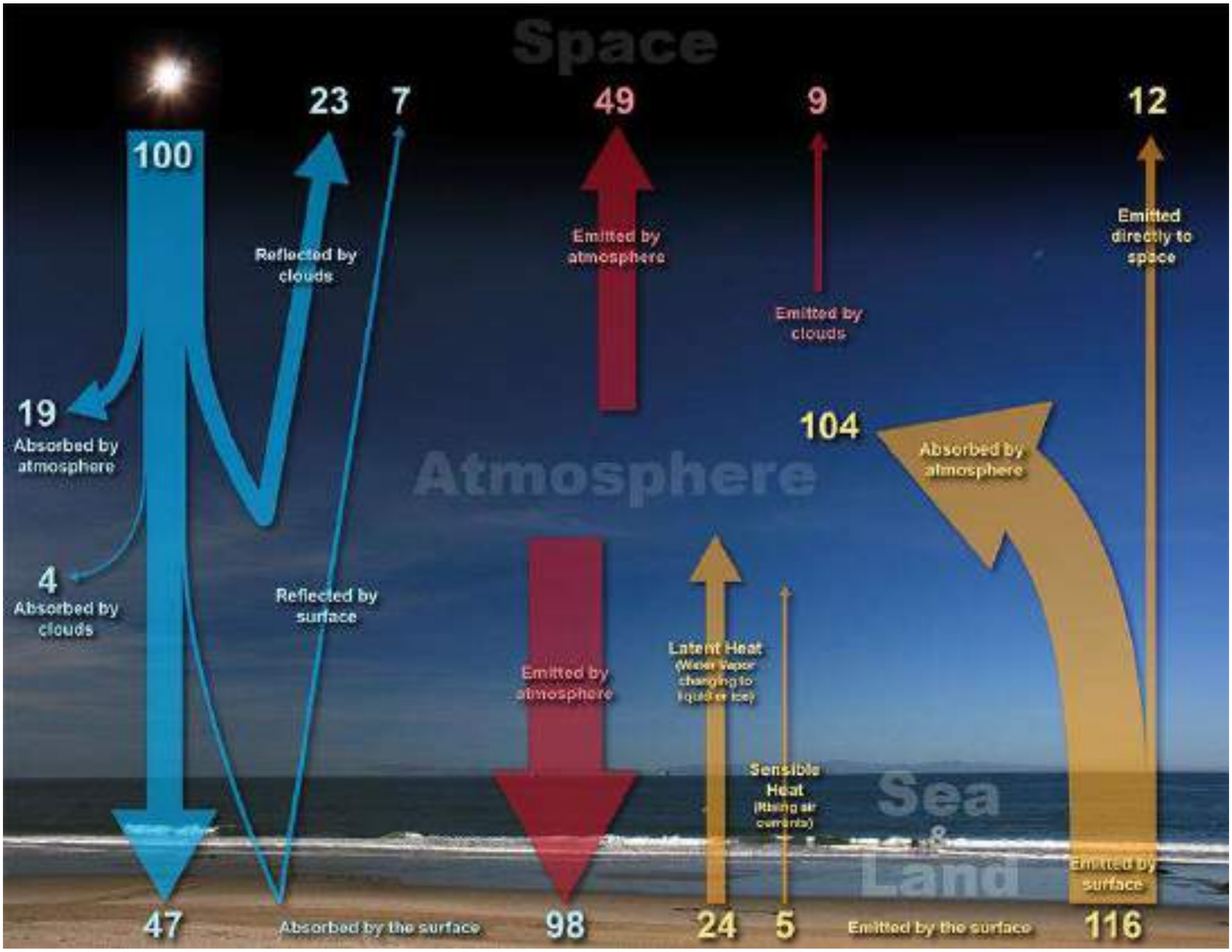
Learning Lesson: Canned Heat

However, since the Earth is much cooler than the Sun, its radiating energy is much weaker (long



wavelength) infrared energy. We can indirectly see this energy radiate into the atmosphere as heat, rising from a hot road, creating shimmers on hot sunny days.

The earth-atmosphere energy balance is achieved as the energy received from the Sun *balances* the energy lost by the Earth back into space. In this way, the Earth maintains a stable average temperature and therefore a stable climate. Using 100 units of energy from the sun as a baseline the energy balance is as follows:



At the top of the atmosphere - Incoming energy from the sun is balanced with outgoing energy from the Earth.	
INCOMING ENERGY	**OUTGOING ENERGY**

UNITS	SOURCE	UNITS	SOURCE
+100	Shortwave radiation from the sun.	-23	Shortwave radiation reflected back to space by clouds.
		-7	Shortwave radiation reflected to space by the earth's surface.
		-49	Longwave radiation from the atmosphere into space.
		-9	Longwave radiation from clouds into space.
		-12	Longwave radiation from the earth's surface into space.
+100	Total Incoming	-100	Total Outgoing

The atmosphere itself - Energy into the atmosphere is balanced with outgoing energy from atmosphere.			
INCOMING ENERGY		OUTGOING ENERGY	
UNITS	SOURCE	UNITS	SOURCE
+19	Absorbed shortwave radiation by gases in the atmosphere.	-9	Longwave radiation emitted to space by clouds.

The atmosphere itself - Energy into the atmosphere is balanced with outgoing energy from atmosphere.			
INCOMING ENERGY		**OUTGOING ENERGY**	
UNITS	**SOURCE**	**UNITS**	**SOURCE**
+4	Absorbed shortwave radiation by clouds.	-49	Longwave radiation emitted to space by gases in atmosphere.
+104	Absorbed longwave radiation from earth's surface.	-98	Longwave radiation emitted to earth's surface by gases in atmosphere.
+5	From convective currents (rising air warms the atmosphere).		
+24	Condensation /Deposition of water vapor (heat is released into the atmosphere by process).		
+156	Total Incoming	-156	Total Outgoing

At the Earth's surface - Energy absorbed is balanced with the energy released.			
INCOMING ENERGY		**OUTGOING ENERGY**	
UNITS	**SOURCE**	**UNITS**	**SOURCE**

At the Earth's surface - Energy absorbed is balanced with the energy released.			
INCOMING ENERGY		**OUTGOING ENERGY**	
UNITS	**SOURCE**	**UNITS**	**SOURCE**
+47	Absorbed shortwave radiation from the sun.	-116	Longwave radiation emitted by the surface.
+98	Absorbed longwave radiation from gases in atmosphere.	-5	Removal of heat by convection (rising warm air).
		-24	Heat required by the processes of evaporation and sublimation and therefore removed from the surface.
+145	Total Incoming	-145	Total Outgoing

The absorption of infrared radiation trying to escape from the Earth back to space is particularly important to the global energy balance. Energy absorption by the atmosphere stores more energy near its surface than it would if there was no atmosphere.

The average surface temperature of the moon, which has no atmosphere, is 0°F (-18°C). By contrast, the average surface temperature of the Earth is 59°F (15°C). This heating effect is called the greenhouse effect.

CLIMATE CHANGE AND ITS EFFECTS

INTRODUCTION

*Corresponding Author: Amrik Singh Ahluwalia, Eternal University, Baru Sahib, Sirmour - 173 101, Himachal Pradesh, India. Email: amrik.s511 @ gmail.com Ajar Nath Yadav, Department of Biotechnology, Dr. Khem Sigh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmour, Himachal Pradesh, India. Email: ajarbiotech @ gmail.com

The super challenges of the 21st century are climate change, energy supply, health and disease invasion, and sustainable environment. The world's climate continues to change at a rate expected to be unprecedented in recent human history.

The increase of about 0.6°C in global average surface temperature has been observed during the twentieth-century. In recent years, human activity and natural factors have led to rapid increase in greenhouse gas (GHG) emissions. The influence of emitted GHG on future climate is estimated due to its capability of absorbing available infrared radiation and its persistence in the atmosphere [1]. The effects of global warming are broader which may include arctic shrinkage, glacial retreat, and worldwide sea level rise. The changing precipitation patterns will result in more floods and drought. The changes will also occur in agricultural yields, there may be addition of new trade routes, vast extinction of species and increase in disease vectors range [2]. In fact, the climate change is not only an environmental issue nor is it the only threat to global prosperity rather is a threat multiplier for diverse other urgent concerns including global security, disease and habitat loss. Climate change is unique in its scale and enormous risks it poses. Climate change, if remained unchecked, possibly will redraw the map of the planet. It can create global living conditions beyond the range, humanity has ever experienced in history. The influence of climatic change is much broader, such as increased frequency of hypoxic events, storm activity, altered rainfall patterns, and flow regimes of freshwater streams and rivers [3]. There is a discernible global pattern of the effects of climate change on crop productivity, which may have implications for food availability. Climate change may jeopardize the stability of entire food systems. The demand for agricultural products has been estimated to increase with increase in global population, which may require a shift toward sustainable intensification of food systems [4]. Rising concentration of atmospheric carbon dioxide is one of the most critical problems as its effects are globally persistent and irreversible on ecological timescales [5]. The primary direct consequences are increasing ocean temperatures [6]. Rising temperatures create additional changes such as increase in ocean stratification, increasing sea levels, reduced sea ice extent, altered ocean circulation patterns, precipitation and freshwater inflows. Acidification is another direct impact of rising CO2 concentrations on oceans [7]. Climate change also affects global biodiversity in several ways. Movement is an integral part of ecology of many animals, which can affect the fitness of individuals and population survival by enabling foraging and predation, behavioral interactions, and migration [8]. Migration may also be observed in fishes in search of suitable conditions due to increase in temperature. Arrival and hatching date in migrating birds can be strongly affected by global warming [9]. Numerous changes occur in animals due to rising temperature such as increased respiration, decrease in the efficiency of nutrient utilization, decrease in milk production reproductive performance especially in dairy cows [10]. Climate is a major factor determining plant physiology, distribution, and interactions [11]. There might be changes in phenological phases of plants which will lead to prolonged growing season and affect the plant fitness. Evidences are in favor of global climate change and its consequences on different aspects of environment. There is a greater need to develop conservation strategies to respond to such global challenges. This review deals with the influence of climate change on biodiversity and impact on environment.

2. IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

Climate change is increasingly recognized as the serious and widespread threat to biodiversity. The alterations in the environment which will be brought up by the climatic changes will be too rapid for many species to adapt to, and ultimately lead to extensive extinctions. Climate change may lead to migrations which in turn will affect biological diversity at regional and global scales. Stress on populations of whales, ringed seals, and polar bear will continue as a result of changes in critical sea-ice habitat interactions. Crops will fail more often, especially on land at lower latitudes where food supply is scarce [12]. The changes in occurrence of drought, strong winds, and winter storms will bring massive loss to commercial forestry [13]. The species must adapt, move, or face extinction with climate change.

2.1. Animal Biodiversity Animals had been already subjected to major shifts in the Earth's climate in the past. Some species perished, while others adapted and thrived. Climate change is already having a negative impact on animal life, and the consequences are likely to be disastrous in the future. Climate change is considered a major threat to the survival of many species in changing ecosystems [14-16]. Many studies have taken into account the economic impact of day by day changing climate on livestock production [17]. In general, a combination of rising temperatures and changing rainfall patterns will certainly affect animal husbandry. Feed is an important constraint for livestock production in the tropics, and will continue to be, and crop productivity is a useful proxy for feed availability in most regions. Crop productivity at mid-to high latitudes may increase slightly for local mean temperature increases while at the lower latitudes, it may decrease for even relatively small local temperature increases. In general climate change may affect the animal agriculture in different ways by influencing livestock [18], nammely, the availability and price of feed grain, quality, and production of forage, reproduction, growth and health, as well as distribution of diseases and pests. These changes can lead to redistribution of livestock in an area. There may be shifts in animal types used for instance change from cattle to buffalo, camels, goats, or sheep; there may be genotype shifts which mean the use of breeds which can well handle adverse conditions. Furthermore, there may be changes in housing of animals [17]. Temperature is likely to become hotter in several places and different species due to their physiological differences will show variations in their susceptibility to changing temperatures [19]. Holstein-Friesian dairy cows are primarily susceptible to heat stress as the ambient temperature exceeds 25°C [20]. The first sign of heat stress is an increase in body temperature and rate of respiration ultimately reducing feed intake and milk output [21,22]. Sheep when exposed to high temperatures, weight loss, decrease of average daily gain, growth rate, and total body solids reflected by impaired reproduction have been observed. When the ambient air temperature is high, appetite decreases and growth of pigs is affected [23]. Further, in such changes, some species of animals may expand their ranges whereas others may move towards the poles or upward in elevation. An example of such a shift is population of red fox in

Canada which have been advancing north and, on the other hand, population of Arctic fox has been retreating [24]. High temperatures and precipitation have been known to decline the population of British ring ouzel which is a shy species of thrush with a high chirping call. The decline in Arctic sea ice have a significant impact on Arctic vertebrate populations including polar bears, seals, and walruses which are adapted to live in sea ice for significant periods of the year [25]. If the sea ice breaks and drifts as a result of polar warming, polar bears will have to move north to find a stable platform. Pregnant females will leave the ice to find their preferred land den area have to swim long distances. In case, the pregnancy of malnourished mothers is successful under sub-optimal habitats, the chances of survival of cubs will be greatly reduced [26]. Climate change has a profound impact on the oceans. The upper ocean is warming [27], potentially affecting invertebrate populations including krill, which are important food sources for whales, seabirds, seals, and penguins [28]. Changes in upper ocean temperatures may alter the range of many species, especially marine mammals. Studies show the expansion in the range of common dolphins common in northwest Scotland which are warmer water species whereas contractions in the range of white-beaked dolphins which are a colder water species [29]. Relatively small changes in temperature alter the metabolism and physiology of fishes, affecting their growth, reproduction, feeding behavior, distribution, migration, and abundance [30].

2.2. Bird Biodiversity Birds are one of the most studied organisms on the planet, and they serve as an important group of indicators for learning about the effects of climate change. The choice of birds for studying climatic changes offer certain advantages such as they are the most well-known kind of organism for climate studies and second, millions of citizen scientists Kour, .: Journal of Applied Biology & Biotechnology 2024;12(2):1-12 et al Kour, et al.: Effect of climate change on biodiversity and environment 2024;12(2):1-12 3 track birds all over the world, contributing to massive datasets [31]. Bird distribution changes have been well described and linked to climate change [32-34]. The vulnerability of species of tropical birds to climate change in particular has been increasingly recognized [35-37]. The weather not only affects the metabolic rate of the birds (e.g., in cold weather where energy expenditure must increase to maintain the body), but also their behavior directly or indirectly [38]. Climate change has been shown to impact breeding. Extreme weather events, such as prolonged freezing spells and droughts, can have catastrophic effects on bird populations, including long-term effects on entire cohorts [39]. The study of Pied Flycatchers Ficedula hypoleuca showed increase in their egg size with warmer springs in Germany and Finland [40]. In Siberia, reproductive success in the planktivorous auklets including crested Aethia cristatella and parakeet Cyclorhynchus psittacula increases at lower sea-surface temperatures. On the other hand, better reproductive success has been observed in the piscivorous puffins such as horned Fratercula corniculata and tufted Lunda cirrhata at higher, sea-surface temperatures. Long-term changes in sea-surface temperatures can affect the viability of each species' population in different ways and change the seabird population in that area [41]. Storms and snowpack have a significant impact on the reproductive schedules of birds breeding at high altitudes. Climate change is expected to have an impact on reproduction as well as the entire annual cycle of birds. The species that mainly adjust the annual cycle and multiply according to rainfall, temperature, and food supply will face fewer difficulties as compared to those that coordinate their annual cycle by a rigid Zeitgeber, like photoperiod [42]. Migration in birds is affected by changes in climatic conditions. It is expected that the greater the distance of migration of the species, the more likely one or more aspects of the annual cycle may become mistimed with local weather and food supplies on the summering grounds. An advancement of 14 days over 47 years in the timing of egg laying in Parus major population in the United Kingdom due to increased spring temperature has been reported [43].

2.3. Plant Biodiversity Climate change is also affecting the life cycles and distributions of the world's vegetation. The combination of the changes in air quality and composition and climate are producing new bioclimate for food production systems. There is extensive evidence that plant seasonal biological events have changed in recent decades along with the global climate change [44]. Some medicinal and aromatic plants have begun to flower earlier. In Britain, the first flowering date for approximately 385 plant species advanced by 4.5 days on average over the previous four decades [45]. Temperature range between 45°C and 65°C can cause severe damage and even death of crop plants. For instance, rice is most sensitive to temperature change at anthesis stage. Exposure for few hours at flowering can reduce floral reproduction [46]. In medicinal plants, the damaging effects of climate change may include decrease in availability and most dramatically in the extinction of species [47]. A study reported extinction of about 600 plant species in the past 250 years [48].Valuable medicinal plants are likewise one of those species that experience dramatic phenological change [49]. In addition to endangering population growth, phenological changes may have an impact on the predictable or consistent availability of medicines to those who rely on them [50,51]. The medicinal plants of arid zone may also be at special risk. The nival or subnival species in montane ecosystems are most vulnerable to habitat loss [52], and future climate change is expected to be most severe in northern latitude mountains [53]. Alpine meadows are once again among the most threatened plant communities [54], and they are shrinking due to warming-induced upslope shrub encroachment [55]. It is thought that species growing at the highest altitudes are most vulnerable to extinction because they will have nowhere to go if they are outcompeted by lower elevation species that are now expanding their ranges to higher elevations [56]. In a survey of plant distribution in Arizona mountains local extinction of 15 species of plants including Muhlenbergia porter, Quercus gambelii and Urochloa arizonica, in comparison with 50 years earlier has been observed [57]. In the alpine Himalayas of Sikkim 75 species of plants, including Rhododendron nivale, Potentilla fruticosa and Lepidium capitatum were observed to be locally extinct in comparison with 1850 [58]. Deserts and arid shrublands are expected to experience the fastest rates of climate change, making compensatory migration difficult [59]. For instance, a significant degradation has been observed in the desert steppe habitat of one of the most widely used wild medicinal plants Glycyrrhiza uralensis, attributed to increasing climate change and anthropogenic disturbance [60]. Sea grasses are declining globally at a rate of about 7% per year, and global climate change is expected to have a negative impact on them, posing a pressing challenge for coastal management [61]. Water temperature greatly influences the physiology, growth rates and reproduction in sea grasses and determines their geographic distribution based on their temperature tolerance [62]. The species of tropical sea grasses including Thalassia testudinum and Syringodium filiforme in the Gulf of Mexico showed reduction in their productivity when summer temperatures were higher [63]. In an investigation in Australia, the leaf growth rates of Thalassia hemprichii, Halodule uninervis, and Cymodocea rotundata were reduced at water temperature above 40°C [64]. Warming is occurring quickly in the Arctic [65]. The fluctuations in ranges of temperature and changes in ice covers and snow patterns are affecting the distribution of Arctic vegetation. It has been observed that the changes in climate possibly will affect the chemical constituents and thus the survival of the aromatic and medicinal plants in Arctic. Certain reports have revealed the impact of the temperature fluctuations on bioactive compounds of the plants [66,67].

2.4. Microbial Biodiversity Microbes inhabiting soil play significant roles in nutrient cycling and protecting plants from environmental stresses [68]. The organisms inhabiting the soil interact with each other and plants in many ways that shape and maintain the ecosystem. Climate change is altering the distribution and diversity of species and at the same time affecting the interactions between organisms [69,70]. Numerous studies have shown that changes in species interactions in response to climate change chain alter biodiversity and function of terrestrial ecosystems [24,71]. There are some reports on soil microbial communities (SMCs) and their diversity and distribution during climatic change [72,73]. Alterations in relative abundance and function of soil communities due to climatic changes has been observed as the members of SMCs vary in their physiology, temperature sensitivity, and growth rates [74,75]. A study observed changes in the relative abundances of soil bacteria and increased the bacterial to fungal ratio of the community due to warming by 5°C [76]. Further, the acceleration in fermentation, methanogenesis and respiration among the microbial communities has also been observed in response to increase in temperature. The microbial community composition (MCCs) of soil constantly changes as they respond to changing resource availability. Certain communities grow quickly and utilize the resources as they are available and some 4 communities adapt and grow slowly and utilize more chemically complex substrates. Guo et al. [77] carried out study on climate warming accelerates temporal scaling of grassland soil microbial biodiversity. The study suggested that the strategies of soil biodiversity preservation and ecosystem management may need to be adjusted in a warmer world. The study of Wu et al. [78] concluded detrimental effects of biodiversity loss might be more severe in a warmer world. Recently, a study has been conducted to measure the effect of climate change in Antarctic microbial communities. The study proposed that climate change studies in Antarctica should consider descriptive studies, shortterm temporary adaptation studies, and long-term adaptive evolution studies and concluded that this will help in understanding and managing the effects of climate change on the Earth [79]. A study investigated the effect of temperature on microbes in dry land soil, boreal, temperate, and tropical soil and response of microbial communities to different temperatures. The study concluded that the rates of respiration per unit biomass were lower in the soils collected from the environments having higher temperature and suggested that thermal adaptation of the microbial communities may lessen positive climate feedbacks [80]. Another study reported increased soil biomass and fungal abundance with higher atmospheric CO_2 . The study showed a limited effect on bacterial diversity with higher atmospheric CO_2 [81]. Drought conditions have been shown to influence fungi and bacteria, but fungi are known to be more sensitive than bacteria. It has been observed that during drought fungal growth increases [82]. Another study observed the effects of elevated levels of CO_2 and precipitation on soil microorganisms. The study suggested that bacterial growth was negatively affected whereas fungal biomass was observed to show an increase with increasing precipitation [83]. On the other hand, it has been suggested that global warming increases the abundance of bacteria and fungi and leads to the alteration of the soil food web. The rise in temperature also makes changes in the physiology of decomposing microorganisms also [84]. Climate change is known to favor the growth of cyanobacteria [85]. Many bloom-forming cyanobacteria grow at high temperatures [86]. The growth of

Microcystis sp. has been observed to increase at elevated CO2 levels [87]. Generally as the environmental conditions change, the resident microbial communities either adapt, become dormant or die [88].

3. BIODIVERSITY RESPONSES TO CLIMATE CHANGE

Climate change is expected to change the diversity of species, the distribution of human pathogens, and ecosystem services around the world. Estimating these changes and designing suitable management strategies for future ecosystem services will need a predictive model that includes the most basic biological responses. One of the key questions in the debate over climate change's ecological impact is whether species can adapt quickly enough to keep up with the rapid pace of climate change [89,90]. Species can, in theory, change in response to climate change, and changes have already been observed. The species can track and follow suitable conditions in space, which is typically accomplished through dispersion. Spatial movement of species tracking appropriate climatic conditions on a regional scale is the best documented response from palaeontological records and recent observations. Over 1000 species of marine invertebrates, insects, and birds have already shown latitudinal and altitudinal range shifts [91], resulting in a decrease in range size, primarily in mountain top and polar species [92]. Furthermore, in order to keep up with abiotic factors that represent cyclic variation, such as on a daily or yearly basis, species may respond to changes by shifting time from daily to seasonal. A meta-analysis of a wide range of plant and animal species found that the average response to climate change was a shift in key phenological events occurring 5.1 days earlier per decade over the last 50 years [93]. The advancement in flowering by more than 10 days per decade has also been observed in some species [91]. Another approach is species may adapt themselves to the changing climate in their local range. Thus, there are multiple responses of the species to cope up with the changing climatic conditions and unable to adapt to new conditions, the species may go extinct either locally or globally [94]. As a result of numerous human-caused changes in the global environment, global biodiversity is changing at an unprecedented rate [95,96]. Quantitative scenarios are emerging as tools to assess the impact of future socio-economic development pathways on biodiversity and ecosystem services. Global marine, freshwater, and terrestrial biodiversity scenarios are analyzed through different measures including change in the abundance of the species, habitat loss, extinction, and distribution shifts [97]. The risk of species extinction address the irreversible component of biodiversity change [98,99]; however, species extinctions have weak links to ecosystem services and respond less rapidly to global change than other factors. Quantitative global extinction scenarios for freshwater and marine organisms are, however, uncommon. According to one of the proposed models based on the relationship between fish diversity and river discharge, 4–22% extinction of fish by 2070 in about 30% of the world rivers, due to reduced river discharge from climate change and increased water withdrawals [100]. Habitat loss and degradation in terrestrial ecosystems encompass a wide range of human-caused changes in natural and semi-natural ecosystems. The distribution shifts are expected to cause the reorganization of ecosystems, including the establishment of novel communities [96]. Scenarios constantly indicate the decline of the biodiversity over the 21st century. The most important factors identified so far to induce changes in biodiversity at global scale includes the changes in the concentration of carbon dioxide, land use, deposition of nitrogen, and on purpose or accidental introduction of alien animals, plants, and microbes in an ecosystem [101]. CLIMATE The changing temperature and precipitation patterns are expected to interact with other drivers to influence an array of biological processes and distribution of species. Alarming predictions about the potential consequences of future climate change are prompting policy responses ranging from the local to the global [102]. To date emission of greenhouse gases are driving earth to significant climate change in the coming decades [103]. The annihilation of evolutionary potential, possible loss of biodiversity and disturbance of ecological services must be taken seriously. Many countries have conservation plans for threatened species, but these plans have generally been developed without taking into account the potential impacts of climate change. Climate change is greatly influencing the biodiversity and represents a significant future challenge for biodiversity conservation strategies [94].The interaction between climate and land use provides opportunities for adaptation to climate change that increase the ability of species to adapt [104]. Preventing detrimental consequences for biodiversity requires immediate action and strategic conservation

4. GLOBAL BIODIVERSITY SCENARIO FOR THE YEAR 2100 5. CONSERVATION OF BIODIVERSITY IN CHANGING Kour, .: Journal of Applied Biology & Biotechnology 2024;12(2):1-12 et al Kour, et al.: Effect of climate change on biodiversity and environment 2024;12(2):1-12 5 plans for years and decades to come [105]. Integration of different approaches and perspectives is required for more accurate information on which species and habitats, which places and how conservation managers can make the most of natural systems' adaptive capacity. In many cases, existing conservation policies and practices are already encouraging measures to reduce vulnerability to climate change such as restoration or creation that improves the functional connectivity of landscapes and habitat management. The assessment of impact of climate change on biodiversity has been especially based on empirical niche models [106]. These models for most species indicate large geographic displacements and widespread extinction. Assessing the biodiversity consequences of climate change is really a multifaceted issue and all aspects of vulnerability such as adaptive capacity, exposure, and sensitivity must be considered for implementation of conservation strategies [Figure 1] [107]. 6. IMPACT OF CLIMATE CHANGE ON ENVIRONMENT In recent years, extensive efforts have been made to monitor and predict climate change in response to fears of global warming. Attention has been focused on the diverse environments including soil and water, and the imminent socio-economic and environmental consequences of rising global temperatures. The fluctuations in temperature will leave a negative impact on organic matter of soil, and diverse physical and chemical properties of soil. Water resources will be greatly affected under changing climate [Figures 2 and 3]

6.1. Soil Health and Fertility Healthy soil is the foundation of agriculture and a basic resource for meeting human needs in the twenty-first century. It is a critical component of ecosystems and earth system functions that helps to deliver primary ecosystem services [108]. The most recent report of the intergovernmental panel on climate change point outs the average rise in the global temperature between 1.1 and 6.4°C by 2090–2099. The changes in the climate will have impact on precipitation patters at global level and will alter both the amount of precipitation received and the distribution of precipitation over the course of an average year in many locations [109]. Each of these factors will affect soil which is of major importance for the food security [110-112]. Food security will be threatened through its effects on soil processes and different properties [113]. Soil moisture is another important component of the hydrological cycle that regulates precipitation partitioning between runoff, evapotranspiration, and deep infiltration [114]. Fluctuations in temperature will influence moisture content of the soil which in turn may impact infiltration and runoff amounts and rates [115]. Further, as a link between the biosphere and the edaphic zone, soil water is fundamental requirement for the terrestrial ecosystems which determines plant growth. Water stress occurs when the soil water level falls below a critical species-specific threshold, which will then lead to morphological and physiological disturbances in plants [116]. Soil erosion is another phenomenon experienced in different parts of the world under changing climate. It is one of the major threats to the economy and society affecting agriculture. The most common reason predicted for soil erosion is the change in the erosive power of rainfall and changes in plant biomass [117]. Although soil erosion is a natural and inevitable process, the accelerated rates of soil loss, is really a serious environmental issue. Theloss due to erosion is estimated to be 30–40 t/ha/year [125,126]. Microorganisms present in the soil play important role in nutrient cycling and thus the decrease in MCCs in soil due to climate change affect the soil health and fertility. Increasing challenges and concerns on global warming and changing climate have led to special attention to soil and its capability in carbon sequestration. In a study, the effect of climate change on soil organic carbon storage using the Rothamsted C model in the agricultural lands of Golestan province has been studied. The results suggested that with increasing temperature, the rate of decomposition of soil organic carbon will increase [127]. Soil organic carbon is an important carbon pool which can alleviate the increasing concentration of atmospheric carbon dioxide as part of the carbon cycling process. A study on the basis of Rothamsted C model concluded soil organic carbon will in general decline during the next decades. Further the rate of decrease of soil organic carbon will be higher over time if there is no addition of organic matter is adopted in China [128]. Another study focused on impact of global climate change on terrestrial soil CH4 emissions. The meta-analysis in the study suggested that future climate change will decline the natural buffering capability of terrestrial ecosystems on CH4 fluxes [129].

6.2. Water Resources Climate change is expected to pose negative impact on water resources and freshwater ecosystems in almost every part of the world. However, the intensity and characteristics of the impact can vary widely from region to region. There may be water shortages in some regions. A study concluded that climate change will lead to water scarcity to meet the rising demand for food. It is estimated to be 60% higher in Africa by 2030, which will spike food prices and worsen food scarcity [130]. The shorter rainy periods and seasonality shifts might affect water resources by reducing water availability with wide ranging consequences for local societies and ecosystems [131].

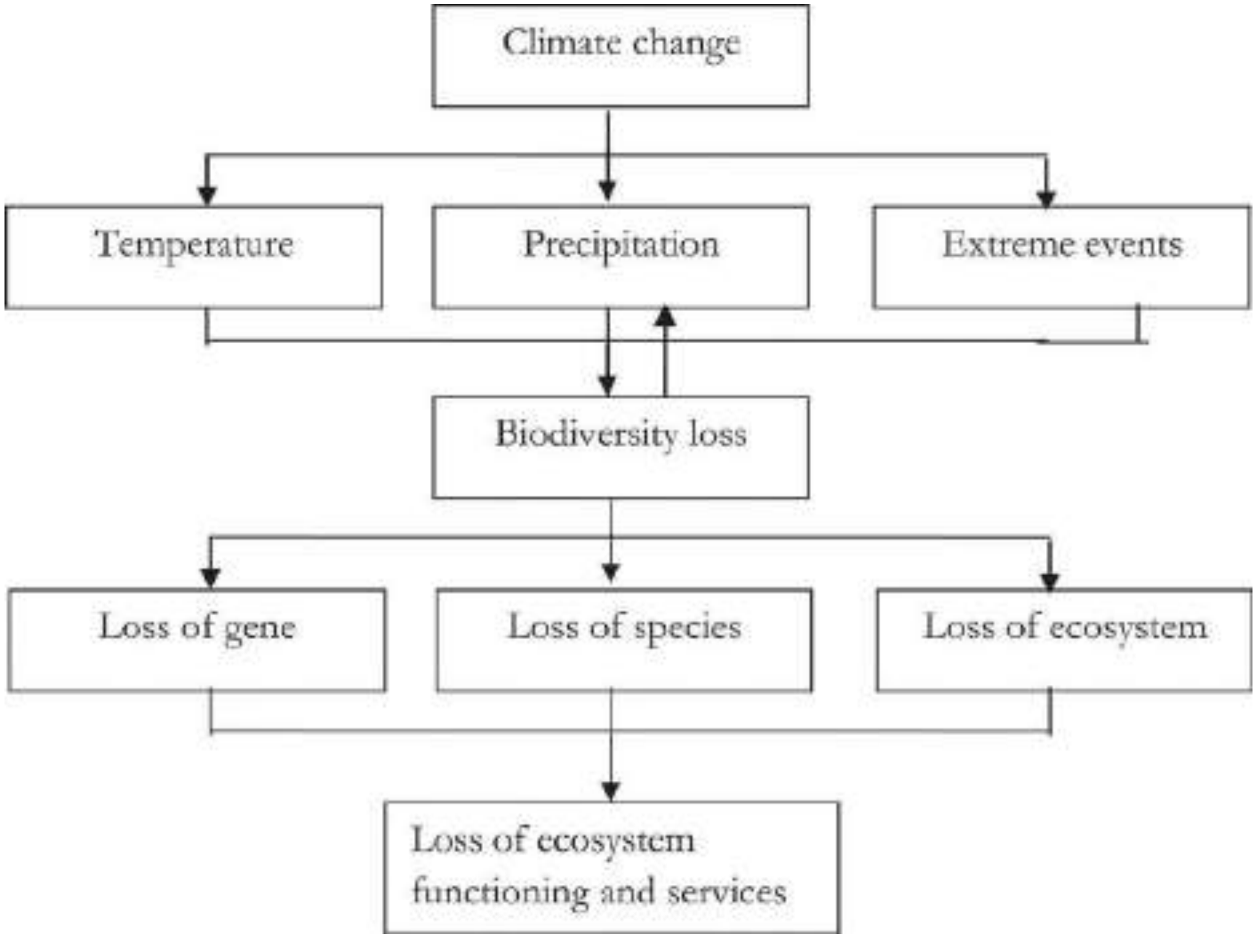
The rise in sea level in coastal regions possibly will threaten the livelihood and lives of millions of people. The occurrence of droughts and floods is likely to increase in many parts of the world. All these factors will contribute to high economic cost and decline in the yield ultimately leading to higher risk of hunger and poverty [132]. A study has been conducted to analyze the impact of climate change on stream flow in the Godavari basin simulated using a conceptual model including CMIP6 dataset. The findings highlighted the importance of taking into consideration the potential impacts of future scenarios on water resources so that effective and sustainable water management practices could be developed [133]. Another study investigated the impact of the climate and land-use changes on water balance in

2037, the end of the National Strategy, for the Mun River Basin, NE Thailand. The study recommended soil-water conservation measures to alleviate the adverse effects of bioenergy [134]. The changing climate will also impact the water quality of lakes. A study has been conducted to investigate the effects of climate change on the water quality of Baiyangdian Lake in the past 30 years using correlation analysis, regression analysis, and the generalized additive model. The major conclusions of the study were the increment in the oxygen demand of organic matter in the lake due to rising temperature, increased total phosphorus in the lake due to increased precipitation and altered nitrogen and dissolved oxygen concentration in lake [135]. It is very important for water resources managers to be aware of the impact the climate change will have on hydrological cycle and flow regime and be prepared to find the strategies to cope with it. The better understanding on the link between the change in climate, water resources and the anthropogenic activities will help the water resource managers to make more rational decisions on the allocation and management of the water resources [136]. Social and environmental aspects including agriculture, biodiversity conservation, and tourism are connected to quality and availability of water resources, and consequently adaptation measures will be strongly bound with policies in a wide spectrum of disciplines [137].

7. CONSERVATION OF SOIL HEALTH, FERTILITY, AND WATER RESOURCES IN CHANGING CLIMATE Soil and water are fundamental and basic necessities. The negative impact of changing climate on these basic resources is major global issue and developing strategies for their conservation is of utmost importance. The major research priorities of current studies are growing more food, conservation of the environment and reduction of global warming. Despite of changes in hydrology, climate, and increasing demand of agricultural commodities, there is a greater need to look further than the traditional approaches of the last century and embracing an expanded view of water and soil conservation to maintain an environmentally sound and sustainable landscape. Most importantly the new strategies must be based on far more effective policies and programs [138]. Agroforestry is one of the emerging technologies for water and soil conservation. It consists of a broad range of the practices including managing and establishing trees purposely around or within croplands, farm animal grounds, and pasture lands with the rationale of managing soil erosion, improving wildlife habitat, developing sustainable agricultural practices, ameliorating the effects of environmental pollution, and also adding to farm economy by harvesting tree based specialty products [139]. Conservation agriculture, another important approach for conservation of soil and water takes into account the conservation of biodiversity, labor and natural resources. It decreases drought stress, raises available soil water and maintains the soil health for a longer term. The strategy is practiced in Argentina, Australia, Brazil, Canada, New Zealand, Paraguay, and USA [140]. Further, it is also becoming popular in China, Kazakhstan, Russia and Ukraine and past decades it is spreading in Africa, Asia, and Europe [141]. Another important approach for maintaining soil health and fertility is the use of beneficial soil microbiomes. Microbes perform countless functions with key role in biogeochemical cycling and sustainability [142]. The utilization of the beneficial microbiomes is an important practice for agro-environmental sustainability. These microbiomes are treasure troves for innovative and potential developments in diverse sectors of agriculture, chemicals, environmental protection, food, and pharmaceuticals. The use of beneficial microbes is the vital practices for the sustainable energy and food production. The current research around the globe is majorly focused on exploring these beneficial microbes for maximizing their application under the limitation of the natural and anthropogenic activities, climate change, use of agro chemicals as these activities are continuously menacing stable agricultural production [143]. In order to fulfill water demand in the near future, it is necessary to rationalize the various means of collecting and storing water. In India, harvesting of rainwater is supposed to contribute in partially meeting the future water requirements. The climate change is expected to make monsoon less reliable as an assured source of water. Thus, efforts are required for more efficient groundwater recharge and rainwater harvesting through adoption and adaptation of technological options. Harnessing excessive monsoon runoff for additional groundwater storage will not only increase the water availability to meet growing demand, but also help to control the damage caused by flooding [144]. Other innovative approaches which may be adopted for water availability include desalination of seawater by evaporation using solar or wind energy which is cost effective and less expensive the cost of tapping groundwater, generation of rainfall using precipitation enhancement such as cloud seeding, and water in surface reservoirs or underground through artificial recharge. Furthermore, increasing irrigation efficiency using another new technology such as sprinkler design with low energy precision application might also be useful [145]. Many NGOs and government organizations are already working on the mitigation strategies for rising climate change. The Indian Council of Agricultural Research under ministry of agriculture and farmers welfare has launched a flagship network project which aims to study the impact of climate change on agricultural sector. The project also takes into account the development and promotion of climate resilient technologies in agriculture which will address vulnerable areas of the country and the output of the projects will help the districts and regions prone to climatic hazards. Rainfed area development scheme is being implemented for promotion of sustainable integrated farming systems. With the help of technological interventions, GOI is preparing efficiently to boost the crop produce and reduce the crop loss. Action against hunger is another important step to cope up with the hunger in scenario of climate crisis. Sankalp Taru Foundation is focusing on protection and conservation of the environment. Mukti is working for the social and economic development and environmental protection of the Sunderbans of West Bengal. Ashoka Trust for Research in Ecology and the Environment is working on issues including biodiversity and conservation, climate change mitigation and development, land and water resources, ecosystem services, and human well-being. Mobius Foundation is working for the environment in Delhi. The Gram Chetna Kendra aims to offer solutions to water problems keeping in mind the frequent damages droughts have induced in 8 Rajasthan. Greenpeace India is working on environment preservation. It has its presence in over 56 countries worldwide across various continents such as Asia, Europe, America, and few others. Greenpeace India promotes four different movements: preserving the oceans, preventing climate change, sustainable agriculture, and preventing another nuclear catastrophe [Figure 4].

8. EFFECTS OF CLIMATE CHANGE ON ECONOMICS It has long been understood that economic consequences are climaterelated. This relationship between climate and economics determines the extent and scale of the market impact of climate change in the next 100 years and beyond. Therefore, recent literature uses panel econometric methods to assess the response of economic results to weather, which is usually defined as implementation based on distribution of climate variables such as precipitation, temperature, and wind [146-148]. This estimation on economically and statistically important effects of weather on an assortment of economic outcomes, including crop yields, industrial output, and labor productivity [149]. The cumulative impact of global climate change is determined by how the world reacts to changes. According to the reports, climate change has already resulted in extreme weather events and a rise in sea level, posing new threats to agricultural production in several parts of the world. Current economic modeling may significantly understate the impact of potentially catastrophic climate change, emphasizing the need for a new generation of models capable of defining a more accurate picture of damages [150-152]. The main dynamic effect is through capital accumulation. Assuming a constant savings rate, if climate change negatively impacts production, the amount of economic investment will be reduced. In the long run, this will lead to lower capital stocks, lower GDP and, in most cases, lower consumption per capita. This effect of capital accumulation can be exacerbated in the context of endogenous growth if low investment slows technological advances while improving labor productivity or human capital accumulation. The second dynamic effect concerns savings. We can expect our forward-thinking agents to predict future climate change and change saving behavior in a perfect world. This, too, will have an impact on capital accumulation, and thus growth and future GDP [153]. Since then, practitioners and academics in development have grappled with the interplay of economic growth and environmental protection. Understanding and acting on these interactions has become critical to development in all countries, particularly in developing ones. The management of the environment has become an essential component of any viable path to poverty reduction and prosperity. Environmental degradation, poor health, and lost economic output result from poor environmental management practices. Poor people are the most vulnerable to these trends, though we must acknowledge that poverty also contributes to them [154,155]. Poor countries and poor people will suffer the most as they rely more on climate sensitive economic activities such as agriculture and possess weaker capability to adapt efficiently. In addition, poor people are also more likely to live in hazard zones and will be more vulnerable to the pests and diseases that follow drought, floods, and heat waves. Climate change can hinder development and growth, increase vulnerability, threaten health and return people to poverty [156]. Given the earth's finite resources, the application of economic principles and empirical findings should be a central component in the quest to meet humanity's aspirations for a good life. A study investigated that increment in temperature considerably reduces the economic performance in Sub-Saharan Africa. In addition, the relationship between real gross domestic product per capita on one hand, and the climate factors on the other, is intrinsically non-linear has been shown in the study [157]. An integrated assessment model (ENVISAGE), including a CGE-based economic module and a climate module has been used to assess the impact of climate change on economic aspects. Results revealed that the influence of climate change is substantial, particularly for developing countries and in the long run, amelioration and adaptation policies are required to bring about sustainability in economic growth [158]. Another study focused on the impact of the climate change shocks on economic growth. The non-linear autoregressive distributional lag technique has been used for estimation of the asymmetric effect of climate change on the economic growth of Pakistan. The report indicated that at national level, tree planting projects, and safeguard greenery at all costs while at international level, adoption of policies and mitigation strategies to control climate change are of major importance [159]. There is a strong case to be made for greater efforts to increase understanding of the environmental, social, and economic dimensions of sustainable development, which necessitates a greater integration of economics, social sciences, and natural sciences [160]. Figure 4: IPBES, global assessment report for policy makers. Kour, .: Journal of Applied Biology & Biotechnology 2024;12(2):1-1

Figure 1. Link between climate change and its impacts on biodiversity and ecosystem services, and the impact of biodiversity loss on climate change



Effects of climate change on oceans

There are many **effects of climate change on oceans**. One of the most important is an increase in ocean temperatures. More frequent marine heatwaves are linked to this. The rising temperature contributes to a rise in sea levels due to the expansion of water as it warms and the melting of ice sheets on land. Other effects on oceans include sea ice decline, reducing pH values and oxygen levels, as well as increased ocean stratification. All this can lead to changes of ocean currents, for example a weakening of the Atlantic meridional overturning circulation (AMOC).[2] The main cause of these changes are the emissions of greenhouse gases from human activities, mainly burning of fossil fuels and deforestation. Carbon dioxide and methane are examples of greenhouse gases. The additional greenhouse effect leads to ocean warming because the ocean takes up most of the additional heat in the climate system.[3] The ocean also absorbs some of the extra carbon dioxide that is in the atmosphere. This causes the pH value of the seawater to drop.[4] Scientists estimate that the ocean absorbs about 25% of all human-caused CO_2 emissions.[4]

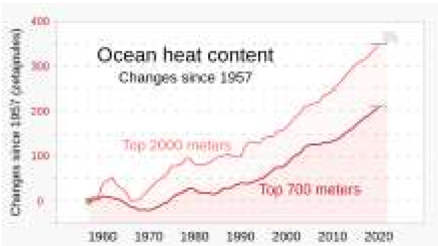
The various layers of the oceans have different temperatures. For example, the water is colder towards the bottom of the ocean. This temperature stratification will increase as the ocean surface warms due to rising air temperatures.[5]:471 Connected to this is a decline in mixing of the ocean layers, so that warm water stabilises near the surface. A reduction of cold, deep water circulation follows. The reduced vertical mixing makes it harder for the ocean to absorb heat. So a larger share of future warming goes into the atmosphere and land. One result is an increase in the amount of energy available for tropical cyclones and other storms. Another result is a decrease in nutrients for fish in the upper ocean layers. These changes also reduce the ocean's capacity to store carbon.[6] At the same time, contrasts in salinity are increasing. Salty areas are becoming saltier and fresher areas less salty.[7]

Warmer water cannot contain the same amount of oxygen as cold water. As a result, oxygen from the oceans moves to the atmosphere. Increased thermal stratification may reduce the supply of oxygen from surface waters to deeper waters. This lowers the water's oxygen content even more.[8] The ocean has already lost oxygen throughout its water column. Oxygen minimum zones are increasing in size worldwide.[5]:471

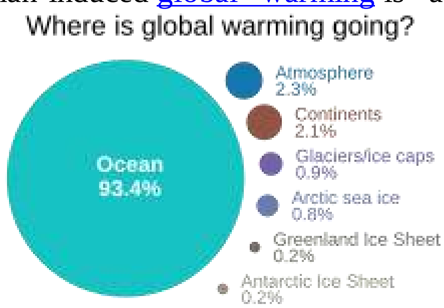
These changes harm marine ecosystems, and this can lead to biodiversity loss or changes in species distribution.[2] This in turn can affect fishing and coastal tourism. For example, rising water temperatures are harming tropical coral reefs. The direct effect is coral bleaching on these reefs, because they are sensitive to even minor temperature changes. So a small increase in water temperature could have a significant impact in these environments. Another example is loss of sea ice habitats due to warming. This will have severe impacts on polar bears and other animals that rely on it. The effects of climate change on oceans put additional pressures on ocean ecosystems which are already under pressure by other impacts from human activities.[2]

Changes due to rising greenhouse gas levels

[edit]



Most excess heat trapped by human-induced global warming is absorbed by the oceans,



penetrating to its deeper layers.[9] Energy (heat) added to various parts of the climate system due to global warming (data from 2007).

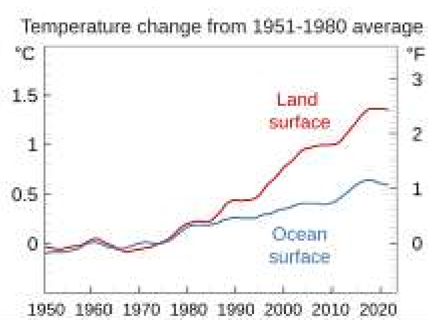
Further information: Climate change and Effects of climate change

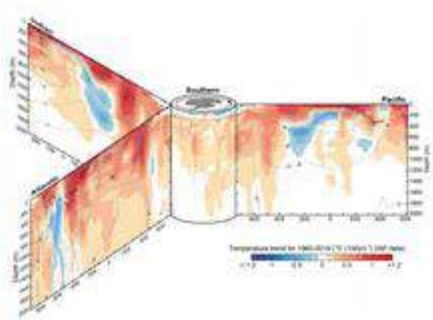
Presently (2020), atmospheric carbon dioxide (CO_2) levels of more than 410 parts per million (ppm) are nearly 50% higher than preindustrial levels. These elevated levels and rapid growth rates are unprecedented in the geological record's 55 million years.[4] The source for this excess CO_2 is clearly established as human-driven, reflecting a mix of fossil fuel burning, industrial, and land-use/land-change emissions.[4] The idea that the ocean serves as a major sink for anthropogenic CO_2 has been discussed in scientific literature since at least the late 1950s.[4] Several pieces of evidence point to the ocean absorbing roughly a quarter of total anthropogenic CO_2 emissions.[4]

The latest key findings about the observed changes and impacts from 2019 include:

It is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system [...]. Since 1993, the rate of ocean warming has more than doubled [...]. Marine heatwaves have very likely doubled in frequency since 1982 and are increasing in intensity [...]. By absorbing more CO2, the ocean has undergone increasing surface acidification [...]. A loss of oxygen has occurred from the surface to 1000 m [...].— *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019),* [2]:9

Rising ocean temperature



Land surface temperatures have increased faster than ocean temperatures as the ocean absorbs about 92% of excess heat generated by climate change.[10] Chart with data from NASA[11] showing how land and sea surface air temperatures have changed vs a pre-industrial baseline.  The illustration of temperature changes from 1960 to 2019 across each ocean starting at the Southern Ocean around Antarctica.[12]

See also: Ocean temperature, Sea surface temperature, and Marine heatwave

It is clear that the ocean is warming as a result of climate change, and this rate of warming is increasing.[2]:9 The global ocean was the warmest it had ever been recorded by humans in 2022.[13] This is determined by the ocean heat content, which exceeded the previous 2021 maximum in 2022.[13] The steady rise in ocean temperatures is an unavoidable result of the Earth's energy imbalance, which is primarily caused by rising levels of greenhouse gases.[13] Between pre-industrial times and the 2011–2020 decade, the ocean's surface has heated between 0.68 and 1.01 °C.[14]:1214

The majority of ocean heat gain occurs in the Southern Ocean. For example, between the 1950s and the 1980s, the temperature of the Antarctic Southern Ocean rose by 0.17 °C (0.31 °F), nearly twice the rate of the global ocean.[15]

The warming rate varies with depth. The upper ocean (above 700 m) is warming the fastest. At an ocean depth of a thousand metres the warming occurs at a rate of nearly 0.4 °C per century (data from 1981 to 2019).[5]:Figure 5.4 In deeper zones of the ocean (globally speaking), at 2000 metres depth, the warming has been around 0.1 °C per century.[5]:Figure 5.4 The warming pattern is different for the Antarctic Ocean (at 55°S), where the highest warming (0.3 °C per century) has been observed at a depth of 4500 m.[5]:Figure 5.4

Marine heatwaves

Marine heatwaves also take their toll on marine life: For example, due to fall-out from the 2019-2021 Pacific Northwest marine heatwave,[16] Bering Sea snow crab populations declined 84% between 2018 and 2022, a loss of 9.8 billion crabs.[17]

This section is an excerpt from Marine heatwave

Scientists predict that the frequency, duration, scale (or area) and intensity of marine heatwaves will continue to increase.[18]:1227 This is because sea surface temperatures will continue to increase with global warming. The IPCC Sixth Assessment Report in 2022 has summarized research findings to date and stated that "marine heatwaves are more frequent [...], more intense and longer [...] since the 1980s, and since at least 2006 very likely attributable to anthropogenic climate change".[19]:381 This confirms earlier findings in a report by the IPCC in 2019 which had found that "marine heatwaves [...] have doubled in frequency and have become longer lasting, more intense and more extensive (very likely).".[20]:67 The extent of ocean warming depends on greenhouse gas emission scenarios, and thus humans' climate change mitigation efforts. Scientists predict that marine heatwaves will become "four times more frequent in 2081–2100 compared to 1995–2014" under the lower greenhouse gas emissions scenario, or eight times more frequent under the higher emissions scenario.[18]:1214

Ocean heat content

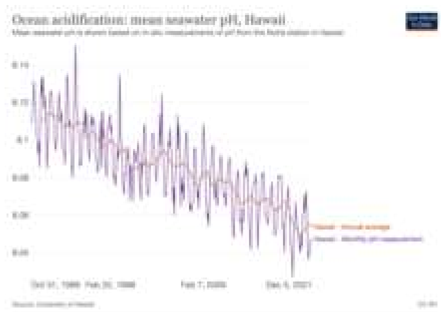
The ocean temperature varies from place to place. Temperatures are higher near the equator and lower at the poles. As a result, changes in total ocean heat content best illustrate ocean warming. When compared to 1969–1993, heat uptake has increased between 1993 and 2017.[5]:457

This section is an excerpt from Ocean heat content

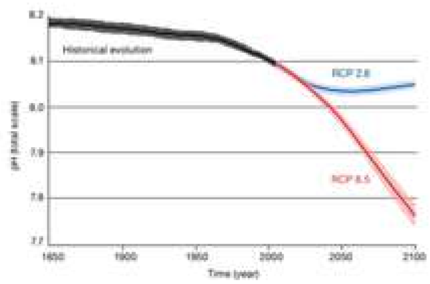
Ocean heat content (OHC) or ocean heat uptake (OHU) is the energy absorbed and stored by oceans. To calculate the ocean heat content, it is necessary to measure ocean temperature at many different locations and depths. Integrating the areal density of a change in enthalpic energy over an ocean basin or entire ocean gives the total ocean heat uptake.[21] Between 1971 and 2018, the rise in ocean heat content accounted for over 90% of Earth's excess energy from global heating.[22][23] The main driver of this increase was caused by humans via their rising greenhouse gas emissions.[24]:1228 By 2020, about one third of the added energy had propagated to depths below 700 meters.[25][26]

In 2023, the world's oceans were again the hottest in the historical record and exceeded the previous 2022 record maximum.[27] The five highest ocean heat observations to a depth of 2000 meters occurred in the period 2019–2023. The North Pacific, North Atlantic, the Mediterranean, and the Southern Ocean all recorded their highest heat observations for more than sixty years of global measurements.[28] Ocean heat content and sea level rise are important indicators of climate change.[29]

Ocean acidification



Ocean acidification: mean seawater pH. Mean seawater pH is shown based on in-situ measurements of pH from the Aloha station.[30]



Change in pH since the beginning of the industrial revolution. RCP2.6 scenario is "low CO_2 emissions". RCP8.5 scenario is "high CO_2 emissions".[31]

This section is an excerpt from Ocean acidification.[edit]

Ocean acidification is the ongoing decrease in the pH of the Earth's ocean. Between 1950 and 2020, the average pH of the ocean surface fell from approximately 8.15 to 8.05.[32] Carbon dioxide emissions from human activities are the primary cause of ocean acidification, with atmospheric carbon dioxide (CO_2) levels exceeding 422 ppm (as of 2024).[33] CO_2 from the atmosphere is absorbed by the oceans. This chemical reaction produces carbonic acid (H_2CO_3) which dissociates into a bicarbonate ion (HCO_3^-) and a hydrogen ion (H^+). The presence of free hydrogen ions (H^+) lowers the pH of the ocean, increasing acidity (this does not mean that seawater is acidic yet; it is still alkaline, with a pH higher than 8). Marine calcifying organisms, such as mollusks and corals, are especially vulnerable because they rely on calcium carbonate to build shells and skeletons.[34]

A change in pH by 0.1 represents a 26% increase in hydrogen ion concentration in the world's oceans (the pH scale is logarithmic, so a change of one in pH units is equivalent to a tenfold change in hydrogen ion concentration). Sea-surface pH and carbonate saturation states vary depending on ocean depth and location. Colder and higher latitude waters are capable of absorbing more CO_2. This can cause acidity to rise, lowering the pH and carbonate saturation levels in these areas. There are several other factors that influence the atmosphere-ocean CO_2 exchange, and thus local ocean acidification. These include ocean currents and upwelling zones, proximity to large continental rivers, sea ice coverage, and atmospheric exchange with nitrogen and sulfur from fossil fuel burning and agriculture.[35][36][37]

A lower ocean pH has a range of potentially harmful effects for marine organisms. Scientists have observed for example reduced calcification, lowered immune responses, and reduced energy for basic functions such as reproduction.[38] Ocean acidification can impact marine ecosystems that provide food and livelihoods for many people. About one billion people are wholly or partially dependent on the fishing, tourism, and coastal management services provided by coral reefs. Ongoing acidification of the oceans may therefore threaten food chains linked with the oceans.[39][40]

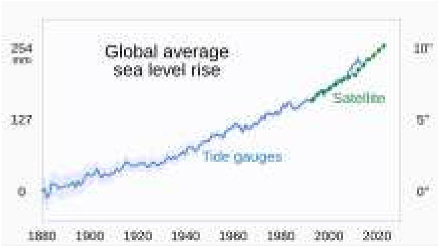
Time scales

Many ocean-related elements of the climate system respond slowly to warming. For instance, acidification of the deep ocean will continue for millennia, and the same is true for the increase in ocean heat content.[41]:43 Similarly, sea level rise will continue for centuries or even millennia even if greenhouse gas emissions are brought to zero, due to the slow response of ice sheets to warming and the continued uptake of heat by the oceans, which expand when warmed.[41]:77

Effects on the physical environment

Sea level rise

Main article: Sea level rise



The global average sea level has risen about 250 millimetres (9.8 in) since 1880,[42] increasing the elevation on top of which other types of flooding (high-tide flooding, storm surge) occur.

Many coastal cities will experience coastal flooding in the coming decades and beyond.[14]:1318 Local subsidence, which may be natural but can be increased by human activity, can exacerbate coastal flooding.[43] Coastal flooding will threaten hundreds of millions of people by 2050, particularly in Southeast Asia.[43]

This section is an excerpt from Sea level rise

Between 1901 and 2018, the average sea level rose by 15–25 cm (6–10 in), with an increase of 2.3 mm (0.091 in) per year since the 1970s.[44]:1216 This was faster than the sea level had ever risen over at least the past 3,000 years.[44]:1216 The rate accelerated to 4.62 mm (0.182 in)/yr for the decade 2013–2022.[45] Climate change due to human activities is the main cause.[46]:5,8 Between 1993 and 2018, melting ice sheets and glaciers accounted for 44% of sea level rise, with another 42% resulting from thermal expansion of water.[47]:1576

Changing ocean currents

Main articles: Ocean § Ocean currents and global climate, and Atlantic meridional overturning circulation


Waves on an ocean coast

Ocean currents are caused by temperature variations caused by sunlight and air temperatures at various latitudes, as well as prevailing winds and the different densities of salt and fresh water. Warm air rises near the equator. Later, as it moves toward the poles, it cools again. Cool air sinks near the poles, but warms and rises again as it moves toward the equator. This produces Hadley cells, which are large-scale wind patterns, with similar effects driving a mid-latitude cell in each hemisphere.[48][page needed] Wind patterns associated with these circulation cells drive surface currents which push the surface water to higher latitudes where the air is colder.[48][page needed] This cools the water, causing it to become very dense in comparison to lower latitude waters, causing it to sink to the ocean floor, forming North Atlantic Deep Water (NADW) in the north and Antarctic Bottom Water (AABW) in the south.[49]

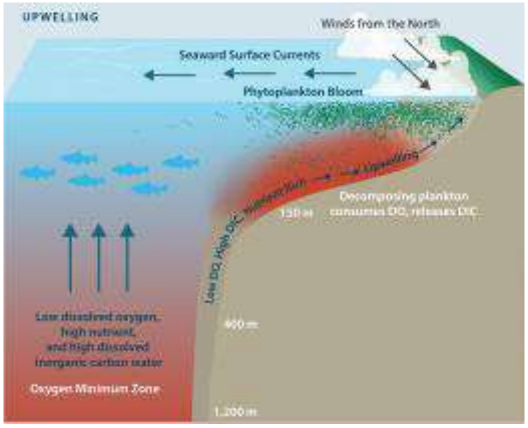
Driven by this sinking and the upwelling that occurs in lower latitudes, as well as the driving force of the winds on surface water, the ocean currents act to circulate water throughout the sea. When global warming is factored in, changes occur, particularly in areas where deep water is formed.[50] As the oceans warm and glaciers and polar ice caps melt, more and more fresh water is released into the high latitude regions where deep water forms, lowering the density of the surface water. As a result, the water sinks more slowly than it would normally.[50]

The Atlantic Meridional Overturning Circulation (AMOC) may have weakened since the preindustrial era, according to modern observations and paleoclimate reconstructions (the AMOC is part of a global thermohaline circulation), but there is too much uncertainty in the data to know for certain.[14]:1237 Climate change projections assessed in 2021 indicate that the AMOC is very likely to weaken over the course of the 21st century.[14]:1214 A weakening of this magnitude could have a significant impact on global climate, with the North Atlantic being particularly vulnerable.[2]:19

Any changes in ocean currents affect the ocean's ability to absorb carbon dioxide (which is affected by water temperature) as well as ocean productivity because the currents transport nutrients (see Impacts on phytoplankton and net primary production). Because the AMOC deep ocean circulation is slow (it takes hundreds to thousands of years to circulate the entire ocean), it is slow to respond to climate change.[51]:137

Increasing stratification

Main articles: Ocean stratification and Ocean § Physical properties



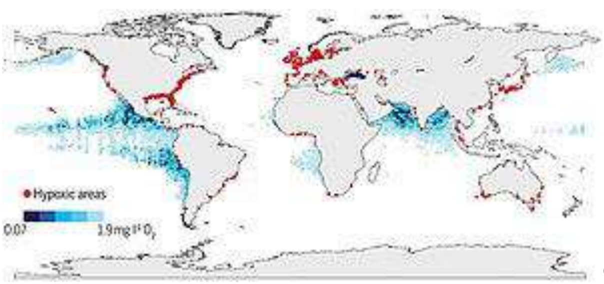
Drivers of hypoxia and ocean acidification intensification in upwelling shelf systems. Equatorward winds drive the upwelling of low dissolved oxygen (DO), high nutrient, and high dissolved inorganic carbon (DIC) water from above the oxygen minimum zone. Cross-shelf gradients in productivity and bottom water residence times drive the strength of DO (DIC) decrease (increase) as water transits across a productive continental shelf.[52][53]

Changes in ocean stratification are significant because they can influence productivity and oxygen levels. The separation of water into layers based on density is known as stratification. Stratification by layers occurs in all ocean basins. The stratified layers limit how much vertical water mixing takes place, reducing the exchange of heat, carbon, oxygen and particles between the upper ocean and the interior.[54] Since 1970, there has been an increase in stratification in the upper ocean due to global warming and, in some areas, salinity changes.[14] The salinity changes are caused by evaporation in tropical waters, which results in higher salinity and density levels. Meanwhile, melting ice can cause a decrease in salinity at higher latitudes.[14]

Temperature, salinity and pressure all influence water density. As surface waters are often warmer than deep waters, they are less dense, resulting in stratification.[54] This stratification is crucial not just in the production of the Atlantic Meridional Overturning Circulation, which has worldwide weather and climate ramifications, but it is also significant because stratification controls the movement of nutrients from deep water to the surface. This increases ocean productivity and is associated with the compensatory downward flow of water that carries oxygen from the atmosphere and surface waters into the deep sea.[51]

Reduced oxygen levels

Main article: Ocean deoxygenation



Global map of low and declining oxygen levels in the open ocean and coastal waters. The map indicates coastal sites where anthropogenic nutrients have resulted in oxygen declines to less than 2 mg L^{-1} (red dots), as well as ocean oxygen minimum zones at 300 metres (blue shaded regions).[55]

Climate change has an impact on ocean oxygen, both in coastal areas and in the open ocean.[55]

The open ocean naturally has some areas of low oxygen, known as oxygen minimum zones. These areas are isolated from the atmospheric oxygen by sluggish ocean circulation. At the same time, oxygen is consumed when sinking organic matter from surface waters is broken down. These low oxygen ocean areas are expanding as a result of ocean warming which both reduces water circulation and also reduces the oxygen content of that water, while the solubility of oxygen declines as the temperature rises.[56]

Overall ocean oxygen concentrations are estimated to have declined 2% over 50 years from the 1960s.[56] The nature of the ocean circulation means that in general these low oxygen regions are more pronounced in the Pacific Ocean. Low oxygen represents a stress for almost all marine animals. Very low oxygen levels create regions with much reduced fauna. It is predicted that these low oxygen zones will expand in future due to climate change, and this represents a serious threat to marine life in these oxygen minimum zones.[2]

The second area of concern relates to coastal waters where increasing nutrient supply from rivers to coastal areas leads to increasing production and sinking organic matter which in some coastal regions leads to extreme oxygen depletion, sometimes referred to as *dead zones*.[57] These dead zones are expanding driven particularly by increasing nutrient inputs, but also compounded by increasing ocean stratification driven by climate change.[2]

Oceans turning green

Satellite image analysis reveals that the oceans have been gradually turning green from blue as climate breakdown continues. The color change has been detected for a majority of the word's ocean surfaces and may be due to changing plankton populations caused by climate change.[58][59]

Changes to Earth's weather system and wind patterns

Further information: Effects of climate change on the water cycle

Climate change and the associated warming of the ocean will lead to widespread changes to the Earth's climate and weather system including increased tropical cyclone and monsoon intensities and weather extremes with some areas becoming wetter and others drier.[14] Changing wind patterns are predicted to increase wave heights in some areas.[60][14]:1310

Intensifying tropical cyclones

Human-induced climate change "continues to warm the oceans which provide the memory of past accumulated effects".[61] The result is a higher ocean heat content and higher sea surface temperatures. In turn, this "invigorates tropical cyclones to make them more intense, bigger, longer lasting and greatly increases their flooding rains".[61] One example is Hurricane Harvey in 2017.[61]

This section is an excerpt from Tropical cyclones and climate change.

Climate change affects tropical cyclones in a variety of ways: an intensification of rainfall and wind speed, an increase in the frequency of very intense storms and a poleward extension of where the cyclones reach maximum intensity are among the consequences of human-induced climate change.[62][63] Tropical cyclones use warm, moist air as their source of energy or *fuel*. As climate change is warming ocean temperatures, there is potentially more of this fuel available.[64]

Between 1979 and 2017, there was a global increase in the proportion of tropical cyclones of Category 3 and higher on the Saffir–Simpson scale. The trend was most clear in the north Indian Ocean,[65][66] North Atlantic and in the Southern Indian Ocean. In the north Indian Ocean, particularly the Arabian Sea, the frequency, duration, and intensity of cyclones have increased significantly. There has been a 52% increase in the number of cyclones in the Arabian Sea, while the number of very severe cyclones have increased by 150%, during 1982–2019. Meanwhile, the total duration of cyclones in the Arabian Sea has increased by 80% while that of very severe cyclones has increased by 260%.[65] In the North Pacific, tropical cyclones have been moving poleward into colder waters and there was no increase in intensity over this period.[67] With 2 °C (3.6 °F) warming, a greater percentage (+13%) of tropical cyclones are expected to reach Category 4 and 5 strength.[62] A 2019 study indicates that climate change has been driving the observed trend of rapid intensification of tropical cyclones in the Atlantic basin. Rapidly intensifying cyclones are hard to forecast and therefore pose additional risk to coastal communities.[68]

Salinity changes

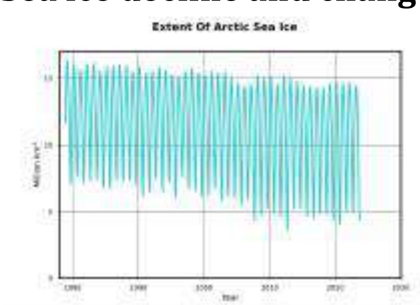
Further information: Ocean § Salinity, and Effects of climate change on the water cycle

Due to global warming and increased glacier melt, thermohaline circulation patterns may be altered by increasing amounts of freshwater released into oceans and, therefore, changing ocean salinity. Thermohaline circulation is responsible for bringing up cold, nutrient-rich water from the depths of the ocean, a process known as upwelling.[69]

Seawater consists of fresh water and salt, and the concentration of salt in seawater is called salinity. Salt does not evaporate, thus the precipitation and evaporation of freshwater influences salinity strongly. Changes in the water cycle are therefore strongly visible in surface salinity measurements, which has been known since the 1930s.[7][70]

The long term observation records show a clear trend: the global salinity patterns are amplifying in this period.[71][72] This means that the high saline regions have become more saline, and regions of low salinity have become less saline. The regions of high salinity are dominated by evaporation, and the increase in salinity shows that evaporation is increasing even more. The same goes for regions of low salinity that are becoming less saline, which indicates that precipitation is becoming more intensified.[73][5]

Sea ice decline and changes



Decline in arctic sea ice extent (area) from 1979 to 2022

Sea ice decline occurs more in the Arctic than in Antarctica, where it is more a matter of *changing* sea ice conditions.

This section is an excerpt from Arctic sea ice decline. [edit]

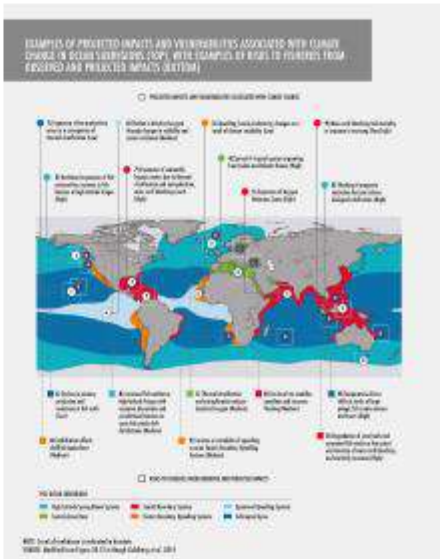
Sea ice in the Arctic region has declined in recent decades in area and volume due to climate change. It has been melting more in summer than it refreezes in winter. Global warming, caused by greenhouse gas forcing is responsible for the decline in Arctic sea ice. The decline of sea ice in the Arctic has been accelerating during the early twenty-first century, with a decline rate of 4.7% per decade (it has declined over 50% since the first satellite records).[74][75][76] Summertime sea ice will likely cease to exist sometime during the 21st century.[77]

This section is an excerpt from Antarctic sea ice § Recent trends and climate change. [edit]

Sea ice extent in Antarctica varies a lot year by year. This makes it difficult determine a trend, and record highs and record lows have been observed between 2013 and 2023. The general trend since 1979, the start of the satellite measurements, has been roughly flat. Between 2015 and 2023, there has been a decline in sea ice, but due to the high variability, this does not correspond to a significant trend.[78] The flat trend is in contrast with Arctic sea ice, which has seen a declining trend.[78][79]

Impacts on biological processes

[edit]



Examples of projected impacts and vulnerabilities for fisheries associated with climate change

Ocean productivity

[edit]

Further information: Ocean § Oxygen, photosynthesis and carbon cycle

The process of photosynthesis in the surface ocean releases oxygen and consumes carbon dioxide. This photosynthesis in the ocean is dominated by phytoplankton – microscopic free-floating algae. After the plants grow, bacterial decomposition of the organic matter formed by photosynthesis in the ocean consumes oxygen and releases carbon dioxide. The sinking and bacterial decomposition of some organic matter in deep ocean water, at depths where the waters are out of contact with the atmosphere, leads to a reduction in oxygen concentrations and increase in carbon dioxide, carbonate and bicarbonate.[51] This cycling of carbon dioxide in oceans is an important part of the global carbon cycle.

The photosynthesis in surface waters consumes nutrients (e.g. nitrogen and phosphorus) and transfers these nutrients to deep water as the organic matter produced by photosynthesis sinks upon the death of the organisms. Productivity in surface waters therefore depends in part on the transfer of nutrients from deep water back to the surface by ocean mixing and currents. The increasing stratification of the oceans due to climate change therefore acts generally to reduce ocean productivity. However, in some areas, such as previously ice covered regions, productivity may increase. This trend is already observable and is projected to continue under current projected climate change.[14][failed verification] In the Indian Ocean for example, productivity is estimated to have declined over the past sixty years due to climate warming and is projected to continue.[80]

Ocean productivity under a very high emission scenario (RCP8.5) is very likely to drop by 4-11% by 2100.[5]:452 The decline will show regional variations. For example, the tropical ocean NPP will decline more: by 7–16% for the same emissions scenario.[5]:452 Less organic matter will likely sink from the upper oceans into deeper ocean layers due to increased ocean stratification and a reduction in nutrient supply.[5]:452 The reduction in ocean productivity is due to the "combined effects of warming, stratification, light, nutrients and predation".[5]:452

Calcifying organisms and ocean acidification

This section is an excerpt from Ocean acidification § Complexity of research findings.

The full ecological consequences of the changes in calcification due to ocean acidification are complex but it appears likely that many calcifying species will be adversely affected by ocean acidification.[81][82]:413 Increasing ocean acidification makes it more difficult for shell-accreting organisms to access carbonate ions, essential for the production of their hard exoskeletal shell.[83] Oceanic calcifying organism span the food chain from autotrophs to heterotrophs and include organisms such as coccolithophores, corals, foraminifera, echinoderms, crustaceans and molluscs.[84][85]

Overall, all marine ecosystems on Earth will be exposed to changes in acidification and several other ocean biogeochemical changes.[86] Ocean acidification may force some organisms to reallocate resources away from productive endpoints in order to maintain calcification.[87] For example, the oyster *Magallana gigas* is recognized to experience metabolic changes alongside altered calcification rates due to energetic tradeoffs resulting from pH imbalances.[88]

Harmful algal blooms

Further information: Harmful algal bloom

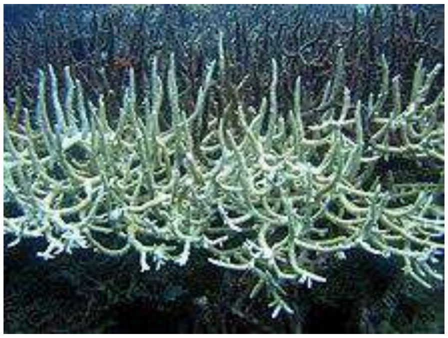
Although the drivers of harmful algal blooms (HABs) are poorly understood, they appear to have increased in range and frequency in coastal areas since the 1980s.[2]:16 This is the result of human induced factors such as increased nutrient inputs (nutrient pollution) and climate change (in particular the warming of water temperatures).[2]:16 The parameters that affect the formation of HABs are ocean warming, marine heatwaves, oxygen loss, eutrophication and water pollution.[89]:582 These increases in HABs are of concern because of the impact of their occurrence on local food security, tourism and the economy.[2]:16

It is however also possible that the perceived increase in HABs globally is simply due to more severe bloom impacts and better monitoring and not due to climate change.[90]:463

Impacts on coral reefs and fisheries

Coral reefs

Further information: Coral bleaching, Coral reef, and Coral



Bleached Staghorn coral in the Great Barrier Reef.

While some mobile marine species can migrate in response to climate change, others such as corals find this much more difficult. A coral reef is an underwater ecosystem characterised by reef-building corals. Reefs are formed by colonies of coral polyps held together by calcium carbonate.[91] Coral reefs are important centres of biodiversity and vital to millions of people who rely on them for coastal protection, food and for sustaining tourism in many regions.[92]

Warm water corals are clearly in decline, with losses of 50% over the last 30–50 years due to multiple threats from ocean warming, ocean acidification, pollution and physical damage from activities such as fishing. These pressures are expected to intensify.[92]

The warming ocean surface waters can lead to bleaching of the corals which can cause serious damage and/or coral death. The IPCC Sixth Assessment Report in 2022 found that: "Since the early 1980s, the frequency and severity of mass coral bleaching events have increased sharply worldwide".[90]:416 Marine heatwaves have caused coral reef mass mortality.[90]:381 It is expected that many coral reefs will suffer irreversible changes and loss due to marine heatwaves with global temperatures increasing by more than 1.5 °C.[90]:382

Coral bleaching occurs when thermal stress from a warming ocean results in the expulsion of the symbiotic algae that resides within coral tissues. These symbiotic algae are the reason for the bright, vibrant colors of coral reefs.[93] A 1-2°C sustained increase in seawater temperatures is sufficient for bleaching to occur, which turns corals white.[94] If a coral is bleached for a prolonged period of time, death may result. In the Great Barrier Reef, before 1998 there were no such events. The first event happened in 1998 and after that, they began to occur more frequently. Between 2016 and 2020 there were three of them.[95]

Apart from coral bleaching, the reducing pH value in oceans is also a problem for coral reefs because ocean acidification reduces coralline algal biodiversity.[96] The physiology of coralline algal calcification determines how the algae will respond to ocean acidification.[96]

This section is an excerpt from Ocean acidification § Corals.

Warm water corals are clearly in decline, with losses of 50% over the last 30–50 years due to multiple threats from ocean warming, ocean acidification, pollution and physical damage from activities such as fishing, and these pressures are expected to intensify.[97][82]:416

The fluid in the internal compartments (the coelenteron) where corals grow their exoskeleton is also extremely important for calcification growth. When the saturation state of aragonite in the external seawater is at ambient levels, the corals will grow their aragonite crystals rapidly in their internal compartments, hence their exoskeleton grows rapidly. If the saturation state of aragonite in the external seawater is lower than the ambient level, the corals have to work harder to maintain the right balance in the internal compartment. When that happens, the process of growing the crystals slows down, and this slows down the rate of how much their exoskeleton is growing. Depending on the aragonite saturation state in the surrounding water, the corals may halt growth because pumping aragonite into the internal compartment will not be energetically favorable.[98] Under the current progression of carbon emissions, around 70% of North Atlantic cold-water corals will be living in corrosive waters by 2050–60.[99]

Effects on fisheries

This section is an excerpt from Climate change and fisheries

Fisheries are affected by climate change in many ways: marine aquatic ecosystems are being affected by rising ocean temperatures,[100] ocean acidification[101] and ocean deoxygenation, while freshwater ecosystems are being impacted by changes in water temperature, water flow, and fish habitat loss.[102] These effects vary in the context of each fishery.[103] Climate change is modifying fish distributions[104] and the productivity of marine and freshwater species. Climate change is expected to lead to significant changes in the availability and trade of fish products.[105] The geopolitical and economic consequences will be significant, especially for the countries most dependent on the sector. The biggest decreases in maximum catch potential can be expected in the tropics, mostly in the South Pacific regions.[105]:iv

The impacts of climate change on ocean systems has impacts on the sustainability of fisheries and aquaculture, on the livelihoods of the communities that depend on fisheries, and on the ability of the oceans to capture and store carbon (biological pump). The effect of sea level rise means that coastal fishing communities are significantly impacted by climate change, while changing rainfall patterns and water use impact on inland freshwater fisheries and aquaculture.[106] Increased risks of floods, diseases, parasites and harmful algal blooms are climate change impacts on aquaculture which can lead to losses of production and infrastructure.[105]

It is projected that "climate change decreases the modelled global fish community biomass by as much as 30% by 2100".[107]

Impacts on marine mammals

Regions and habitats particularly affected

Some effects on marine mammals, especially those in the Arctic, are very direct such as loss of habitat, temperature stress, and exposure to severe weather. Other effects are more indirect, such as changes in host pathogen associations, changes in body condition because of predator–prey interaction, changes in exposure to toxins and CO_2 emissions, and increased human interactions.[108] Despite the large potential impacts of ocean warming on marine mammals, the global vulnerability of marine mammals to global warming is still poorly understood.[109]

Marine mammals have evolved to live in oceans, but climate change is affecting their natural habitat.[110][111][112][113] Some species may not adapt fast enough, which might lead to their extinction.[114]

It has been generally assumed that the Arctic marine mammals were the most vulnerable in the face of climate change given the substantial observed and projected decline in Arctic sea ice. However, research has shown that the North Pacific Ocean, the Greenland Sea and the Barents Sea host the species that are most vulnerable to global warming.[109] The North Pacific has already been identified as a hotspot for human threats for marine mammals[115] and is now also a hotspot for vulnerability to global warming. Marine mammals in this region will face double jeopardy from both human activities (e.g., marine traffic, pollution and offshore oil and gas development) and global warming, with potential additive or synergetic effects. As a result, these ecosystems face irreversible consequences for marine ecosystem functioning.[109]

Marine organisms usually tend to encounter relatively stable temperatures compared to terrestrial species and thus are likely to be more sensitive to temperature change than terrestrial organisms.[116] Therefore, the ocean warming will lead to the migration of increased species, as endangered species look for a more suitable habitat. If sea temperatures continue to rise, then some fauna may move to cooler water and some range-edge species may disappear from regional waters or experience a reduced global range.[116] Change in the abundance of some species will alter the food resources available to marine mammals, which then results in marine mammals' biogeographic shifts. Furthermore, if a species is unable to successfully migrate to a suitable environment, it will be at risk of extinction if it cannot adapt to rising temperatures of the ocean.

Arctic sea ice decline leads to loss of the sea ice habitat, elevations of water and air temperature, and increased occurrence of severe weather. The loss of sea ice habitat will reduce the abundance of seal prey for marine mammals, particularly polar bears.[117] Sea ice changes may also have indirect effects on animal health due to changes in the transmission of pathogens, impacts on animals' body condition due to shifts in the prey-based food web, and increased exposure to toxicants as a result of increased human habitation in the Arctic habitat.[118]

Sea level rise is also important when assessing the impacts of global warming on marine mammals, since it affects coastal environments that marine mammal species rely on.[119]

Polar bears

A polar bear waiting in the Fall for the sea ice to form.

This section is an excerpt from Polar bear conservation § Climate change.[edit]

The key danger for polar bears posed by the effects of climate change is malnutrition or starvation due to habitat loss. Polar bears hunt seals from a platform of sea ice. Rising temperatures cause the sea ice to melt earlier in the year, driving the bears to shore before they have built sufficient fat reserves to survive the period of scarce food in the late summer and early fall.[120] Reduction in sea-ice cover also forces bears to swim longer distances, which further depletes their energy stores and occasionally leads to drowning.[121] Thinner sea ice tends to deform more easily, which appears to make it more difficult for polar bears to access seals.[122] Insufficient nourishment leads to lower reproductive rates in adult females and lower survival rates in cubs and juvenile bears, in addition to poorer body condition in bears of all ages.[123]

Seals

Further information: Ringed seal § Climate change

[Harp seal](#) mother nursing pup on [sea ice](#)

Seals are another marine mammal that are susceptible to climate change.[114] Much like polar bears, some seal species have evolved to rely on sea ice. They use the ice platforms for breeding and raising young seal pups. In 2010 and 2011, sea ice in the Northwest Atlantic was at or near an all-time low and harp seals as well as ringed seals that bred on thin ice saw increased death rates.[124][125] Antarctic fur seals in South Georgia in the South Atlantic Ocean saw extreme reductions over a 20-year study, during which scientists measured increased sea surface temperature anomalies.[126]

Dolphins

Climate change has had a significant impact on various dolphin species. For example: In the Mediterranean, increased sea surface temperatures, salinity, upwelling intensity, and sea levels have led to a reduction in prey resources, causing a steep decline in the short-beaked common dolphin subpopulation in the Mediterranean, which was classified as endangered in 2003.[127] At the Shark Bay World Heritage Area in Western Australia, the local population of the Indo-Pacific bottlenose dolphin had a significant decline following a marine heatwave in 2011.[128] River dolphins are highly affected by climate change as high evaporation rates, increased water temperatures, decreased precipitation, and increased acidification occur.[129][130]

This section is an excerpt from Dolphin § Impacts of climate change

Dolphins are marine mammals with broad geographic extent, making them susceptible to climate change in various ways. The most common effect of climate change on dolphins is the increasing water temperatures across the globe.[131] This has caused a large variety of dolphin species to experience range shifts, in which the species move from their typical geographic region to cooler waters.[132][133] Another side effect of increasing water temperatures is the increase in harmful algae blooms, which has caused a mass die-off of bottlenose dolphins.[131]

North Atlantic right whales

This section is an excerpt from North Atlantic right whale § Climate change

Anthropogenic climate change poses a clear and growing threat to right whales.[134][135] Documented effects in the scientific literature include impacts on reproduction, range, prey access, interactions with human activities, and individual health condition.[135]

Climate-driven changes to ocean circulation and water temperatures have affected the species' foraging and habitat use patterns, with numerous harmful consequences.[136] Warming waters lead to decreased abundance of an important prey species, the zooplankton *Calanus finmarchicus*.[137] This reduction in prey availability affects the health of the right whale population in numerous ways. The most direct impacts are on the survival and reproductive success of individual whales, as lower *C. finmarchicus* densities have been associated with malnutrition-related health issues[138] and difficulties successfully giving birth to and rearing calves.[136][139]

Potential feedback effects

Methane release from methane clathrate

Rising ocean temperatures also have the potential to impact methane clathrate reservoirs located under the ocean floor sediments. These trap large amounts of the greenhouse gas methane, which ocean warming has the potential to release. However, it is currently considered unlikely that gas clathrates (mostly methane) in subsea clathrates will lead to a "detectable departure from the emissions trajectory during this century".[41]:107

In 2004 the global inventory of ocean methane clathrates was estimated to occupy between one and five million cubic kilometres.[140]

CLIMATE ACTION

CLIMATE change-adoption,

What is climate change adaptation?

Climate change adaptation refers to actions that help reduce vulnerability to the current or expected impacts of climate change like weather extremes and hazards, sea-level rise, biodiversity loss, or food and water insecurity.

Many adaptation measures need to happen at the local level, so rural communities and cities have a big role to play. Such measures include planting crop varieties that are more resistant to drought and practicing regenerative agriculture, improving water storage and use, managing land to reduce wildfire risks, and building stronger defences against extreme weather like floods and heat waves.

However, adaptation also needs to be driven at the national and international levels. In addition to developing the policies needed to guide adaptation, governments need to look at large-scale measures such as strengthening or relocating infrastructure from coastal areas affected by sea-level rise, building infrastructure able to withstand more extreme weather conditions, enhancing early warning systems and access to disaster information, developing insurance mechanisms specific to climate-related threats, and creating new protections for wildlife and natural ecosystems.

Why do we need to adapt? And why is it so urgent?

Scientific studies show that the Earth is now about 1.1°C warmer than it was in the 1800s. This warming is causing widespread and rapid changes in our planet's atmosphere, ocean and ecosystems. As a result, weather and climate extremes are becoming more frequent in every region of the world.

According to climate models, without significant climate action, the world is headed for 2.5 to 2.9°C temperature rise above pre-industrial levels this century, which is well above the safety limits established by scientists.

With every fraction of a degree of warming, the impacts of climate change will become more frequent and more intense – and adaptation will become that much harder and more expensive for people and ecosystems.

The urgency is especially great for developing countries, which are already feeling the impacts of climate change and are particularly vulnerable due to a combination of factors, including their geographical and climatic conditions, their high dependence on natural resources, and their limited capacity to adapt to a changing climate. Adaptation is also particularly important for women and young children, older populations, ethnic minorities, Indigenous Peoples, refugees and displaced persons, who are shown to be disproportionately affected by climate change.

Even in very positive scenarios in which we manage to significantly and swiftly cut greenhouse gas emissions, climate change will continue to impact our world for decades to come because of the energy already trapped in the system. This means cutting down emissions is only one part of our response to the climate crisis: adaptation is needed to limit the impacts and safeguard people and nature.

What are the challenges related to climate change adaptation?

Efforts to adapt to the impacts of climate change face a number of significant challenges.

The first major bottleneck for adaptation action is the availability of and access to finance. In fact, the adaptation finance needs of developing countries are estimated to be 10 to 18 times larger than what is currently available from public sources.

Finance is needed to drive investment in a range of adaptation solutions, so countries can learn what works and scale up what is most effective. But it is also needed to empower communities – those on the frontlines of climate change – in locally-led, locally-appropriate action.

Another major challenge is information and knowledge gaps. Accurate climate data is not easily available in many developing countries – localized risk assessments often do not exist – and systems for monitoring, learning and evaluation of adaptation are still fragmented. Without these pieces of the puzzle, it is difficult for governments, communities and the private sector to plan effectively and make sound decisions on where to invest.

Finally, institutional and governance constraints are a major issue. Challenges of coordination among sectors and levels of government, and lack of specialized knowledge and experience – for example in realizing climate-risk informed planning and investments – are hindering effective adaptation in many countries.

What is the Global Goal on Adaptation?

The Global Goal on Adaptation, often referred to as "GGA", is a key component of the Paris Agreement. It commits all 196 Parties of the Paris Agreement to enhancing resilience, reducing vulnerability, and supporting adaptation actions.

Its inclusion in the Paris Agreement was significant because it underscores the equal importance of adapting to climate change alongside efforts to reduce emissions. It also recognizes the vulnerability of developing countries to climate impacts and encourages support for their adaptation efforts.

At COP28 in Dubai, as part of the Global Stocktake, world leaders took decisions on the GGA, now named the "UAE Framework for Global Climate Resilience." Countries agreed to global time-bound targets around specific themes and sectors – for example in areas such as water and sanitation, food and agriculture, and poverty eradication and livelihoods – as well as under what's called the "adaptation cycle," a global framework guiding countries on the steps necessary to plan for and implement adaptation.

These were important steps forward, however there is still a lot of work to be done to accelerate adaptation globally. The targets set need to be more detailed and a clear roadmap for increasing finance towards adaptation needs to be drawn. This includes realizing the goal of doubling adaptation finance by 2025. Developed countries must deliver pledged contributions to the Green Climate Fund, Adaptation Fund, the Least Developed Countries Fund and Special Climate Change Fund to support the world's most vulnerable countries. At the same time, all governments must find new innovative sources of finance, including mobilizing the private sector, which has historically favoured mitigation initiatives.

What are National Adaptation Plans and why do they matter?

National Adaptation Plans (NAPs) are comprehensive medium and long-term strategies that outline how a nation will adapt to the changing climate and reduce its vulnerability to climate-related risks. Often, countries will focus their NAPs on key sectors that contribute to their economy, food security and natural resources.

NAPs are a way for countries to prioritize their adaptation efforts, integrating climate considerations into their national policies and development plans, and mobilizing the required finance by supporting the development of effective financing strategies and directing investments.

NAPs are also crucial because they enable countries to systematically assess their vulnerability to climate change, identify adaptation needs and design effective strategies to build resilience.

Notably, these plans link closely to Nationally Determined Contributions (NDCs) and other national and sectoral policies and programmes.

What are some examples of climate adaptation around the world?

There are a great number of countries leading the way in climate change adaptation, many of them showing outsized ambition and innovation, despite limited resources.

In the Pacific, the small island state of Tuvalu has drawn on the best available science – and around 270,000 cubic meters of sand – to reclaim a 780m-long, 100m-wide strip of land to protect against sea level rise and storm waves beyond 2100. This is an important initiative for a low-lying atoll country comprised of only around 26 square kilometres of land.

Other countries such as Malawi and Pakistan are modernizing the capture and use of climate data and early warning systems, equipping communities, farmers and policy makers with the information they need to protect lives and livelihoods.

Cuba and Colombia are leading the way on nature-based approaches, restoring crucial ecosystems – mangroves, wetlands and more – to protect against floods and drought. In this process, Colombia is capitalising on the knowledge of its Indigenous Peoples, who have invaluable expertise in adapting to extreme environmental changes.

Bhutan, the world's first carbon-negative country, and Chad are among the world's Least Developed Countries (LDCs) to finalize National Adaptation Plans. The result of years of meticulous planning and rigorous consultation, the plans are crucial roadmaps for adaptation in the years ahead. In Bhutan's case, the plan is deeply rooted in the country's unique ethos of Gross National Happiness.

How does UNDP support countries on climate change adaptation?

For UNDP, adapting to climate change is inseparable from sustainable development and each one of the 17 Sustainable Development Goals. Adaptation is therefore a key pillar of UNDP's support to developing countries worldwide.

Today, UNDP is the largest service provider in the UN system on climate change adaptation with active projects targeting more than 164 million people across more than 90 countries, including 13 Small Island Developing States and 44 Least Developed Countries.

Since 2002, with finance via global funds such as the Green Climate Fund, Global Environment Facility and Adaptation Fund, and hand-in-hand with governments, UNDP has completed more than 173 adaptation projects across 79 countries. This work has contributed to building the resilience of millions of people worldwide. For example, more than 3 million people are now covered by enhanced climate information and early warning systems, more than 645,000 people are benefitting from climate-smart agricultural practices, and 473,000 people have improved access to water.

Vulnerability assessment –IPCC Framework (AR5 &AR6)

IPCC fifth assessment report: climate change 2014 - impacts, adaptation, and vulnerability (IPCC WGII AR5)

Source

Intergovernmental Panel on Climate Change (IPCC)

This document presents the Working Group II (WGII) contribution to the IPCC Fifth Assessment Report (AR5). It details the impacts of climate change to date, the future risks from a changing climate, and the opportunities for effective action to reduce risks. A total of 309 coordinating lead authors, lead authors, and review editors, drawn from 70 countries, were selected to produce the report. They enlisted the help of 436 contributing authors, and a total of 1,729 expert and government reviewers.

The report concludes that responding to climate change involves making choices about risks in a changing world. The nature of the risks of climate change is increasingly clear, though climate change will also continue to produce surprises. The report identifies vulnerable people, industries, and ecosystems around the world. It finds that risk from a changing climate comes from vulnerability (lack of preparedness) and exposure (people or assets in harm's way) overlapping with hazards (triggering climate events or trends). Each of these three components can be a target for smart actions to decrease risk.

Download

- View full summary for policymakers English
- View report by chapters English

Document links last validated on: 18 December 2019

Editors' recommendations

- IPCC Report: A changing climate creates pervasive risks but opportunities exist for effective responses
- Special report on managing the risks of extreme events and disasters to advance climate change adaptation (SREX)
- More about words into action implementation guide for local disaster risk reduction and resilience strategies

The **Sixth Assessment Report** (**AR6**) of the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) is the sixth in a series of reports which assess the available scientific information on climate change. Three Working Groups (WGI, II, and III) covered the following topics: The Physical Science Basis (WGI); Impacts, Adaptation and Vulnerability (WGII); Mitigation of Climate Change (WGIII). Of these, the first study was published in 2021, the second report February 2022, and the third in April 2022. The final synthesis report was finished in March 2023. It includes a summary for policymakers and was the basis for the 2023 United Nations Climate Change Conference (COP28) in Dubai.[1]

The first of the three working groups published its report on 9 August 2021, *Climate Change 2021: The Physical Science Basis*.[2][3] A total of 234 scientists from 66 countries contributed to this first working group (WGI) report.[4][5] The authors[6] built on more than 14,000 scientific papers to produce a 3,949-page report, which was then approved by 195 governments.[7] The Summary for Policymakers (SPM) document was drafted by scientists and agreed to line-by-line by the 195 governments in the IPCC during the five days leading up to 6 August 2021.[6]

In the report, there are guidelines for both responses in the near term and in the long-term. According to the report, the main source of the increase in global warming is due to the increase in CO_2 emissions, stating that it is likely or very likely to exceed 1.5 °C under higher emission scenarios.[8]

According to the WGI report, it is only possible to avoid warming of 1.5 °C (2.7 °F) or 2.0 °C (3.6 °F) if massive and immediate cuts in greenhouse gas emissions are made.[2] *The Guardian* described the report as "its starkest warning yet" of "major inevitable and irreversible climate changes",[9] a theme echoed by many newspapers[10] as well as political leaders and activists around the world.

Production

See also: Intergovernmental Panel on Climate Change § Assessment reports

In April 2016, at the 43rd session which took place in Nairobi, Kenya, the topics for three Special Reports (SR) and one methodology report on Greenhouse Gases (GHG) inventories in the AR6 assessment cycle were decided.[11][12] These reports were completed in the interim phase since the finalisation of the Fifth Assessment Report and the publication of results from the Sixth Assessment Report.

Structure

The sixth assessment report is made up of the reports of three working groups (WG I, II, and III) and a synthesis report which concluded the assessment in early 2023.[13]

- *The Physical Science Basis of Climate Change* in August 2021[14][15] (WGI contribution)
- *Impacts, Adaptation and Vulnerability* in February 2022 (WGII contribution)
- *Mitigation of Climate Change* in April 2022 (WGIII contribution)
- *Synthesis Report* in March 2023[16]

Geopolitics

[Geopolitics](#) has been included in [climate models](#) for the first time, in the form of five [Shared Socioeconomic Pathways](#): SSP1 "Taking the Green Road", SSP2 "Middle of the Road", SSP3 "A Rocky Road", SSP4 "A Road Divided", and SSP5 "Taking the Highway", which have been published in 2016.

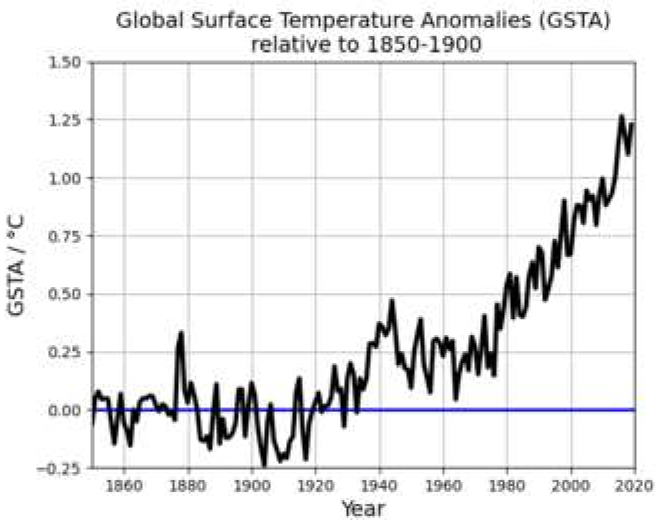
Those pathways assume that international cooperation and worldwide increase in GDP will facilitate adaptation to climate change. The geopolitical pathways served as one of the sources for the formation of the Shared Socioeconomic Pathways in the report among with other sources.[17]:1–98ff One of the assumptions is that enough GDP and technology derived from [fossil fuels](#) development will permit to adapt even to 5.0 °C (9.0 °F) temperature rise. Some experts assume, that while the odds for a worst-case scenario (5 °C) and the best base-case (1.5 °C) today seem lower, the most plausible outcome is around 3.0 °C (5.4 °F).[18]

Special reports during same assessment cycle

Sequence of release dates of special IPCC reports during the same assessment cycle:

- *[Special Report on Global Warming of 1.5 °C](#)* (SR15) in October 2018
  - *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* in May 2019
- *[Special Report on Climate Change and Land](#)* (SRCCL) in August 2019
- *[Special Report on the Ocean and Cryosphere in a Changing Climate](#)* (SROCC) in September 2019

Working Group 1 report (physical science basis)



Variation of annual observed [global average temperature](#) (1850–2019) relative to the 1850–1900 average (blue line), as reported in the Summary for Policymakers (SPM)[19]

A total of 234 scientists from 66 countries contributed to the first of three working group reports.[4][5] Working group 1 (WGI) published *Climate Change 2021: The Physical Science Basis*.[2][3] The report's authors[6] built on more than 14,000 scientific papers to produce a 3,949-page report, which was then approved by 195 governments.[7] The Summary for Policymakers (SPM) document was drafted by scientists and agreed to line-by-line by the 195 governments in the IPCC during the five days leading up to 6 August 2021.[8] It was published on Monday, 9 August 2021.

According to the report, it is only possible to avoid warming of 1.5 °C or 2 °C if massive and immediate cuts in [greenhouse gas emissions](#) are made.[2] In a front-page story, *[The Guardian](#)* described the report as "its starkest warning yet" of "major inevitable and irreversible climate changes",[9] a theme echoed by many newspapers around the world.[10]

The Technical Summary (TS) provides a level of detail between the Summary for Policymakers (SPM) and the full report. In addition, an interactive atlas was made "for a flexible spatial and temporal analysis of both data-driven climate change information and assessment findings in the report".[20]

Important findings of WG 1 report

The Working Group 1 (WGI) report, *Climate Change 2021: The Physical Science Basis* comprises thirteen chapters and is focused on the foundational consensus of the climate science behind the causes and effects of human greenhouse gas emissions. Compared with previous assessments, the report included much more detail on the [regional effects of climate change](#),[7] although more research is needed on [climate change in eastern and central North America](#).[21] [Sea-level rise](#) by 2100 is likely to be from half to one metre, but two to five metres is not ruled out, as [ice sheet](#) instability processes are still poorly understood.[21]

The report quantifies [climate sensitivity](#) as between 2.5 °C (4.5 °F) and 4.0 °C (7.2 °F) for each doubling of [carbon dioxide in the atmosphere](#),[7] while the best estimate is 3 °C.[22]:SPM-11 In all the represented Shared Socioeconomic Pathways the temperature reaches the 1.5 °C warming limit, at least for some period of time in the middle of the 21st century. However, [Joeri Rogelj](#), director of the [Grantham Institute](#) and a lead IPCC author, said that it is possible to completely avoid warming of 1.5 °C, but to achieve that the world would need to cut emissions by 50% by the year 2030 and by 100% by the year 2050. If the world does not begin to drastically cut emissions by the time of the next report of the IPCC, then it will no longer be possible to prevent 1.5 °C of warming.[23] SSP1-1.9 is a new pathway with a rather low radiative forcing of 1.9 W/m^2 in 2100 to model how people could keep warming below the 1.5 °C threshold. But, even in this scenario, the global temperature peaks at 1.6 °C in the years 2041–2060 and declines after.[21]

Shared Socioeconomic Pathways in the IPCC Sixth Assessment Report [24]:14

- v
- t
- e

SSP	Scenario	Estimated warming (2041–2060)	Estimated warming (2081–2100)	Very likely range in °C (2081–2100)
SSP1-1.9	very low GHG emissions: CO_2 emissions cut to net zero around 2050	1.6 °C	1.4 °C	1.0 – 1.8
SSP1-2.6	low GHG emissions: CO_2 emissions cut to net zero around 2075	1.7 °C	1.8 °C	1.3 – 2.4
SSP2-4.5	intermediate GHG emissions: CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2.0 °C	2.7 °C	2.1 – 3.5
SSP3-7.0	high GHG emissions: CO_2 emissions double by 2100	2.1 °C	3.6 °C	2.8 – 4.6
SSP5-8.5	very high GHG emissions: CO_2 emissions triple by 2075	2.4 °C	4.4 °C	3.3 – 5.7

The IPCC Sixth report did not estimate the likelihoods of the scenarios[24]:12 but a 2020 commentary described SSP5–8.5 as highly unlikely, SSP3–7.0 as unlikely, and SSP2–4.5 as likely.[25]

However, a report citing the above commentary shows that RCP8.5 is the best match to the cumulative emissions from 2005 to 2020. [26]

According to AR6 coauthors, the probable temperature rise is in the middle of the scenario spectrum that ranges from 1.5 °C to 5 °C, at about 3 °C at the end of the century.[18] It is likely that 1.5 °C will be reached before 2040.[21] The threats from compound impacts are rated higher than in previous IPCC reports.[21] The famous hockey stick graph has been extended.[21]

Extreme weather is expected to increase in line with temperature, and compound effects (such as heat and drought together) may impact more on society.[21] The report includes a major change from previous IPCC in the ability of scientists to attribute specific extreme weather events.[27]

The global carbon budget to keep below 1.5 °C is estimated at 500 billion more tonnes of greenhouse gas, which would need the whole world to be net zero before 2050.[6] Staying within this budget, if counting from the beginning of the year 2020, gives a 50% chance to stay below 1.5 °C. For having a 67% chance, the budget is 400 billion tonnes and for an 83% chance it is 300 billion tonnes.[22]:SPM-29f The report says that rapidly reducing methane emissions is very important, to make short-term gains to buy time for carbon dioxide emission cuts to take effect.[6]

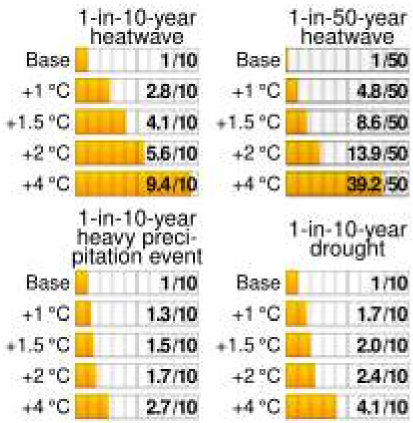
Any future warming will increase the occurrence of extreme weather events. Even in a 1.5 °C temperature rise there will be "an increasing occurrence of some extreme events unprecedented in the observational record". The likelihood of more rare events increases more.[22]:SPM-15

The frequency, and the intensity of such events will considerably increase with warming, as described in the following table:[22]:SPM-18

Increase in frequency and intensity of extreme events with global warming

Name of event	Climate in 1850–1900	1 °C warming	1.5 °C warming	2 °C warming	4 °C warming
1 in 10 years heatwave	Normal	2.8 times more often, 1.2 °C hotter	4.1 times more often, 1.9 °C hotter	5.6 times more often, 2.6 °C hotter	9.4 times more often, 5.1 °C hotter
1 in 50 years heatwave	Normal	4.8 times more often, 1.2 °C hotter	8.6 times more often, 2.0 °C hotter	13.9 times more often, 2.7 °C hotter	39.2 times more often, 5.3 °C hotter

1 in 10 years heavy precipitation event	Normal	1.3 times more often, 6.7% wetter	1.5 times more often, 10.5% wetter	1.7 times more often, 14.0% wetter	2.7 times more often, 30.2% wetter
1 in 10 years drought	Normal	1.7 times more often, 0.3 sd drier	2.0 times more often, 0.5 sd drier	2.4 times more often, 0.6 sd drier	4.1 times more often, 1.0 sd drier



Increase in frequency of extreme events with global warming in the Sixth Assessment Report's Summary for Policymakers[28]

Working Group 2 report (impacts, adaptation and vulnerability)

The second part of the report, a contribution of working group II (WGII), was published on 28 February 2022. Entitled *Climate Change 2022: Impacts, Adaptation & Vulnerability*, the full report is 3675 pages, plus a 37-page summary for policymakers.[29] It contains information on the impacts of climate change on nature and human activity.[30] Topics examined included biodiversity loss, migration, risks to urban and rural activities, human health, food security, water scarcity, and energy. It also assesses ways to address these risks and highlights how climate resilient development can be part of a larger shift towards sustainability.[31]

The report was published during the first week of the 2022 Russian invasion of Ukraine.[32] In the context of the conflict, the Ukrainian delegation connected the Russian aggression to the global dependency on oil, and a Russian official, Oleg Anisimov, apologized for the conflict despite the possible repercussions.[32][33] The Ukrainian delegation also called for news reporting on the war not to overshadow the WGII report.[34]

Important findings of WG 2 report

The report found that climate impacts are at the high end of previous estimates, with all parts of the world being affected.[30] At least 3.3 billion people,[34] about 40% of the world population, now fall into the most serious category of "highly vulnerable", with the worst effects in the developing world.[35] If emissions continue on their current path, Africa will lose 30% of its maize cultivation territory and 50% of its land cultivated for beans.[35] One billion people face flooding due to sea level rise.[34] Climate change, together with other factors, also increases the risk of infectious diseases outbreaks like the COVID-19 pandemic.[36] The report also cites evidence that China will pay the highest financial cost if the temperature continue to rise. The impacts will include food insecurity, water scarcity, flooding, especially in coastal areas where most of the population lives due to higher than average sea level rise, and more powerful cyclones. At some point part of the country may face wet-bulb temperatures higher than humans and other mammals can tolerate more than six hours.[37] Overall, the report identified 127 different negative impacts of climate change, some of them irreversible.[34]

People can protect themselves to some degree from the effects of climate change, which is known as adaptation. Overall, progress on adaptation has been made in all sectors and regions, although this progress is unevenly distributed and many initiatives prioritise immediate risks over longer-term transformational changes.[31] Still, there are feasible and effective adaptation options available and many adaption actions have benefits beyond reducing climate risks, including positive effects on the Sustainable Development Goals.[38]: Figure SPM.4 For example, the majority of current adaptations address water-related risks; adaptations like improved water management, water storage and irrigation reduce vulnerability and can also provide economic and ecological benefits.[38]: SPM.C.2.1 Similarly, adaptation actions like agroforestry, farm- and landscape diversification and urban agriculture can increase food availability, while at the same time improving sustainability.[38]: SPM.C.2.2

The report further highlighted the need for conservation in order to maintain biodiversity, and mitigate the effects of climate change. The report reads, "Recent analyses, drawing on a range of lines of evidence, suggest that maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems."[31] The report was critical of technological approaches to carbon dioxide removal, instead indicating that urbanisation could help drive adoption of mitigation strategies such as public transport and renewable energy.[35] The report also warns there are high risks associated with strategies such as solar radiation management; planting forests in unnatural locations; or "poorly implemented bioenergy, with or without carbon capture and storage".[38]: SPM-19, 20

In line with the emphasis on adaptation limits, the report also highlights loss and damage, meaning negative consequences of climate change that cannot be avoided through adaptation. The report states that such losses and damages are already widespread: droughts, floods and heatwaves are becoming more frequent, and a mass extinction is already underway.[30] Taking near-term actions to limit warming to below 1.5 °C would substantially reduce future losses and damages, but cannot eliminate them all.[31] Previously, rich countries have resisted taking responsibility for these losses.[35]

The report states that even a temporary overshoot of the 1.5 degree limit will lead to negative effects on humans and ecosystems. According to the report: "Depending on the magnitude and duration of overshoot, some impacts will cause release of additional greenhouse gases (medium confidence) and some will be irreversible, even if global warming is reduced (high confidence)".[38]:SPM-20 Climate resilient development will be more difficult if the global temperature will rise by 1.5 degrees above pre-industrial levels, while if it will rise by more than 2 degrees it will become impossible "in some regions and sub-regions".[38]:SPM-32,33,35

Although the report's outlook is bleak, its conclusion argues that there is still time to limit warming to 1.5 °C (2.7 °F) by drastic cuts to greenhouse gas emission, but such action must be taken immediately.[35] Moreover, climate resilient development can have both adaptation and mitigation benefits, but it requires international cooperation and collaborations with local communities and organisations.[38]:SPM-32,33,35

Working Group 3 report (mitigation of climate change)

The report was presented on 4 April 2022.[39] Some observers are worried that the conclusions might be watered down, considering the way the reports are adopted.[40] According to The Observer, some countries "have sought to make changes that would weaken the final warnings".[40]

Important findings of WG 3 report

The report uses some new approaches like to include different social aspects, the participation of youth, indigenous people, cities, businesses in the solution.[41]:SPM-2,3 It states that "International cooperation is a critical enabler for achieving ambitious climate change mitigation goals."[41]:SPM-62 For preventing global temperature from rising more than 2 degrees above the preindustrial level, international cooperation needs to be much stronger than now as many developing countries need support from other countries higher than present for strong climate action.[42]

According to the report demand side mitigation measures can reduce GHG emissions by 40–70% by the year 2050 compared to scenarios in which countries will fulfill its national pledges given before 2020. For being implemented successfully those measures should be linked "with improving basic wellbeing for all".[41]:SPM-44

The report concluded that in order to achieve net zero emissions, it is necessary to employ carbon dioxide removal technologies, stating "All global pathways that limit warming to 1.5 °C ... with no or limited overshoot, and those that limit warming to 2 °C... involve rapid and deep and in most cases immediate GHG emission reductions in all sectors. Modelled mitigation strategies to achieve these reductions include transitioning from fossil fuels without CCS to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demand side measures and improving efficiency, reducing non-CO_2 emissions, and deploying carbon dioxide removal (CDR) methods to counterbalance residual GHG emissions".[43][44] The report compares different methods of carbon dioxide removal (CDR) including agroforestry, reforestation, blue carbon management, restoration of peatland and others.[41]:SPM-47

Cities have great potential for reducing greenhouse gas emissions. With full scale mitigation action the emissions of cities could be brought down to near zero, with the worst-case scenario assuming a non-mitigatable remainder of 3 $GtCO_2$-eq. City planning, supporting mixed use of space, transit, walking, cycling and sharing vehicles can reduce urban emissions by 23–26%. Urban forests, lakes and other blue and green infrastructure can reduce emissions directly and indirectly (e.g. by reducing the energy demand for cooling).[45]

Buildings emitted 21% of global GHG emissions in the year 2019. 80–90% of their emissions can be cut while helping to achieve other Sustainable Development Goals. The report introduces a new scheme for reducing GHG emissions in buildings: SER = Sufficiency, Efficiency, Renewable. Sufficiency measures do not need very complex technology, energy supply, maintenance or replacement during the life of the building. Those include, natural ventilation, green roofs, white walls, mixed use of spaces, collective use of devices etc.[46] Reducing GHG emissions from buildings is linked to sharing economy and circular economy.[47]

The IPCC found that decent living standards could be achieved using less energy than prior consensus assumed. According to the report for reaching well being for all, the required energy consumption is "between 20 and 50 GJ cap-1 yr-1 depending on context." More equitable income distribution can lower emissions. Mitigation pathways based on low demand and high efficiency can achieve decent living standards and well being for all. Pathways based on reducing consumption, involving sustainable development have less negative outcomes than pathways based on high consumption and narrow mitigation. According to table TS30, narrow mitigation can increase habitat loss by 600%, while avoiding habitat degradation by around 95%. Mitigation with sustainable development did not harm forest cover and biodiversity.[48]

The report mentions some improvement in global climate action. For example, the rate of deforestation slowed after 2010 and the total forest cover increased in the latest years due to reforestation in Europe, Asia and North America.[49]

Reactions to all three working group reports

In science

The publication of the Working Group 1 report in 2021 was during the Northern Hemisphere summer, where there was much extreme weather, such as a Western North America heat wave, flooding in Europe, extreme rainfall in India and China, and wildfires in several countries.[4][50] Some scientists are describing these extreme weather events as clear gaps in the models used for writing the report, with the lived experience proving more severe than the consensus science.[50][51]

In politics

After publication of the Working Group 1 report, EU Vice President Frans Timmermans said that it is not too late to prevent runaway climate change.[52] UK Prime Minister Boris Johnson said that the next decade will be pivotal to the future of the planet.[53]

Rick Spinrad, administrator of the US's National Oceanic and Atmospheric Administration, stated that his agency "will use the new insights from this IPCC report to inform the work it does with communities to prepare for, respond to, and adapt to climate change".[54]

The United States special presidential envoy for climate, John Kerry, said about the Working Group 2 report: "We have seen the increase in climate-fuelled extreme events, and the damage that is left behind – lives lost and livelihoods ruined. The question at this point is not whether we can altogether avoid the crisis – it is whether we can avoid the worst consequences."[30]

NGOs and activists

Swedish climate activist Greta Thunberg said that the Working Group 1 report "confirms what we already know from thousands [of] previous studies and reports – that we are in an emergency".[55]

Environmentalist Inger Andersen commented: "Nature can be our saviour ... but only if we save it first."[35]

In media

In a front-page story, dedicated to the report *The Guardian* described the Working Group 1 report as the "starkest warning yet" of "major inevitable and irreversible climate changes".[9][56] This message was echoed by many media channels after the release of the report.[10]

The Working Group 3 report found that there is no evidence that sustainable development requires fossil fuels.[57] Climate journalist Amy Westervelt reacting to the report, described this finding as one of the most radical, debunking a common refrain by energy poverty advocates, that development requires use of fossil fuels.[57]

From the United Nations

The Secretary-General of the UN, António Guterres, called the report of Working Group 1 a "code red for humanity".[58] Responding to the Working Group 2 report, he called it "an atlas of human suffering and a damning indictment of failed climate leadership"[30] and "the facts are undeniable ... the world's biggest polluters are guilty of arson of our only home."[59] He also said that the report of Working Group 3 described "litany of broken climate promises [by policy makers]" and in his remarks called for more action, saying "Climate activists are sometimes depicted as dangerous radicals. But, the truly dangerous radicals are the countries that are increasing the production of fossil fuels."[60]

Synthesis report for all three working group reports

The synthesis report which summarises the entire document was finalised at the 58th plenary meeting of the panel at Interlaken in March 2023 and was published on 20 March 2023. It includes a summary for policymakers and was the basis for the 2023 United Nations Climate Change Conference (COP28) in Dubai.[1]

In the report, there are guidelines for both responses in the near term and in the long-term. According to the report, the main source of the increase in global warming is due to the increase in CO_2 emissions, stating that it is likely or very likely to exceed 1.5 °C under higher emission scenarios.[8]

The panel published a longer report,[61] a summary for policymakers[62] a presentation[63] and a short "Headline Statements" document.[64] Some key example *headline statements* include:

- "Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals."
- "Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5°C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards (*high confidence*). Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years (*high confidence*)."
- "Climate change is a threat to human well-being and planetary health (*very high confidence*). There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (*very high confidence*)."

Society and culture

Leaks

During the preparation of the three main AR6 reports, a small group of scientists leaked some information on the results of Working Group III (Mitigation of Climate Change) through the organization Scientist Rebellion. As governments can change the summaries for policymakers (SPM) for IPCC reports, the scientists were afraid that politicians might dilute this information in the summary. According to the leaked information, humanity should cut GHG emissions by 50% by 2030 and completely by 2050 in order to limit warming to 1.5 °C (2.7 °F). These efforts require strong changes in lifestyle and economy.[65][56]

Lack of participation from Global South scholars

Like other major international scientific processes, the IPCC has been accused of not sufficiently including scholars from the Global South. For example, some aspects of the production can prevent African scholars from participating, such as publication requirements and being an expert reviewer before joining the panel of contributors.[66]

Choices for climate action: A review of the multiple roles individuals play

Author links open overlay panelSam Hampton [1] [2], Lorraine Whitmarsh [1]
Show more

https://doi.org/10.1016/j.oneear.2023.08.006Get rights and content

Summary

Tackling climate change requires significant behavior change to reduce emissions, yet the scale required is far from being achieved. Behaviors are influenced by psychological characteristics, social and cultural norms, material and spatial environments, and political conventions. Much social scientific debate continues to be characterized by calls for *either* individual *or* system change, but a more cross-cutting perspective to understand various factors that can enable and accelerate pro-environmental choices is needed. This review provides an interdisciplinary synthesis of evidence on the potential and limitations of individual choice to mitigate climate change. We identify six domains of individual choice for climate action (food, energy, transport, shopping, influence, and citizenship). We find that individual, social, physical, and political factors combine to shape low-carbon choices but in ways specific to each domain, demanding different responses from policy-makers. Effective climate action requires a mix of interventions which address the multiple roles played by individuals: structural change by governments ("upstream" interventions), businesses and local authorities making sustainable options more available and attractive ("midstream"), and informational measures to shape individuals' decision-making ("downstream").

Introduction

Aiming to limit global temperature rise to less than 2°C, the European Union, United Kingdom, and United States have committed to achieving net-zero emissions by 2050, while China is aiming for 2060. Meeting these ambitious targets will require changes to everyday practices and lifestyles, including reducing flying and driving, decreasing red meat and dairy products in diets, and adopting low-carbon technologies. While there is an increase in some pro-environmental behaviors (e.g., recycling) in many countries, most of the behavior changes required are not yet happening.[1] Those with the largest carbon footprints will need to make the most substantial behavioral changes, and the distribution of individual impacts is highly uneven.[2] Besides changes to *consumption* behaviors, individuals can take climate action to indirectly cut emissions through activities such as influencing others, making professional choices, voting, or protesting.[3]

The choices made by individuals will have a critical bearing on global efforts to address climate change. However, individual choices are influenced by a wide range of factors, and many everyday behaviors are subject to habit, rather than deliberative choice.[4] Our behaviors are influenced by psychological characteristics, social and cultural norms, material and spatial environments, and political conventions. The ways in which these factors combine create conditions that either *constrain* or *enable* the translation of individual choices into sustained low-carbon lifestyles and routines.

There is a substantial and growing body of work on the behaviors and choices needed to deliver radical carbon emissions.[5] Some of this work has been subject to critique, however, for its apparent tendency to over-emphasize the need for individual behavior change without adequately acknowledging or addressing those structures and systems that embed the consumption of fossil fuels into everyday life, constrain individual agency, and create barriers to low-carbon lifestyles.[6] Such debates reflect the philosophical tussle between structure and agency, which is as old as social science itself.[7,8] But there is a danger that academic exchanges create theoretical and methodological schisms that can serve to confuse and even deter those outside social scientific niches, such as policy-makers.[9] In the absence of a comprehensive understanding of what can influence pro-environmental choices, and in light of the escalating climate emergency, there is a need for more philosophically agnostic approaches that synthesize evidence across the social sciences on the potential for, and limits to, behavior change to mitigate climate change.

In this review, we address this need by gathering and presenting a wide range of evidence in a coherent and accessible way for audiences within and outside of the academic social sciences. It draws on evidence spanning psychology, sociology, geography, and interdisciplinary climate research, but does not follow a systematic review methodology. Instead, our aim was to construct an account of the full breadth of climate choices using illustrative examples that help the reader to navigate a complex and expanding body of research. Reflecting the evidence base, these are somewhat skewed toward Europe and North America, but where possible we include examples from elsewhere. We first identify six major "domains" of choice. Four of these represent the key sources of individual and household greenhouse gas (GHG) emissions: energy, transportation, diet, and the consumption of other goods and services (termed "shopping" as shorthand). The other two domains concern those sets of choices that have important, but indirect, impacts on climate mitigation: the ability to influence others as a family member, social agent, and organizational participant; and civic activities, such as voting. We further map out combinations of psychological, socio-cultural, material, and political factors that can help to foster low-carbon choices, and also those in which incumbent structures create barriers to individuals seeking sustainable lifestyles. In order to enable and accelerate more sustainable choices, a mix of upstream (e.g., structural), midstream (e.g., choice environment), and downstream (e.g., informational) interventions are required. This review contributes new heuristic frameworks to explain the scope, potential, and limitations of individual choice for climate action.

Choosing climate: Understanding the potential of choice

In recent years there has been much debate over who should bear responsibility for climate change. Since the advent of ecological footprint, there has been substantial effort to quantify the climate impacts of different entities, including corporations,[10] territories,[11] households,[12] and individuals.[13] Around two-thirds of GHG emissions can be linked to household consumption, amounting to a global average of around 6 tonnes of carbon dioxide equivalent per person.[14] In advanced liberal economies, climate policy has hitherto been focused on maximizing opportunities for emissions reductions that have minimal impact on individuals. The UK government for instance, boasts of a 47.3% reduction in emissions since 1990,[15] thanks to the widespread deployment of renewable electricity generation and the improved efficiency of appliances and vehicles. However, its statutory advisors on climate policy, the Climate Change Committee, have highlighted the need for substantially greater social engagement on emissions reduction if climate targets are to be met.[16]

For individuals, the major activities that generate emissions involve transport and mobility; the use of energy in the home for space heating, hot water, and running appliances; food and diets; and the consumption of goods and services. Reviewing studies that quantify the mitigation potential of pro-environmental behaviors, Ivanova and colleagues compiled evidence across each of these activity domains.[14] Their findings show that there is considerable heterogeneity in the reduction potential of behaviors across contexts. For transport choices, they find that the greatest potential for emissions reductions is from living car-free, shifting to battery electric vehicles, taking one less long-haul flight, and shifting to public transport. The most impactful energy-related decisions include installing renewable electricity generation, renovating homes to be more energy efficient, and switching to a heat pump or other renewable heating system. Food-related choices include reducing meat consumption (especially adopting a vegan diet) and improving the efficiency of cooking equipment. Other pro-climate consumption choices include not having pets and buying services from the sharing economy.

A plethora of tools have been created to help individuals estimate their own carbon footprints, sponsored by governments,[17,18] global charities,[19] and corporations.[20] These are intended to enable individuals to learn about the impacts of their own behaviors, the unequal distribution of footprints within and between countries,[2] and help make more informed, sustainable choices. Certainly, there is evidence that individuals' knowledge and awareness of their contribution to climate change is limited,[21] that they tend to overestimate the contribution of waste behaviors (e.g., recycling), and underestimate the contribution of diet and air travel.[22] Although research has consistently found weak causal links between the provision of information about climate impacts and more sustainable consumption choices,[5,23] the *way* in which information is delivered (content, timing, context, type of messenger) is crucial.[24] Moreover, there are multiple forms of knowledge (e.g., action-related, effectiveness knowledge[25]) that play a part in shaping environmental behaviors, besides scientific knowledge about the impacts of certain activities.

The rationale for creating tools to raise awareness among individuals has been subject to further criticism on the basis that by placing the onus on individuals, attention is deflected from the principal culprits of climate change. The Carbon Disclosure Project attributes responsibility for 70% of global GHG emissions to just 100 companies,[26] while a widely read blog article from 2020 criticizes the concept of the carbon footprint, declaring it a "sham … intended to manipulate your thinking about one of the greatest environmental threats of our time."[27] Clearly, the role of individual action on climate is subject to disagreement, and as global GHG emissions continue to rise, the degree to which individuals should take responsibility for climate action has become a mainstream debate.

A further criticism of emissions calculators is that individuals are reduced to their role as *consumers*. Carbon footprints typically quantify the emissions associated with the consumption of energy, transport fuel, food, and other goods, providing users with an estimate of their personal impact alongside tips for making lower-carbon choices and appeals such as "it's time to go on a low-carbon diet."[27] But individuals are much more than consumers. They are also family and community members, workers and professionals, and citizens and voters.[3] Several academic researchers have sought to build the case for greater public discourse on the topic of climate change, not just in politics and the media, but in everyday conversations at home and among social networks.[28,29] Climate scientist Katherine Hayhoe's TED talk titled "The most important thing you can due to fight climate change: talk about it," has been viewed over 4 million times, while the popular movie *Don't Look Up* was released alongside guidance for individual action spanning multiple roles.[30]

Individuals can also help to address climate change as citizens: voting, protesting, and lobbying for change. Some climate scientists are leading by example by taking direct action.[31] Whereas the link between knowledge of climate change and sustainable consumption choices is weak, evidence from Germany indicates that increased environmental awareness *has* translated into strong pressure on political actors, as a result of changed voter behavior.[32] Considering the activities of individuals in roles other than as consumers helps to shift the focus beyond the comparatively narrow framing of choice and agency that is encouraged by a focus on individual carbon footprints.[33] Whereas an emphasis on personal impacts can engender feelings of guilt and powerlessness,[34] focusing on *influence* and *climate citizenship* can foster more constructive, empowering associations with climate change. Figure 1 represents the six major domains of individual choice for climate action and identifies some of the most impactful behaviors.

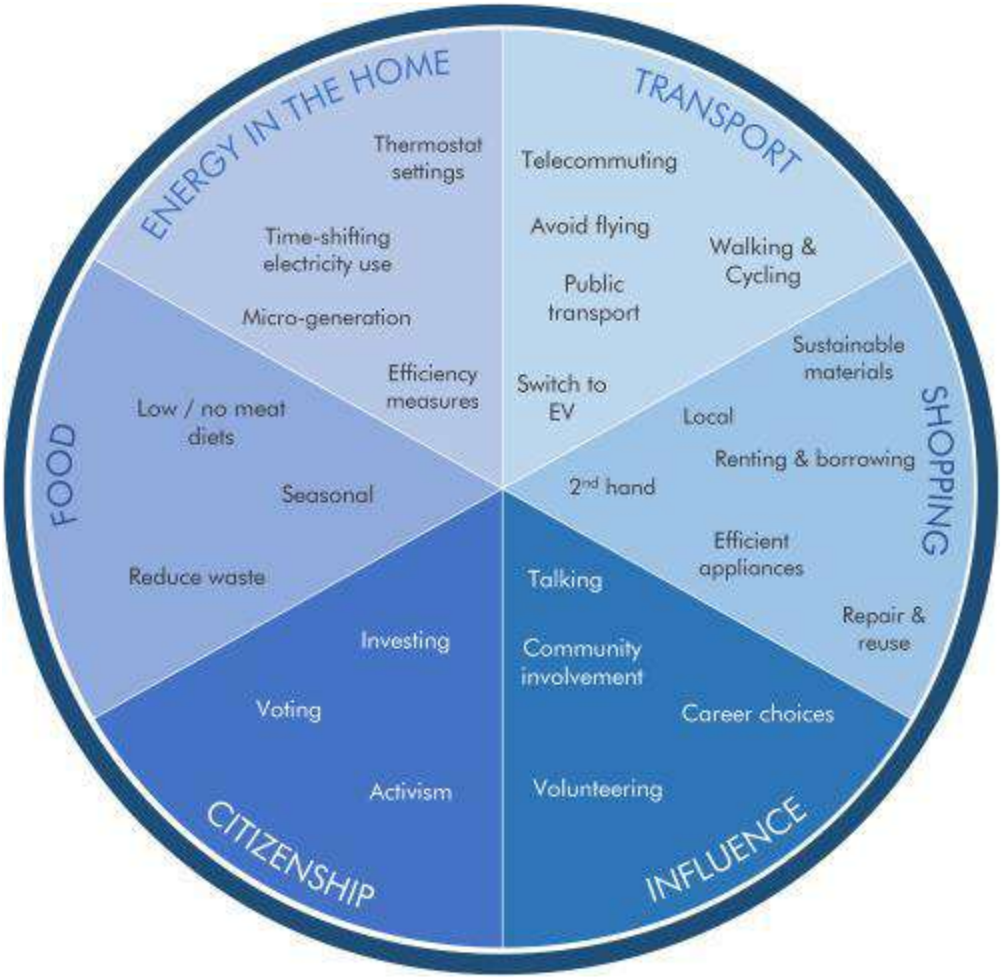


Figure 1. The six domains of choice for climate action

Food, energy, transport, and shopping represent direct emissions-related choices and constitute the majority of individual carbon footprints. Influence and citizenship are important, indirect domains of choice that have a bearing on climate change. Examples of key choices within each are represented.

Influences on individual choice capabilities

Human behavior is subject to a variety of influences, and a plethora of theoretical frameworks have been developed to understand how behaviors and habits become established, entrenched, changed, and discontinued.[35,36,37,38] These models tend to distinguish between intrinsic (values, personality traits, and abilities) and extrinsic (norms, meanings, and material and political structures) influences, and conventionally, psychologists have focused their efforts on understanding the former category.[5] Understanding the distribution and strength of these influences is crucial for those seeking to encourage pro-environmental behavior change. However, empirical and theoretical research has shown that the distinction between intrinsic and extrinsic influences is often blurred. For instance, we know that family dynamics[39,40] and wealth[41] are important predictors of an individual's environmental behaviors, but neither can easily be categorized as either internal or external factors. Alongside the emergence of environmental psychology as a discipline in its own right, there have been calls to move beyond the simple distinction between individual (intrinsic) and structural (extrinsic) factors, to distinguish different types of influence.[5,42]

Several more integrative, interdisciplinary frameworks have been created, but none have been widely adopted in either climate research or policy-making. Notable examples include the concept of carbon capability,[33] the individual-social-material (ISM) framework,[43] and the capability, opportunity, motivation-behavior model (COM-B).[44] Each approach balances individual and structural influences and combines these with an appreciation of their context and inter-connectedness. Inspired by these models, Figure 2 identifies four main sources of influence and provides examples of factors that typically enable, or place constraints on, individual choice.

Influences on climate choice capabilities		Examples of choice enablers	Common constraints on individual agency	Indicative references
Individual	Psychological	Pro-environmental values; personality traits; digital skills	Resistance to change, perceived lack of agency	Brick & Lewis, 2016[45] Marshall et al. 2019[46]
	Demographic	Education; member of socially advantaged groups (younger, ethnic majority, male, heterosexual)	Disability; member of disadvantaged groups (ethnic minority, female, sexuality)	Wisner, 2010[47] Latter, 2022[48] Lovelock 2010[49]
Social	Cultural	Low-carbon norms; social pressure to decarbonise; positive role models; aspirational environmentalism	High-consumption norms; consumption-linked identity; negative images of environmentalism	Whitmarsh et al. 2017[50] Nielsen et al. 2021[1]
	Social capital	Prevalence of community organisations; strength of social networks	Community deprivation; loneliness	Jones & Clark 2014[51] Sharp et al. 2011[52]
Physical	Material	Income and wealth; asset ownership; availability of green products	Renting housing; poor infrastructure; poverty; limited consumer choices	Huebner et al. 2015[53] McKenna et al. 2022[54]
	Spatial	Access to infrastructure (active transport, electrical grid); renewable potential (sunny/windy)	Isolation; limited infrastructure; planning constraints (heritage buildings); extreme weather	Gill & Moeller 2018[55] Goldthau et al. 2020[56]
Political	Governance & Democracy	Locally devolved powers; multiple channels for engagement; citizens assemblies; right to protest; freedom of press, transparency; subsidies available	Excessively bureaucratic, technocratic, or autocratic systems; lack of transparency and accountability	Niemeyer, 2013[57] Fiorino, 2018[58] Climate Assembly UK, 2020[59]

1. Download: Download high-res image (1MB)
2. Download: Download full-size image

Figure 2. Influences to enable and constrain climate choices can be divided into individual, social, physical, and political categories
Examples of choice enablers and common constraints are provided alongside indicative references.[45,46,47,48,49,50,51,52,53,54,55,56,57,58,59]

These diverse sources of influence do not work in isolation, and when combined they have uneven effects on individuals and their behavior. For instance, the uptake of urban cycling is predicted by age and gender,[60] but is also strongly influenced by the availability of (physical) low-carbon transport infrastructure, which is in turn moderated by economic and political factors. How these influences combine also has different effects with respect to the six domains of climate choice. The remainder of this section highlights the complex interplay of influences on individual choice, drawing on systematic reviews and meta-analyses where available, and providing illustrative examples from different geographical and behavioral contexts.

Food and diet choices

Compared with other domains, food and diet choices are relatively frequent and situational and are highly mediated by social, cultural, and health-related norms.[61] Individual choices are said to bear relatively low behavioral costs and few long-term consequences for the decision-maker (although their cumulative effects are significant).[62] Economic, spatial, and political factors influence the options available for dietary choices, such as the availability, range, and price of plant-based foods.[63,64,65] However, several systematic reviews and other assessments of food choice determinants conclude that individual and social factors are the strongest predictors of behavior.[66,67,68,69] Despite the relative degree of agency in this domain, individuals are known to be resistant to changing their diets, and various psychological barriers have been identified that help to explain this. These include lack of knowledge (or outright denial) of evidence linking foodstuffs to GHG emissions, as well as conflicting priorities or limited resources (financial, time).[70]

Diets are strongly influenced by social and cultural norms and traditions.[67,69] Meat consumption is significantly influenced by gender,[71] and at least in some cultures is associated with masculinity, while vegetarianism connotes femininity and weakness.[72] Internationally, the number of people following a vegetarian diet varies widely. India has the highest proportion (22%) and absolute population of vegetarians, while Serbia, Hungary, and Russia are the top three meat-eating countries.[73] Practical barriers can compound socio-cultural norms: where vegetarianism is rare, it can be difficult to find sufficient meat-free options in cafés and restaurants. Skill and know-how are also important prerequisites for more climate-friendly food practices. Cooking varied, tasty vegetarian meals can demand new skillsets among people living in cultures where meat dishes are more traditional, while flexibility and creativity are needed to minimize household food waste.[74]

Influences on transport and mobility choices

A meta-analysis of psychological and behavioral determinants of transport choices found the strongest predictors to be intentions, habits, and past experiences.[75] However, material and spatial factors such as the cost and availability of public transport and electric vehicles (EVs), active travel infrastructure, and urban density and design set the context and boundaries for individual choice. The decision to adopt an EV is simply not available to many low-income households with little access to charging infrastructure.[76,77] Flying is strongly correlated with income.[78] A systematic review-of-reviews found that individual, social, and infrastructural factors unambiguously influence mode-choice, but that urban form explains the most variation in transport behaviors.[79] Supporting this observation, international evidence has consistently shown that the biggest barrier to individuals choosing to walk or cycle more is the perception of safety.[80,81,82] The provision of safe, segregated infrastructure is the most significant predictor of active travel in urban areas across the United States.[83]

Although physical factors dominate, social and cultural influences also impact low-carbon travel behaviors. The uptake of cycling is lower among women and ethnic minorities,[84] while in some countries such as the United States, the use of public transport such as urban buses can be stigmatized.[85] Urban planning and design for active travel is often politically contentious. For instance, in response to climate change, many urban municipalities in the United Kingdom have introduced low-traffic neighborhoods and other controls on car access, with unforeseen controversy and even reports of violence among residents.[86] The reallocation of road space became a key political issue for local elections in the United Kingdom in 2022, and polling in London found that support and opposition was split according to political opinion.[86]

Energy consumption in the home

Domestic energy use is most strongly predicted by building characteristics such as fabric efficiency, dwelling area, and heating system type.[53,87] Socio-demographic factors including number of occupants, age, and income have also been found to predict annual consumption,[87,88] although the strength of these variables is inconsistent across studies.[89] Nonetheless, individual choices *can* have a significant impact on domestic energy usage, and a large-scale study from the United Kingdom demonstrated that everyday conservation behaviors such as setting lower set-point temperatures, using warm clothes in cold weather, and switching off lights significantly predicted gas and electricity consumption.[54] Psychological factors are influential, particularly with respect to action-related and effectiveness knowledge.[25] Householders struggle to estimate their overall energy use[90] and to identify the greatest opportunities for conservation,[91] while many (particularly older people) find heating controls confusing and difficult to use.[92]

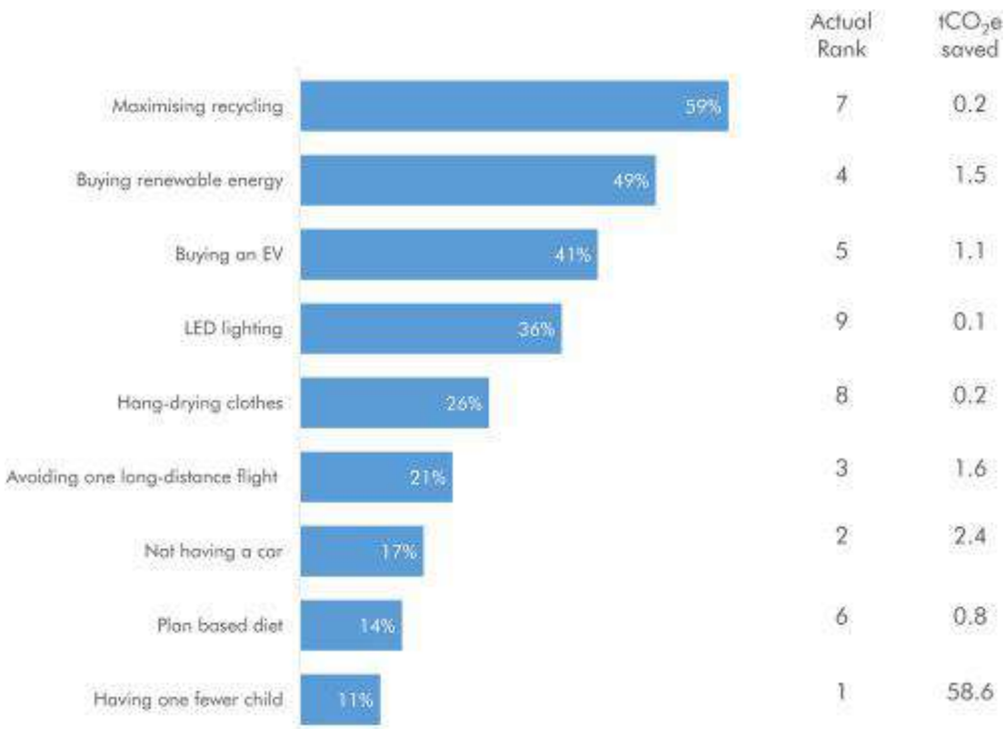
Given the significance of building characteristics, non-habitual choices have an important influence on emissions. These include the installation of efficiency measures such as insulation and glazing, as well as investments in rooftop solar arrays and low-carbon heating systems (e.g., heat pumps). Here, household income and tenure are key variables. Income and home ownership correspond with higher energy use; however, access to capital also boosts a household's capability to invest in one-off, impactful measures.[89] In rented properties, landlords lack the incentive to invest in efficiency or renewable technologies, as it is tenants who typically pay energy bills. Tenants are reluctant to invest in property upgrades or may be contractually prevented from doing so. This "split-incentive" problem limits energy-related choice capabilities for millions of householders,[93] especially in countries where home ownership is relatively low, such as Germany[94] and Japan.[95]

Consumption of goods and services

Non-food consumption involves myriad behaviors that range from buying clothes, pets, and household goods, to services such as education. As such, there are no systematic evidence reviews spanning all consumption or shopping behaviors. While income is the strongest predictor of overall consumption, reviews of sustainable consumption find that social and individual factors are significant influences. Predictors of shopping behaviors depend on the products and services in question.[14] For instance, a systematic review of sustainable fashion consumption found social norms, knowledge, and values to be key drivers,[96] while adoption of "sharing economy" activities are predicted by perceptions of control, injunctive norms (perceptions of peer-approval), platform trustworthiness, and risk.[97,98]

Social and economic context is important too. A representative survey of individuals in the United Kingdom and Brazil in 2019 asked respondents a series of questions about buying habits.[50] Environmental concern was found to be higher in Brazil than in the United Kingdom, and individuals there were more likely to avoid buying new things and buy items with less packaging. However, these social norms are influenced in turn by material and economic factors: in Brazil, items with less packaging are often cheaper, whereas this is not the case in the United Kingdom.

The carbon impacts of shopping behaviors can hinder climate-conscious choices. Emissions "embodied" in goods and services are less visible to consumers than those associated with driving fossil fueled vehicles, for example, and carbon labeling on products is not widespread. This is one reason why awareness of the carbon emissions associated with consumption behaviors is relatively low. In fact, the most popular and best supported pro-environmental behaviors tend to have limited potential for emissions reductions.[1,33] Figure 3 shows results from a global survey demonstrating a mismatch between what individuals perceive to be the most effective choices for reducing emissions and actual impacts.



1. Download: Download high-res image (180KB)
2. Download: Download full-size image

Figure 3. Choices for climate: Perception vs. reality

Survey participants were asked “From this list of options, which three do you think would most reduce the greenhouse gas emissions of an individual living in one of the world’s richer countries?” Respondents tend to overestimate the significance of recycling. Source: Ipsos, 2021, n = 21,011.[1]

Influencing others

In one conceptual model of “carbon capability,” the ability to influence others is posited as the pinnacle activity for individuals seeking to take climate action.[99] The ability of individuals to influence others on climate change varies according to the different roles and capacities they play in different contexts, although evidence on what predicts their capacity to influence others is limited. In personal relationships (e.g., friends, family), personality traits are likely to be important, and we know that openness, conscientiousness, and extraversion predict pro-environmental attitudes and behaviors.[45,100] In a professional context, some individuals (e.g., in customer-facing, communications, human-resources, or leadership roles) can leverage greater influence over others than those in other roles.[3,101,102] In this context, personality traits can again be important: conscientiousness and agreeableness are significant predictors of ethical leadership behaviors, for instance.[103] However, the presence of human and social capital,[104,105] organizational norms and values,[106] and the strength of network ties[107] all influence the ability of leaders to effect change.

Katherine Hayhoe[29] and others[28] have argued, when it comes to influencing others on climate, talking to people within and beyond one’s immediate social circles is important. In the United States, those with higher risk perceptions and knowledge of global warming are more likely to talk with family and friends about climate change.[108] Holding climate conversations appears to be one of the more straightforward choices an individual might make. But social discourse is mediated by politics, norms, and complex, context-specific interpersonal dynamics. For instance, climate change is becoming increasingly polarized in many countries[109,110] and on social media,[111] and many commentators have expressed concern that climate change is being dragged into so called “culture wars” that are characterized by divergent views along social, political, and demographic lines.[112,113]

Climate citizenship

Like the ability to influence others, the willingness to take part in civic activity such as voting, direct action, and investing money in environmentally sustainable funds and pensions is influenced to a great extent by individual factors. Individuals who attach personal meaning to social and political events or who exhibit high openness traits are more likely to engage in political activism,[114,115,116] while participation in *Fridays for Future* climate strikes among Swiss students was predicted by low trust in governments, high trust in climate scientists, and faith in the success of protest for achieving change.[117,118] General voting behavior is linked with personality characteristics and socio-demographic variables, although studies from the United Kingdom,[119] Nigeria,[120] and across the EU[121] highlight how the weight of these vary in different contexts. More specific to climate citizenship, support for climate policies in the United States is unsurprisingly predicted by beliefs and attitudes toward global warming, but Republican voters who support climate action are more influenced by injunctive norms and risk perceptions than Democrats.[122] In the United Kingdom, women are slightly more supportive of net-zero policies than men; older age groups have higher support for transport and consumption policies such as low-traffic neighborhoods, frequent flyer levies, and carbon taxes, while younger age groups favor policies that encourage EV uptake and dietary change.[123] It is often asserted that motivated reasoning (biased information processing in accordance with prevailing beliefs) lies behind attitudes to climate change and policy support, even among individuals with high levels of scientific knowledge.[124,125] However, other studies have argued that the evidence for motivated reasoning is relatively weak,[126,127] and there is a need for further empirical research to inform interventions to address polarization.[128]

There is a tendency in research that models socio-technical pathways to a more sustainable future, to emphasize the need for community-led activity at the local level, highlighting the multiple benefits associated with climate-oriented transitions.[129,130,131] Examples include community ownership of renewable energy assets, car sharing, local farming cooperatives, and peer-to-peer energy trading.[132] Each of these relies on abundant social capital, which is a product of multifaceted economic, social, and political variables.[133]

Last, political regimes and governance arrangements have a direct bearing on an individual's potential to be a good climate citizen. Autocratic regimes often prevent voting and place severe restrictions on protest, while the ability of individuals to contribute to political and policy-making processes varies significantly across democracies. In many liberal democracies, there has been an increase in climate activism in recent years. High-profile examples of direct action such as transport disruption[134] and protests in art galleries[135] have helped to keep climate change prominent in news media and public discourse. However, freedom to protest in many countries remains highly limited and in the United Kingdom, the 2022 Police, Crime, Sentencing, and Courts Act increased police powers to break-up and prevent protests, largely in response to climate activism. Nonetheless, even in authoritarian regimes, activism can influence politics and policy,[136] as demonstrated by the easing of COVID-19 restrictions in China following protests in late 2022.[137]

Closing the gap: Enabling choices for climate action

To achieve net-zero emissions, there is a need for transformation in each of the six domains of climate-related activity. This section outlines the type and scale of change needed to enable individuals to make choices for climate action. We identify areas of everyday life where attitudes, motivations, and social norms are becoming more environmentally oriented, and physical factors are increasingly enabling climate action. Domains of choice where high-emissions behaviors remain entrenched and resistant to change are also highlighted.

Food and diet choices

As they are, Western diets are not compatible with a stable climate. It has been estimated that the food-related emissions of those consuming Western diets could be reduced by up to 40% through individual choices such as reducing meat consumption and reducing food waste.[138] Neither are they healthy: in the United Kingdom, individuals eat more than twice the amount of meat considered safe.[139] However, recent polling there found strong support for substituting red for white meat, and reducing overall meat consumption and food waste.[140] Given the influence of individual and social factors on dietary behaviors, a key challenge is to shift the social and psychological norms that embed food choices into everyday life.

There is a growing body of research focused on how to encourage more climate-friendly food choices.[141] Two independent meta-analyses have found choice architecture interventions (or "nudges") have significant effects in the food domain,[62,142] although approaches are context specific. For instance in restaurant settings, effective social norm interventions include encouraging the use of "doggy bags"[143] for reducing food waste, and "dynamic norm" messages that indicate that other people are reducing meat in their diets can also help to promote more sustainable food choices.[144] On the other hand, a systematic review found mixed results for different interventions designed to reduce meat consumption,[145] and a trial of 59 interventions found that while information provision was effective at changing choices in *virtual* environments, this did not translate into *actual* diet behaviors.[146] Effect sizes are more robust when it comes to changing defaults such as reducing portion sizes[147] and serving vegetarian meals at catered events.[148] However, as a behavioral intervention, changing defaults risks consumer backlash, especially where there is insufficient trust, or where the choice-architect's motivations are unclear or unsupported.[149,150] Nonetheless, public acceptance of low-meat alternatives appears to be growing in many countries[151,152] and in different contexts: even Burger King is experimenting with changing its default menu options to plant-based burgers.[153]

One barrier to individuals making climate-conscious food choices is the lack of awareness relating to the carbon impacts of foodstuffs.[154,155] Carbon labeling for food items attracted significant interest from grocery retailers in the 2000s,[156] but progress has been limited by the difficulty of calculating supply chain emissions.[157] The idea is once again gaining traction,[158] helped by the digitalization of agriculture, which is enabling greater product traceability and emissions estimates.[159]

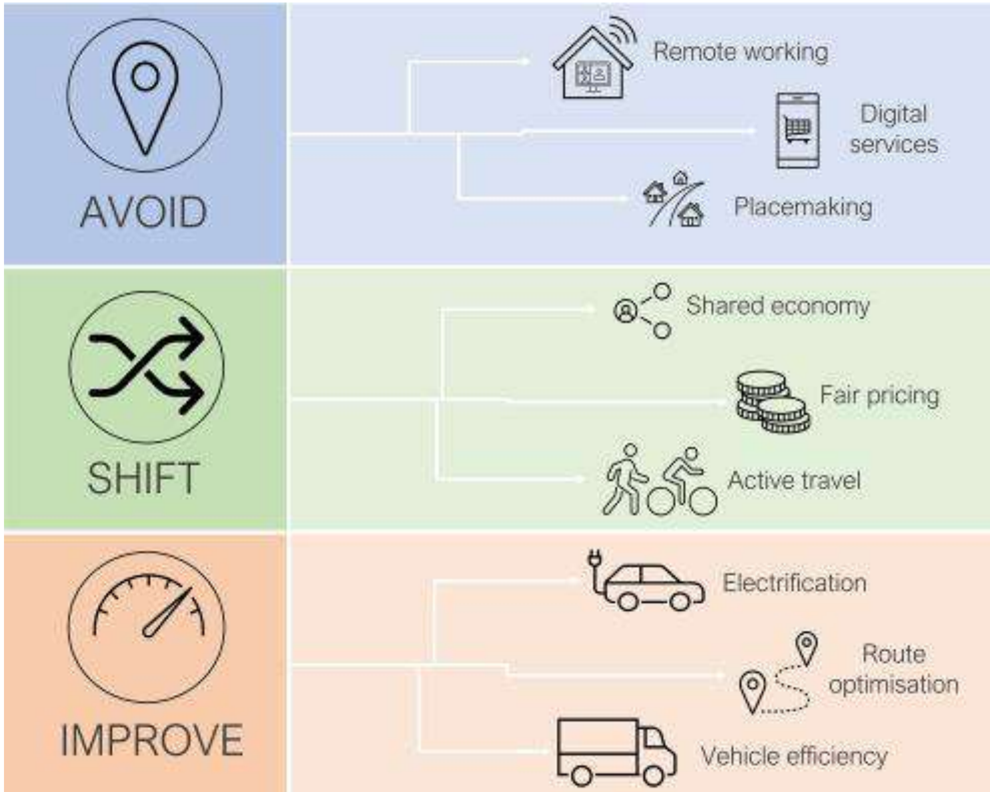
In emerging economies, there is a concerning trend toward increasing meat in diets,[160] with consequences for increasing methane emissions (from ruminant livestock) and deforestation.[161] Technological innovations such as lab-grown meat may help to mitigate this trend, but are likely to be insufficient alone.[162] There is a need for upstream changes to enable pro-environmental food choices. In many countries, subsidy regimens and international trade deals actively encourage emissions-intensive livestock farming, and a carbon tax on the highest impact foods is politically divisive.[140] Recalibrating complex food systems toward more sustainable outcomes is a major challenge, requiring collaboration among governments, the food industry, and civil society.[163]

Enabling low-carbon transport choices

In Europe, the transport sector is responsible for nearly 25% of greenhouse gas emissions, and emissions have remained stubbornly high compared with other sectors such as power and industry that have seen reductions.[164] Consistent with analysis of behavioral determinants,[79] most research points to the need for investment in low-carbon transport infrastructure, which is currently insufficient for driving emissions reductions.[165,166]

In the 2000s, the potential of soft measures to change behavior attracted interest from some European governments, and the United Kingdom's Department of Transport commissioned a major study into the potential of "soft measures" to effect traffic reduction. It found that interventions such as the promotion of workplace or individualized travel plans, car sharing schemes, and awareness campaigns have potential to reduce national road traffic levels by around 11%, and up to 21% of peak urban traffic.[167] Since then, several innovations driven by digital technologies, such as app-enabled shared mobility, telework, and online shopping have reduced barriers to implementing "soft" measures; and yet evidence from systematic reviews indicates limited impact to date,[79] while road traffic has steadily risen across Organisation for Economic Co-operation and Development (OECD) countries.[168,169]

There is growing agreement among transport researchers that overall demand reduction will be required to meet climate goals.[170] Figure 4 depicts the influential "avoid, shift, improve" framework that emphases the need to *first* reduce mobility demand, then encourage the greater use of public transport and active modes, before focusing on fuel switching for private vehicles. In Europe, however, most policies in this domain focus on promoting the adoption of EVs and a modal shift to public transport.[164] Crucially, the avoidance of travel often falls outside the scope of transport policy. Digitalization is a key driver, but the benefits of digital services are uneven and they risk compounding social exclusion and rural deprivation.[171] Other interventions to drive down travel demand include creating "15-min neighborhoods" by prioritizing *access* to local amenities in planning and development policy.[172]



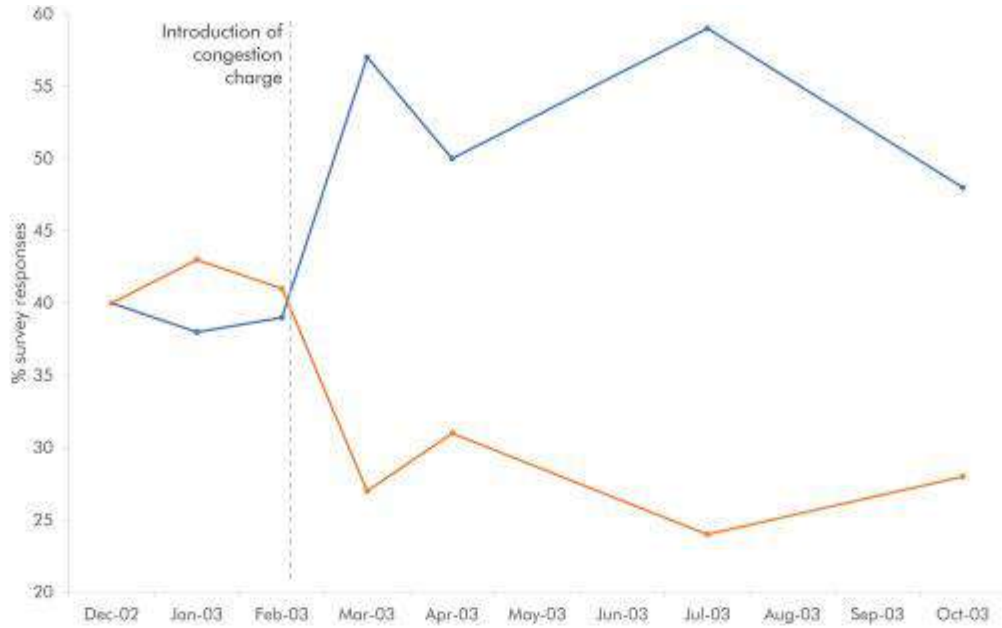
1. Download: Download high-res image (369KB)
2. Download: Download full-size image

Figure 4. The Avoid, Shift, Improve framework helps policy-makers to prioritize investments for transport emissions reduction

The COVID-19 pandemic disrupted travel behaviors, but there is mixed evidence about its effect on long-term habits. The adoption of teleworking practices has increased dramatically in many countries[173] and emerging evidence suggests it may have lasting effects.[174] In the United Kingdom, car usage remains below 2019 levels and there has been a substantial increase in walking for shorter trips.[175] However, the use of passenger vehicles in the United States had recovered to pre-pandemic levels by the end of 2021.[176] Some cities have capitalized on the disruption caused by the pandemic, leveraging this "moment of change" to reallocate road space for active travel. Many deployed "pop-up" bike lanes during the pandemic,[177] and Sydney, Australia, and Mexico City, Mexico, are among those that have since made these permanent.[178]

Besides investing in active travel infrastructure and public transport provision, urban municipalities have a role to play in addressing social and cultural barriers. The Netherlands boasts world-leading cycling infrastructure, but participation remains lower among women and ethnic minorities than other groups. From 2015 to 2021, the City of Leiden, Netherlands, launched a campaign called Flink Fietsen (translation: "cool cycling") aiming to normalize cycling among women and older people and in poor weather. In the United States, Seattle, Portland, and San Francisco have sought to overcome the stigma of bus travel by equivalizing fares with light rail, introducing bus lanes, and giving routes equal prominence on public transit maps.[179,180]

After decades of emissions stasis, there is an urgent need to accelerate transport decarbonization, and policy-makers cannot afford to rely on the shift to EVs. Direct policy interventions, such as the reallocation of road space, restrictions on private car access in cities, or the introduction of congestion charging, are needed in urban environments, but they often generate controversy that can halt progress and temper the ambitions of political leaders. However, evidence suggests that individuals tend to resist change, until it has happened. For instance, Figure 5 shows that support for London's congestion charge grew following its introduction. Climate-conscious policy-makers should be reassured, and hold their nerve.



1. Download: Download high-res image (166KB)
2. Download: Download full-size image

Figure 5. Support for London congestion charge over time

Source: TFL,[181] recreated from BIT[148]; support is in blue, opposition in orange.

Energy consumption in the home

Evidence has found that habitual domestic energy behaviors can be influenced by social norms, feedback, and smart technologies. Studies led by US utility Opower found that informing customers about the average consumption by neighbors and similar households led to reductions of 2%,[182] while visual and accessible feedback via in-home displays has been shown to reduce electricity and gas consumption by 1%–3% in large control studies.[183,184] Given that heating controls are a barrier to energy conservation,[92] there are opportunities to enhance user capabilities. A proliferation of smart thermostats and zonal control systems in recent years has led to design improvements,[185] although evidence of their effectiveness for energy savings is mixed.[92,186] How installers (e.g., plumbers, heating engineers) select and explain controls to users also has a significant effect on how effectively they are used.[187,188,189]

Progress toward enabling non-habitual, one-off choices for improving the energy performance of housing varies internationally. In Europe for instance, the differing uptake of energy efficiency and renewable technologies can be largely explained by the ambition and effectiveness of national policy, rather than economic cost-benefit.[190,191,192] However, the energy price crisis that began in 2021 is rapidly changing the economics of energy efficiency and renewable generation, and demand for domestic photovoltaic installations is increasing, representing 28% of all new solar capacity globally in 2021.[193] China is driving this trend, with installations expected to reach 108 GW in 2022. In Europe, the market for domestic heat pumps is growing. Having already achieved high penetration in Scandinavia,[194] deployment is accelerating in France and Italy.[195] However in the United Kingdom, Netherlands, and the United States, where natural gas dominates domestic heating supply, there remain a series of barriers to householders choosing heat pumps, including high installation costs, skill shortages, and low public awareness.[196] Alongside the challenge of decarbonizing heating, demand for cooling is projected to triple by 2050, driven by population growth in (increasingly) warm climates and changing comfort preferences.[197] While co-deployment of solar photovoltaics will help to offset the substantial increase in peak electricity demand, the International Energy Agency stresses the need for appliance efficiency to limit emissions.[198]

The split-incentive problem remains an intransigent barrier in the rented sector, but the introduction of Minimum Energy Efficiency Standards in the United Kingdom, Netherlands, and parts of the United States is a promising development.[171,199] Germany—an outlier for home ownership compared with comparable countries—is using its recently introduced carbon pricing mechanism to incentivize landlords to invest in building energy upgrades.[200,201]

Sustainable consumption of goods and services

The avoid, shift, improve framework applies to the consumption of non-food products. The most impactful choices are those involving consuming fewer products overall, followed by buying second-hand items or paying for services (such as car clubs over car ownership), and finally improving the quality, longevity, and sourcing of goods we do buy.

While in some advanced economies a trend toward minimalism and dematerialization has emerged in recent years, these practices remain exceptional,[202] and outweighed by economic forces in which consumption is seen as a key driver for growth and is encouraged by a raft of government policies and commercial activities. Similarly, while public concern for the impact of plastics on marine life in recent years raised pressure on retailers to reduce packaging and single-use items, progress remains limited to certain products such as straws and cutlery,[203] and behaviors such as buying products with less packaging[50] or using recycled materials[204] remain uncommon. Nonetheless, with strong public support for bans on single-use plastics,[205] there is potential for regulation to drive down unsustainable consumption.

Other key enablers of climate-friendly consumption choices are the development of the sharing and the circular economy. Polling from the European Union[206] and the United Kingdom[140] has found broad public support for these, but there is a need for innovation in business models and practices, aided by digitalization and the development of new materials and recycling methods. However, it is also essential that innovations such as paying for services or peer-to-peer trading are made accessible to wider publics, including those without digital capabilities.[207] Moreover, evidence from a UK study indicates that knowledge and awareness of sustainable consumption practices remain low,[140] and consumers find it difficult to distinguish between the environmental claims of one company's products over another.[208] A recent global study found that 40% of environmental claims made online could be potentially misleading.[209] Examples include vague use of language such as "eco" and "green" without accompanying evidence, use of unaccredited environmental labels, and the omission of information relating to emissions or pollution. Advertising standards agencies, consumer protection bodies, and anti-monopoly authorities have a key role to play in monitoring and regulating "greenwash."

Given the mismatch between public perception and reality associated with environmental behaviors (Figure 3), there is a need to enhance awareness and "carbon literacy," especially with respect to less visible, embodied emissions. Achieving this will require a range of interventions, from product carbon labeling and increased media coverage (see next section), to school-aged education and training.[210]

Leveraging the power of influence

Building the capacity of individuals to influence others toward pro-climate choices begins with awareness raising. The news media plays a crucial role. People who consume climate change news are more concerned about climate change, consider themselves to be more knowledgeable about the issue, and—importantly—tend to feel more empowered.[211] However, as a driver of public concern, news media is secondary to elite cues, protest, and extreme weather events, which are among those sources that drive climate coverage in the news.[212] A repeated finding is that the provision of factual information about climate change fails to influence opinion,[212] but when given information about the *views* of the scientific community, individuals are more likely to support climate policies. In other words, people relate to people, not facts.[213] In the context of increasingly polarized attitudes toward climate change, there is a need for interventions to enable more open and constructive discourse among diverse individuals. For influential institutions such as the news media, combating mis- and dis-information is essential to counteract polarization.[112] Greenpeace, The Nature Conservancy, and even the World Economic Forum have produced guides to help individuals talk about climate change with others in a variety of contexts.[214,215,216]

The workplace is a crucial site of (two-way) influence. This can be exerted by individuals in management and leadership roles through human-resource management practices such as rewards, education, and training[102]; green initiatives[217]; or values-based activities.[106,218] With respect to environmental behaviors, there is relatively little research on home-to-work and work-to-home spillover, and empirical work to date has shown mixed results.[219] For instance, a social-marketing experiment examining the effects of sustainable food interventions in the workplace found that positive spillover effects *can* be produced, but depend on various individual and material factors.[220] However, it is clear that pressure from employees and jobseekers is driving many organizations to adopt more sustainable practices,[221,222,223] and with unemployment at historically low levels in many OECD countries,[224] evidence that green businesses find it easier to recruit and retain staff is helping to drive action on climate change by corporations.[225]

Becoming climate citizens

Different trends enable and constrain climate citizenship. Climate change has (finally) entered mainstream political debate, meaning that it is easier than ever for voters to choose political candidates based on their climate stance. In many countries, climate action is no longer a partisan issue, although concern remains higher among left-wing voters[211]; and in the United States and Brazil, where climate policies have global ramifications, it continues to be politically divisive.[226] Addressing public polarization on climate change is essential in order to build consensus support for action. Different moral framings,[227] values-based engagement,[228,229] use of imagery,[230] and targeted provision of information[231] can help to counteract polarization. While political parties, corporate branding and communications agencies, and news media outlets may hold the greatest sway in countering polarization through public engagement and eradicating mis-information, these pivotal actors respond to the choices that individuals make as consumers (e.g., of media) and as organizational and political activists.[3,223,232,233,234]

Recent trends are making it easier for individuals to participate in climate action at multiple levels of governance. Both national and local governments are increasingly employing methods of deliberative and participative democracy, diversifying the ways in which citizens' voices are heard.[235,236,237] However, while citizens panels or assemblies can represent a cross-section of views on climate, they do not enable mass participation. Examples of "e-democracy" include online petitions and deliberative opinion polling that can enable individuals to engage more actively in the political process.

Digital technologies help connect communities at multiple scales, enabling pro-environmental solutions such as peer-to-peer energy trading.[238] It is easier than ever (for those with digital capabilities) to engage in grassroots climate action. This is also being supported by the global trend toward greater autarky that has emerged in response to supply chain disruption, trade wars, and a focus on energy and resource security by national governments. Whether this trend has negative ramifications for global cooperation on climate is yet to be seen, but in the meantime "slowbalization" is bringing a renewed focus on local and community solutions, boosting opportunities for participation in sustainability initiatives.[239] Building the social capital that is needed for such projects to be successful can be difficult, but trends such as telecommuting and increased part-time working are helping, as residents invest more of their time and money in the local community.[240] Directing these investments toward climate action can generate positive feedback loops: individuals getting involved in renewable energy projects, farming cooperatives, or circular economy activities can help to enhance social capital, boost the local economy, and build the local capabilities that enable further climate action.

Toward an ecology of choice for climate action

Individual choices are at the sharp end of climate action, with the potential to drive down emissions and keep global temperature rise within safe limits. Identifying six domains of choice for climate action, this review has shown that the capabilities to make choices for climate are unevenly distributed among populations, and depend on individual, social, material, physical, and political factors, which combine in complex ways, depending on context. Choices are thus best conceived as part of an ecology of decision-making with myriad influences. To achieve climate goals, all elements of the ecology must be addressed through a range of interventions, including information provision, social marketing, choice architecture, economic measures, infrastructure change, and regulation (see Figure 6). There is a tendency in behavior change scholarship and policy discourse to focus on so called "downstream" interventions: those focused on educating, persuading and encouraging individuals to make more sustainable everyday consumption choices[5,241] However, as this review has demonstrated, individual consumption behaviors are influenced by a range of social, physical, and political factors that can constrain or enable pro-environmental choice capabilities. Extending the metaphor of a river-based ecosystem, there is a need to design and implement more *midstream* and *upstream* interventions. Midstream interventions relate to the "choice environment," where actors such as businesses, service providers, and local governments can act to make sustainable options easier, more available, and socially acceptable.[241] Midstream initiatives might also identify "moments of change," such as when individuals move home, start new jobs, or when energy-intensive appliances breakdown, designing timely interventions to take advantage of habit discontinuity and enable individuals to establish more sustainable routines.[5] Upstream activities involve substantive change to the structures and systems that set the conditions and context for individual choice, and are typically considered the domain of government departments and market regulators. However, individuals have significant agency for shaping the success of interventions at all levels, acting in different capacities.

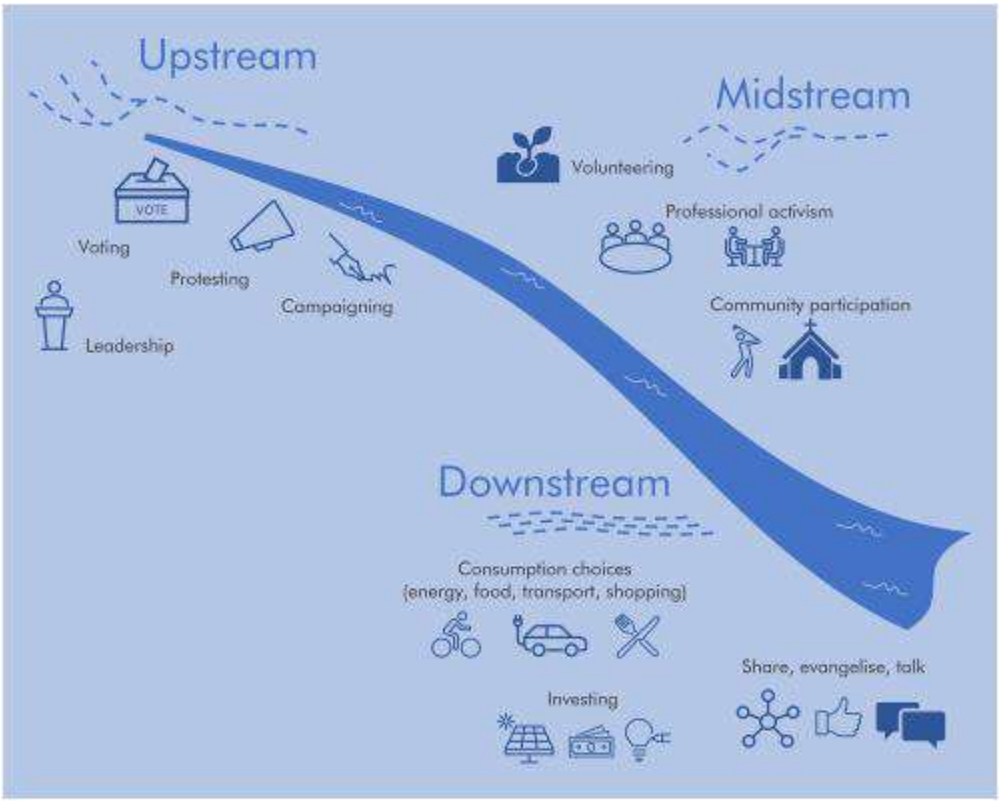


Figure 6. The *riverine ecology* of choice for climate action
A combination of upstream, midstream, and downstream interventions is needed to enable and scale choices for climate action.

For upstream interventions, individuals in positions of leadership can influence systemic change, while as this review has shown, activism (within organizational settings and the public realm), and political participation can help to reshape the terms of debate on climate change, and accelerate policy and action. The choices individuals make as organizational members are key for shaping the midstream choice environment. These include effecting change within business or public sector organizations; helping to set environmental policies and targets in line with national and global climate targets[10,242]; volunteering in local initiatives to enhance nature recovery or facilitate the sharing economy; or spreading the word about the need for climate action among sports, religious, or cultural groups. Last, while individual consumption choices have the most immediate potential to reduce carbon emissions in the four domains of food, transport, domestic energy, and shopping, individuals can also help to accelerate downstream change when acting as economic and social agents. One-off, high-impact choices such as choosing to invest in rooftop solar, renewable heating systems, or even switching pension and savings to sustainable providers can deliver significant emissions savings for individuals, but when coupled with choices to share experiences of making low-carbon choices and evangelize about their benefits, these can have catalyzing effects.[3]

To meet the scale of the challenge posed by climate change, there is a need for transformation in the lifestyles led by individuals across much of the world. Choice is a central component of this transformation, and this review has highlighted the power of decision-making that extends beyond individual consumption behavior. There is a need for change among systems of provision and governance, businesses and communities, and in social and cultural norms that each set the context for individual decision-making. Individuals acting as citizens, influencers, investors, professionals, and consumers hold the key to delivering this change.

Acknowledgments

This research has been enabled by funding from the Economic and Social Research Council (ESRC) grant ref: ES/V015133/1. Funding has also been received from ES/S012257/1. We thank the peer reviewers for their detailed and constructive comments in preparing this manuscript for publication.

Author contributions

Conceptualization, methodology, investigation, S.H. and L.W. Writing – Original Draft, S.H. Writing – Review & Editing, L.W.

Declaration of interests

The authors declare no competing interests.

References

1. 1

   Ipsos

   Perils of Perception

   Environmental Perils (2021)

   Google Scholar

2. 2

   L. Chancel

   Global carbon inequality over 1990–2019

   Nat. Sustain., 5 (2022), pp. 931-938, 10.1038/s41893-022-00955-z
   View in ScopusGoogle Scholar

3. 3

   K.S. Nielsen, K.A. Nicholas, F. Creutzig, T. Dietz, P.C. Stern

   The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions

   Nat. Energy, 6 (2021), pp. 1011-1016

   CrossrefView in ScopusGoogle Scholar

4. 4

   T. Kurz, B. Gardner, B. Verplanken, C. Abraham

   Habitual behaviors or patterns of practice? Explaining and changing repetitive climate-relevant actions

   WIREs Clim. Change, 6 (2015), pp. 113-128, 10.1002/wcc.327
   View in ScopusGoogle Scholar

5. 5

   L. Whitmarsh, W. Poortinga, S. Capstick

   Behaviour change to address climate change

   Curr. Opin. Psychol., 42 (2021), pp. 76-81, 10.1016/j.copsyc.2021.04.002
   View PDFView articleView in ScopusGoogle Scholar

6. 6

   E. Shove

   Beyond the ABC: Climate Change Policy and Theories of Social Change

   Environ. Plan. A., 42 (2010), pp. 1273-1285, 10.1068/a42282
   View in ScopusGoogle Scholar

7. 7

   A. Giddens

   The Constitution of Society [electronic Resource] : Outline of the Theory of Structuration

   Wiley (1984)

   Google Scholar

8. 8

   A. Reckwitz

Toward a theory of social practices: a development in culturalist theorizing

Eur. J. Soc. Theor, 5 (2002), pp. 243-263

View in ScopusGoogle Scholar

9. 9

S. Hampton, R. Adams

Behavioural economics vs social practice theory: Perspectives from inside the United Kingdom government

Energy Res. Social Sci., 46 (2018), pp. 214-224, 10.1016/j.erss.2018.07.023
View PDFView articleView in ScopusGoogle Scholar

10. 10

J. Walenta

The making of the corporate carbon footprint: the politics behind emission scoping

Journal of Cultural Economy, 14 (2021), pp. 533-548, 10.1080/17530350.2021.1935297
View in ScopusGoogle Scholar

11. 11

M. Bhattacharya, J.N. Inekwe, P. Sadorsky

Consumption-based and territory-based carbon emissions intensity: Determinants and forecasting using club convergence across countries

Energy Econ., 86 (2020), Article 104632, 10.1016/j.eneco.2019.104632
View PDFView articleView in ScopusGoogle Scholar

12. 12

B. Goldstein, D. Gounaridis, J.P. Newell

The carbon footprint of household energy use in the United States

Proc. Natl. Acad. Sci. USA, 117 (2020), pp. 19122-19130, 10.1073/pnas.1922205117
View in ScopusGoogle Scholar

13. 13

S. Wynes, K.A. Nicholas

The climate mitigation gap: education and government recommendations miss the most effective individual actions

Environ. Res. Lett., 12 (2017), Article 074024, 10.1088/1748-9326/aa7541
View in ScopusGoogle Scholar

14. 14

D. Ivanova, J. Barrett, D. Wiedenhofer, B. Macura, M. Callaghan, F. Creutzig

Quantifying the potential for climate change mitigation of consumption options

Environ. Res. Lett., 15 (2020), Article 093001, 10.1088/1748-9326/ab8589
View in ScopusGoogle Scholar

15. 15

BEIS (2022)

UK Greenhouse Gas Emissions, Provisional Figures

Department for Business, Energy and Industrial Strategy (2021)

Google Scholar

16. 16

Climate Change Committee

The Sixth Carbon Budget: The UK's Path to Net Zero (Climate Change Committee)

(2020)

Google Scholar

17. 17

US EPA Carbon Footprint Calculator. https://www3.epa.gov/carbon-footprint-calculator.
Google Scholar

18. 18

DEFRA

Act on CO2 Calculator: Public Trial Version. Data, Methodology and Assumptions Paper

Department for Environment, Food and Rural Affairs (2007)

Google Scholar

19. 19

WWF Footprint Calculator https://footprint.wwf.org.uk/.
Google Scholar

20. 20

BP Know Your Carbon Footprint. https://www.knowyourcarbonfootprint.com/.
Google Scholar

21. 21

HM Government

Climate Change and Net Zero: Public Awareness and Perceptions

(2021)

Google Scholar

22. 22

S. Wynes, J. Zhao, S.D. Donner

How well do people understand the climate impact of individual actions?

Climatic Change, 162 (2020), pp. 1521-1534, 10.1007/s10584-020-02811-5
View in ScopusGoogle Scholar

23. 23

F. Brocklehurst, C. Whittle, C. McAlister, L. Whitmarsh

Can the provision of energy and resource efficiency information influence what consumers buy? A review of the evidence

Proceedings of the eceee Summer Study Conference (2019)

Google Scholar

24. 24

A.M. van Valkengoed, W. Abrahamse, L. Steg

To select effective interventions for pro-environmental behaviour change, we need to consider determinants of behaviour

Nat. Human Behav., 6 (2022), pp. 1482-1492, 10.1038/s41562-022-01473-w
View in ScopusGoogle Scholar

25. 25

J. Frick, F.G. Kaiser, M. Wilson

Environmental knowledge and conservation behavior: exploring prevalence and structure in a representative sample

Pers. Indiv. Differ., 37 (2004), pp. 1597-1613, 10.1016/j.paid.2004.02.015
View PDFView articleView in ScopusGoogle Scholar

26. 26

P. Griffin

The Carbon Majors Database. CDP Carbon Majors Report

CDP Worldwide (2017)

Google Scholar

27. 27

M. Kaufman

The Carbon Footprint Sham: A “Successful, Deceptive” PR Campaign

Mashable (2020)

https://mashable.com/feature/carbon-footprint-pr-campaign-sham
Google Scholar

28. 28

A. Corner, J. Clarke

Talking Climate: From Research to Practice in Public Engagement

Palgrave) (2016)

Google Scholar

29. 29

K. Hayhoe

Saving Us: A Climate Scientist’s Case for Hope and Healing in a Divided World First One

Signal Publishers/Atria Books (2021)

hardcover edition. (One Signal Publishers/Atria Books)

Google Scholar

30. 30

Count Us in, and Netflix Take a Step with Don't Look up & Count Us In. https://dontlookup.count-us-in.com/steps.
Google Scholar

31. 31

S. Capstick, A. Thierry, E. Cox, O. Berglund, S. Westlake, J.K. Steinberger

Civil disobedience by scientists helps press for urgent climate action

Nat. Clim. Change, 12 (2022), pp. 773-774, 10.1038/s41558-022-01461-y
View in ScopusGoogle Scholar

32. 32

S. Venghaus, M. Henseleit, M. Belka

The impact of climate change awareness on behavioral changes in Germany: changing minds or changing behavior?

Energy Sustain. Soc., 12 (2022), p. 8, 10.1186/s13705-022-00334-8
View in ScopusGoogle Scholar

33. 33

L. Whitmarsh, G. Seyfang, S. O’Neill

Public engagement with carbon and climate change: To what extent is the public ‘carbon capable

Global Environ. Change, 21 (2011), pp. 56-65, 10.1016/j.gloenvcha.2010.07.011
View PDFView articleView in ScopusGoogle Scholar

34. 34

C. Hickman, E. Marks, P. Pihkala, S. Clayton, R.E. Lewandowski, E.E. Mayall, B. Wray, C. Mellor, L. van Susteren

Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey

Lancet Planet. Health, 5 (2021), pp. e863-e873, 10.1016/S2542-5196(21)00278-3
View PDFView articleView in ScopusGoogle Scholar

35. 35

I. Ajzen

The theory of planned behavior

Organ. Behav. Hum. Decis. Process., 50 (1991), pp. 179-211, 10.1016/0749-5978(91)90020-T
View PDFView articleView in ScopusGoogle Scholar

36. 36

A. Darnton

An Overview of Behaviour Change Models and Their Uses

Centre for Sustainable Development, University of Westminster (2008)

Google Scholar

37. 37

T. Jackson

Motivating Sustainable Consumption: A Review of Evidence on Consumer Behaviour and Behavioural Change

A report to the Sustainable Development Research Network (2005)

Google Scholar

38. 38

P.C. Stern

New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior

J. Soc. Issues, 56 (2000), pp. 407-424, 10.1111/0022-4537.00175
View in ScopusGoogle Scholar

39. 39

A. Grønhøj, J. Thøgersen

Like father, like son? Intergenerational transmission of values, attitudes, and behaviours in the environmental domain

J. Environ. Psychol., 29 (2009), pp. 414-421, 10.1016/j.jenvp.2009.05.002
View PDFView articleView in ScopusGoogle Scholar

40. 40

H. Pearce, L. Hudders, D. Van de Sompel

Young energy savers: Exploring the role of parents, peers, media and schools in saving energy among children in Belgium

Energy Res. Social Sci., 63 (2020), Article 101392, 10.1016/j.erss.2019.101392
View PDFView articleView in ScopusGoogle Scholar

41. 41

S. Moser, S. Kleinhückelkotten

Good Intents, but Low Impacts: Diverging Importance of Motivational and Socioeconomic Determinants Explaining Pro-Environmental Behavior, Energy Use, and Carbon Footprint

Environ. Behav., 50 (2018), pp. 626-656, 10.1177/0013916517710685
View in ScopusGoogle Scholar

42. 42

K.S. Nielsen, S. Clayton, P.C. Stern, T. Dietz, S. Capstick, L. Whitmarsh

How psychology can help limit climate change

Am. Psychol., 76 (2021), pp. 130-144, 10.1037/amp0000624
View in ScopusGoogle Scholar

43. 43

A. Darnton, D. Evans, Scottish Government

Influencing Behaviours: A Technical Guide to the ISM Tool

Scottish Government (2013)

Google Scholar

44. 44

S. Michie, M.M. van Stralen, R. West

The behaviour change wheel: A new method for characterising and designing behaviour change interventions

Implement. Sci., 6 (2011), p. 42, 10.1186/1748-5908-6-42
View in ScopusGoogle Scholar

45. 45

C. Brick, G.J. Lewis

Unearthing the “Green” Personality: Core Traits Predict Environmentally Friendly Behavior

Environ. Behav., 48 (2016), pp. 635-658, 10.1177/0013916514554695
View in ScopusGoogle Scholar

46. 46

N.A. Marshall, L. Thiault, A. Beeden, R. Beeden, C. Benham, M.I. Curnock, A. Diedrich, G.G. Gurney, L. Jones, P.A. Marshall, *et al.*
Our Environmental Value Orientations Influence How We Respond to Climate Change

Front. Psychol., 10 (2019), p. 938

View in ScopusGoogle Scholar

47. 47

B. Wisner

Climate change and cultural diversity

Int. Soc. Sci. J., 61 (2010), pp. 131-140, 10.1111/j.1468-2451.2010.01752.x
View in ScopusGoogle Scholar

48. 48

B. Latter

Climate Change Communication and Engagement With Older People in England

Front. Commun. (Lausanne)., 7 (2022)

Google Scholar

49. 49

B. Lovelock

Disability and going green: a comparison of the environmental values and behaviours of persons with and without disability

Disabil. Soc., 25 (2010), pp. 467-484, 10.1080/09687591003755856
View in ScopusGoogle Scholar

50. 50

L. Whitmarsh, S. Capstick, N. Nash

Who is reducing their material consumption and why? A cross-cultural analysis of dematerialization behaviours

Philos. Trans. A Math. Phys. Eng. Sci., 375 (2017), Article 20160376, 10.1098/rsta.2016.0376
View in ScopusGoogle Scholar

51. 51

N. Jones, J.R.A. Clark

Social capital and the public acceptability of climate change adaptation policies: a case study in Romney Marsh, UK

Climatic Change, 123 (2014), pp. 133-145, 10.1007/s10584-013-1049-0
View in ScopusGoogle Scholar

52. 52

E.B. Sharp, D.M. Daley, M.S. Lynch

Understanding Local Adoption and Implementation of Climate Change Mitigation Policy

Urban Aff. Rev., 47 (2011), pp. 433-457, 10.1177/1078087410392348
View in ScopusGoogle Scholar

53. 53

G.M. Huebner, I. Hamilton, Z. Chalabi, D. Shipworth, T. Oreszczyn

Explaining domestic energy consumption – The comparative contribution of building factors, socio-demographics, behaviours and attitudes

Appl. Energy, 159 (2015), pp. 589-600, 10.1016/j.apenergy.2015.09.028
View PDFView articleView in ScopusGoogle Scholar

54. 54

E. McKenna, J. Few, E. Webborn, B. Anderson, S. Elam, D. Shipworth, A. Cooper, M. Pullinger, T. Oreszczyn

Explaining daily energy demand in British housing using linked smart meter and socio-technical data in a bottom-up statistical model

Energy Build., 258 (2022), Article 111845, 10.1016/j.enbuild.2022.111845
View PDFView articleView in ScopusGoogle Scholar

55. 55

B. Gill, S. Moeller

GHG Emissions and the Rural-Urban Divide. A Carbon Footprint Analysis Based on the German Official Income and Expenditure Survey

Ecol. Econ., 145 (2018), pp. 160-169, 10.1016/j.ecolecon.2017.09.004
View PDFView articleView in ScopusGoogle Scholar

56. 56

A. Goldthau, L. Eicke, S. Weko

The Global Energy Transition and the Global South

M. Hafner, S. Tagliapietra (Eds.), The Geopolitics of the Global Energy Transition Lecture Notes in Energy, Springer International Publishing) (2020), pp. 319-339, 10.1007/978-3-030-39066-2_14
View in ScopusGoogle Scholar

57. 57

S. Niemeyer

Democracy and Climate Change: What Can Deliberative Democracy Contribute?

Aust. J. Polit. Hist., 59 (2013), pp. 429-448, 10.1111/ajph.12025
View in ScopusGoogle Scholar

58. 58

D.J. Fiorino

Can Democracy Handle Climate Change?

John Wiley & Sons (2018)

Google Scholar

59. 59

CAUK

The Path to Net Zero: Climate Assembly UK Full Report (Climate Assembly UK)

(2020)

Google Scholar

60. 60

R. Aldred, J. Woodcock, A. Goodman

Does More Cycling Mean More Diversity in Cycling?

Transport Rev., 36 (2016), pp. 28-44, 10.1080/01441647.2015.1014451
View articleView in ScopusGoogle Scholar

61. 61

J. Sobal, C.A. Bisogni

Constructing Food Choice Decisions

Ann. Behav. Med., 38 (2009), pp. s37-s46, 10.1007/s12160-009-9124-5
Google Scholar

62. 62

S. Mertens, M. Herberz, U.J.J. Hahnel, T. Brosch

The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains

Proc. Natl. Acad. Sci. USA, 119 (2022), Article e2107346118, 10.1073/pnas.2107346118
View in ScopusGoogle Scholar

63. 63

N. Larson, M. Story

A Review of Environmental Influences on Food Choices

Ann. Behav. Med., 38 (2009), pp. s56-s73, 10.1007/s12160-009-9120-9
Google Scholar

64. 64

S. Bridle-Fitzpatrick

Tortillas, Pizza, and Broccoli

Food Cult. Soc., 19 (2016), pp. 93-128, 10.1080/15528014.2016.1147871
View in ScopusGoogle Scholar

65. 65

T.M. Marteau, N. Chater, E.E. Garnett

Changing behaviour for net zero 2050

BMJ, 375 (2021), p. n2293, 10.1136/bmj.n2293
View in ScopusGoogle Scholar

66. 66

E. Köster

Diversity in the determinants of food choice: A psychological perspective

Food Qual. Prefer., 20 (2009), pp. 70-82, 10.1016/j.foodqual.2007.11.002
View PDFView articleView in ScopusGoogle Scholar

67. 67

T. Cruwys, K.E. Bevelander, R.C.J. Hermans

Social modeling of eating: A review of when and why social influence affects food intake and choice

Appetite, 86 (2015), pp. 3-18, 10.1016/j.appet.2014.08.035
View PDFView articleView in ScopusGoogle Scholar

68. 68

G. Leng, R.A.H. Adan, M. Belot, J.M. Brunstrom, K. de Graaf, S.L. Dickson, T. Hare, S. Maier, J. Menzies, H. Preissl, *et al.*
The determinants of food choice

Proc. Nutr. Soc., 76 (2017), pp. 316-327, 10.1017/S002966511600286X

View in ScopusGoogle Scholar

69. 69

J.P. Enriquez, J.C. Archila-Godinez

Social and cultural influences on food choices: A review

Crit. Rev. Food Sci. Nutr., 62 (2022), pp. 3698-3704, 10.1080/10408398.2020.1870434
View in ScopusGoogle Scholar

70. 70

R.D. Gifford, A.K.S. Chen

Why aren't we taking action? Psychological barriers to climate-positive food choices

Climatic Change, 140 (2017), pp. 165-178, 10.1007/s10584-016-1830-y
View in ScopusGoogle Scholar

71. 71

C. Tobler, V.H.M. Visschers, M. Siegrist

Eating green. Consumers' willingness to adopt ecological food consumption behaviors

Appetite, 57 (2011), pp. 674-682, 10.1016/j.appet.2011.08.010
View PDFView articleView in ScopusGoogle Scholar

72. 72

M.B. Ruby, S.J. Heine

Meat, morals, and masculinity

Appetite, 56 (2011), pp. 447-450, 10.1016/j.appet.2011.01.018
View PDFView articleView in ScopusGoogle Scholar

73. 73

I. Mori

Diets Around the World: An Exploration

(2018)

Google Scholar

74. 74

A. Warde

The Practice of Eating

John Wiley & Sons (2016)

Google Scholar

75. 75

P. Lanzini, S.A. Khan

Shedding light on the psychological and behavioral determinants of travel mode choice: A meta-analysis

Transport. Res. F Traffic Psychol. Behav., 48 (2017), pp. 13-27, 10.1016/j.trf.2017.04.020
View PDFView articleView in ScopusGoogle Scholar

76. 76

K. Canepa, S. Hardman, G. Tal

An early look at plug-in electric vehicle adoption in disadvantaged communities in California

Transport Pol., 78 (2019), pp. 19-30, 10.1016/j.tranpol.2019.03.009
View PDFView articleView in ScopusGoogle Scholar

77. 77

H.A.U. Khan, S. Price, C. Avraam, Y. Dvorkin

Inequitable access to EV charging infrastructure

Electr. J., 35 (2022), Article 107096, 10.1016/j.tej.2022.107096
View PDFView articleView in ScopusGoogle Scholar

78. 78

R. Fouquet, T. O'Garra

In pursuit of progressive and effective climate policies: Comparing an air travel carbon tax and a frequent flyer levy

Energy Pol., 171 (2022), Article 113278, 10.1016/j.enpol.2022.113278
View PDFView articleView in ScopusGoogle Scholar

79. 79

A. Javaid, F. Creutzig, S. Bamberg

Determinants of low-carbon transport mode adoption: systematic review of reviews

Environ. Res. Lett., 15 (2020), Article 103002, 10.1088/1748-9326/aba032
View in ScopusGoogle Scholar

80. 80

L. Tatah, Y. Wasnyo, M. Pearce, T. Oni, L. Foley, E. Mogo, C. Obonyo, J.C. Mbanya, J. Woodcock, F. Assah

Travel Behaviour and Barriers to Active Travel among Adults in Yaoundé, Cameroon

Sustainability, 14 (2022), p. 9092, 10.3390/su14159092
View in ScopusGoogle Scholar

81. 81

P. Chillón, D. Hales, A. Vaughn, Z. Gizlice, A. Ni, D.S. Ward

A cross-sectional study of demographic, environmental and parental barriers to active school travel among children in the United States

Int. J. Behav. Nutr. Phys. Activ., 11 (2014), p. 61, 10.1186/1479-5868-11-61
View in ScopusGoogle Scholar

82. 82

T. Lorenc, G. Brunton, S. Oliver, K. Oliver, A. Oakley

Attitudes to walking and cycling among children, young people and parents: a systematic review

J. Epidemiol. Community Health, 62 (2008), pp. 852-857, 10.1136/jech.2007.070250
View in ScopusGoogle Scholar

83. 83

H.T.K. Le, R. Buehler, S. Hankey

Correlates of the Built Environment and Active Travel: Evidence from 20 US Metropolitan Areas

Environ. Health Perspect., 126 (2018), Article 077011, 10.1289/EHP3389
View in ScopusGoogle Scholar

84. 84

E.K. Nehme, A. Pérez, N. Ranjit, B.C. Amick, H.W. Kohl

Sociodemographic Factors, Population Density, and Bicycling for Transportation in the United States

J. Phys. Activ. Health, 13 (2016), pp. 36-43, 10.1123/jpah.2014-0469
View in ScopusGoogle Scholar

85. 85

A. Hess

Race, Class, and the Stigma of Riding the Bus in America

The Atlantic (2012)

Google Scholar

86. 86

N. Bosetti, K. Connelly, C. Harding, D. Rowe

Street Shift: The Future of Low-Traffic Neighbourhoods

Centre for London) (2022)

Google Scholar

87. 87

A. Satre-Meloy

Investigating structural and occupant drivers of annual residential electricity consumption using regularization in regression models

Energy, 174 (2019), pp. 148-168, 10.1016/j.energy.2019.01.157
View PDFView articleView in ScopusGoogle Scholar

88. 88

C.f. Chen, X. Xu, Z. Cao, A. Mockus, Q. Shi

Analysis of social–Psychological factors and financial incentives in demand response and residential energy behavior

Front. Energy Res., 11 (2023)

Google Scholar

89. 89

E. Frederiks, K. Stenner, E. Hobman

The Socio-Demographic and Psychological Predictors of Residential Energy Consumption: A Comprehensive Review

Energies, 8 (2015), pp. 573-609, 10.3390/en8010573
View in ScopusGoogle Scholar

90. 90

T. Marghetis, S.Z. Attari, D. Landy

Simple interventions can correct misperceptions of home energy use

Nat. Energy, 4 (2019), pp. 874-881, 10.1038/s41560-019-0467-2
View in ScopusGoogle Scholar

91. 91

S.Z. Attari, M.L. DeKay, C.I. Davidson, W. Bruine de Bruin

Public perceptions of energy consumption and savings

Proc. Natl. Acad. Sci. USA, 107 (2010), pp. 16054-16059, 10.1073/pnas.1001509107
View in ScopusGoogle Scholar

92. 92

K.J. Lomas, S. Oliveira, P. Warren, V.J. Haines, T. Chatterton, A. Beizaee, E. Prestwood, B. Gething

Do domestic heating controls save energy? A review of the evidence

Renew. Sustain. Energy Rev., 93 (2018), pp. 52-75, 10.1016/j.rser.2018.05.002
View PDFView articleView in ScopusGoogle Scholar

93. 93

H. Nie, R. Kemp, J.-H. Xu, V. Vasseur, Y. Fan

Split incentive effects on the adoption of technical and behavioral energy-saving measures in the household sector in Western Europe

Energy Pol., 140 (2020), Article 111424, 10.1016/j.enpol.2020.111424
View PDFView articleView in ScopusGoogle Scholar

94. 94

Eurostat

Distribution of Population by Tenure Status, Type of Household and Income Group

EU-SILC survey (2023)

Google Scholar

95. 95

Statistics Japan

Homeownership. Homeownership｜Statistics Japan : Prefecture Comparisons

(2022)

https://stats-japan.com/t/kiji/23131
Google Scholar

96. 96

C.S. Dabas, C. Whang

A systematic review of drivers of sustainable fashion consumption: 25 years of research evolution

Journal of Global Fashion Marketing, 13 (2022), pp. 151-167, 10.1080/20932685.2021.2016063
View in ScopusGoogle Scholar

97. 97

A. Akande, P. Cabral, S. Casteleyn

Understanding the sharing economy and its implication on sustainability in smart cities

J. Clean. Prod., 277 (2020), Article 124077, 10.1016/j.jclepro.2020.124077
View PDFView articleView in ScopusGoogle Scholar

98. 98

M. ter Huurne, A. Ronteltap, R. Corten, V. Buskens

Antecedents of trust in the sharing economy: A systematic review

J. Consum. Behav., 16 (2017), pp. 485-498, 10.1002/cb.1667
View in ScopusGoogle Scholar

99. 99

J. Wei, H. Chen, X. Cui, R. Long

Carbon capability of urban residents and its structure: Evidence from a survey of Jiangsu Province in China

Appl. Energy, 173 (2016), pp. 635-649, 10.1016/j.apenergy.2016.04.068
View PDFView articleView in ScopusGoogle Scholar

100. 100

A.R.B. Soutter, T.C. Bates, R. Mõttus

Big Five and HEXACO Personality Traits, Proenvironmental Attitudes, and Behaviors: A Meta-Analysis

Perspect. Psychol. Sci., 15 (2020), pp. 913-941, 10.1177/1745691620903019
View in ScopusGoogle Scholar

101. 101

K.S. Nielsen, T.M. Marteau, J.M. Bauer, R.B. Bradbury, S. Broad, G. Burgess, M. Burgman, H. Byerly, S. Clayton, D. Espelosin, *et al.*
Biodiversity conservation as a promising frontier for behavioural science

Nat. Human Behav., 5 (2021), pp. 550-556, 10.1038/s41562-021-01109-5

View in ScopusGoogle Scholar

102. 102

L.D. Zibarras, P. Coan

HRM practices used to promote pro-environmental behavior: a UK survey

Int. J. Hum. Resour. Manag., 26 (2015), pp. 2121-2142, 10.1080/09585192.2014.972429
View in ScopusGoogle Scholar

103. 103

K. Kalshoven, D.N. Den Hartog, A.H.B. De Hoogh

Ethical Leader Behavior and Big Five Factors of Personality

J. Bus. Ethics, 100 (2011), pp. 349-366, 10.1007/s10551-010-0685-9
View in ScopusGoogle Scholar

104. 104

C.W. Choo

Sensemaking, knowledge creation, and decision making: Organizational knowing as emergent strategy

Strategic management of intellectual capital and organizational knowledge (2006)

Google Scholar

105. 105

W.B. Stevenson, R.F. Radin

Social Capital and Social Influence on the Board of Directors

J. Manag. Stud., 46 (2009), pp. 16-44, 10.1111/j.1467-6486.2008.00800.x
View in ScopusGoogle Scholar

106. 106

S. Hampton, R. Blundel, A. Wahga, T. Fawcett, C. Shaw

Transforming small and medium-sized enterprises to address the climate emergency: The case for values-based engagement

Corp. Soc. Responsib. Environ. Manag., 29 (2022), pp. 1424-1439, 10.1002/csr.2279
View in ScopusGoogle Scholar

107. 107

D. Centola

Change: How to Make Big Things Happen

John Murray Publishers Ltd) (2021)

Google Scholar

108. 108

M.T. Ballew, A. Leiserowitz, C. Roser-Renouf, S.A. Rosenthal, J.E. Kotcher, J.R. Marlon, E. Lyon, M.H. Goldberg, E.W. Maibach

Climate Change in the American Mind: Data, Tools, and Trends

Environment, 61 (2019), pp. 4-18, 10.1080/00139157.2019.1589300
View in ScopusGoogle Scholar

109. 109

C. Funk

The Politics of Climate

Pew Research Center Science & Society (2016)

https://www.pewresearch.org/science/2016/10/04/the-politics-of-climate/
Google Scholar

110. 110

S. Chinn, P.S. Hart, S. Soroka

Politicization and Polarization in Climate Change News Content

Science Communication (2020), pp. 1985-2017, 10.1177/1075547019900290
Google Scholar

111. 111

M. Falkenberg, A. Galeazzi, M. Torricelli, N. Di Marco, F. Larosa, M. Sas, A. Mekacher, W. Pearce, F. Zollo, W. Quattrociocchi, A. Baronchelli

Growing polarization around climate change on social media

Nat. Clim. Change, 12 (2022), pp. 1114-1121, 10.1038/s41558-022-01527-x

View in ScopusGoogle Scholar

112. 112

J. King, L. Janulewicz, F. Arcostanzo

Deny, Deceive, Delay: Documenting and Responding to Climate Disinformation at COP26 and beyond

(2022)

Google Scholar

113. 113

L.D. Bevan, T. Colley, M. Workman

Climate change strategic narratives in the United Kingdom: Emergency, Extinction, Effectiveness

Energy Res. Social Sci., 69 (2020), Article 101580, 10.1016/j.erss.2020.101580
View PDFView articleView in ScopusGoogle Scholar

114. 114

L.E. Duncan, A.J. Stewart

Personal Political Salience: The Role of Personality in Collective Identity and Action

Polit. Psychol., 28 (2007), pp. 143-164, 10.1111/j.1467-9221.2007.00560.x
View in ScopusGoogle Scholar

115. 115

N. Curtin, A.J. Stewart, L.E. Duncan

What Makes the Political Personal? Openness, Personal Political Salience, and Activism

J. Pers., 78 (2010), pp. 943-968, 10.1111/j.1467-6494.2010.00638.x
View in ScopusGoogle Scholar

116. 116

C. Roser-Renouf, E.W. Maibach, A. Leiserowitz, X. Zhao

The genesis of climate change activism: from key beliefs to political action

Climatic Change, 125 (2014), pp. 163-178, 10.1007/s10584-014-1173-5
View in ScopusGoogle Scholar

117. 117

V. Cologna, G. Hoogendoorn, C. Brick

To strike or not to strike? an investigation of the determinants of strike participation at the Fridays for Future climate strikes in Switzerland

PLoS One, 16 (2021), Article e0257296, 10.1371/journal.pone.0257296
View in ScopusGoogle Scholar

118. 118

A. Brügger, M. Gubler, K. Steentjes, S.B. Capstick

Social Identity and Risk Perception Explain Participation in the Swiss Youth Climate Strikes

Sustainability, 12 (2020), Article 10605, 10.3390/su122410605
Google Scholar

119. 119

A. Furnham, H. Cheng

Personality traits and socio-demographic variables as predictors of political interest and voting behavior in a British cohort

J. Indiv. Differ., 40 (2019), pp. 118-125, 10.1027/1614-0001/a000283
View in ScopusGoogle Scholar

120. 120

E.E. Dim, J.Y. Asomah

Socio-demographic Predictors of Political participation among women in Nigeria: Insights from Afrobarometer 2015 Data

J. Int. Wom. Stud., 20 (2019), pp. 91-105

View in ScopusGoogle Scholar

121. 121

M. Kitanova

Youth political participation in the EU: evidence from a cross-national analysis

J. Youth Stud., 23 (2020), pp. 819-836, 10.1080/13676261.2019.1636951
View in ScopusGoogle Scholar

122. 122

M.H. Goldberg, A. Gustafson, M.T. Ballew, S.A. Rosenthal, A. Leiserowitz

Identifying the most important predictors of support for climate policy in the United States

Behav. Public Policy, 5 (2021), pp. 480-502, 10.1017/bpp.2020.39
View in ScopusGoogle Scholar

123. 123

Ipsos Mori, and CAST

Net Zero Living

Ipsos Mori and the Centre for Climate Change and Social Transformation (2022)

Google Scholar

124. 124

D.M. Kahan, E. Peters, M. Wittlin, P. Slovic, L.L. Ouellette, D. Braman, G. Mandel

The polarizing impact of science literacy and numeracy on perceived climate change risks

Nat. Clim. Change, 2 (2012), pp. 732-735, 10.1038/nclimate1547
View in ScopusGoogle Scholar

125. 125

C. Drummond, B. Fischhoff

Individuals with greater science literacy and education have more polarized beliefs on controversial science topics

Proc. Natl. Acad. Sci. USA, 114 (2017), pp. 9587-9592, 10.1073/pnas.1704882114
View in ScopusGoogle Scholar

126. 126

J.N. Druckman, M.C. McGrath

The evidence for motivated reasoning in climate change preference formation

Nat. Clim. Change, 9 (2019), pp. 111-119, 10.1038/s41558-018-0360-1
View in ScopusGoogle Scholar

127. 127

R. Bayes, J.N. Druckman

Motivated reasoning and climate change

Current Opinion in Behavioral Sciences, 42 (2021), pp. 27-35, 10.1016/j.cobeha.2021.02.009
View PDFView articleView in ScopusGoogle Scholar

128. 128

E.P. Hennes, T. Kim, L.J. Remache

A goldilocks critique of the hot cognition perspective on climate change skepticism

Current Opinion in Behavioral Sciences, 34 (2020), pp. 142-147, 10.1016/j.cobeha.2020.03.009

View PDFView articleView in ScopusGoogle Scholar

129. 129

C. Bataille, H. Waisman, Y. Briand, J. Svensson, A. Vogt-Schilb, M. Jaramillo, R. Delgado, R. Arguello, L. Clarke, T. Wild, *et al.*
Net-zero deep decarbonization pathways in Latin America: Challenges and opportunities

Energy Strategy Rev., 30 (2020), Article 100510, 10.1016/j.esr.2020.100510

View PDFView articleView in ScopusGoogle Scholar

130. 130

K. Riahi, D.P. van Vuuren, E. Kriegler, J. Edmonds, B.C. O'Neill, S. Fujimori, N. Bauer, K. Calvin, R. Dellink, O. Fricko, *et al.*
The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview

Global Environ. Change, 42 (2017), pp. 153-168, 10.1016/j.gloenvcha.2016.05.009

View PDFView articleView in ScopusGoogle Scholar

131. 131

National Grid

Future Energy Scenarios 2022

(2022)

Google Scholar

132. 132

R. Ford, C. Maidment, C. Vigurs, M.J. Fell, M. Morris

Smart local energy systems (SLES): A framework for exploring transition, context, and impacts

Technol. Forecast. Soc. Change, 166 (2021), Article 120612, 10.1016/j.techfore.2021.120612
View PDFView articleView in ScopusGoogle Scholar

133. 133

P. Selman

Social Capital, Sustainability and Environmental Planning

Plann. Theor. Pract., 2 (2001), pp. 13-30, 10.1080/14649350122850
View in ScopusGoogle Scholar

134. 134

Radio New Zealand

Extinction Rebellion Protesters Arrested at Coal Protest in Dunedin

RNZ (2021)

Google Scholar

135. 135

D. Gayle

Just Stop Oil Activists Throw Soup at Van Gogh's Sunflowers

The Guardian (2022)

Google Scholar

136. 136

F. Wu, E. Martus

Contested environmentalism: the politics of waste in China and Russia

Environ. Polit., 30 (2021), pp. 493-512, 10.1080/09644016.2020.1816367
View in ScopusGoogle Scholar

137. 137

K. Huang, M. Han

Did China’s Street Protests End Harsh COVID Policies? Council on Foreign Relations

(2022)

https://www.cfr.org/blog/did-chinas-street-protests-end-harsh-covid-policies
Google Scholar

138. 138

R. Green, J. Milner, A.D. Dangour, A. Haines, Z. Chalabi, A. Markandya, J. Spadaro, P. Wilkinson

The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change

Climatic Change, 129 (2015), pp. 253-265, 10.1007/s10584-015-1329-y
View in ScopusGoogle Scholar

139. 139

L. Aleksandrowicz, R. Green, E.J.M. Joy, P. Smith, A. Haines

The Impacts of Dietary Change on Greenhouse Gas Emissions, Land Use, Water Use, and Health: A Systematic Review

PLoS One, 11 (2016), Article e0165797, 10.1371/journal.pone.0165797
View in ScopusGoogle Scholar

140. 140

CAST

The Road to Net Zero: UK Public Preferences for Low-Carbon Lifestyles

Centre for Climate Change and Social Transformations (2022)

Google Scholar

141. 141

W. Abrahamse

How to Effectively Encourage Sustainable Food Choices: A Mini-Review of Available Evidence

Front. Psychol., 11 (2020), p. 589674

View in ScopusGoogle Scholar

142. 142

A. Arno, S. Thomas

The efficacy of nudge theory strategies in influencing adult dietary behaviour: a systematic review and meta-analysis

BMC Publ. Health, 16 (2016), p. 676, 10.1186/s12889-016-3272-x
View in ScopusGoogle Scholar

143. 143

M. Giaccherini, M. Gilli, S. Mancinelli, M. Zoli

Nudging food waste decisions at restaurants

Eur. Econ. Rev., 135 (2021), Article 103722, 10.1016/j.euroecorev.2021.103722
View PDFView articleView in ScopusGoogle Scholar

144. 144

G. Sparkman, G.M. Walton

Dynamic Norms Promote Sustainable Behavior, Even if It Is Counternormative

Psychol. Sci., 28 (2017), pp. 1663-1674, 10.1177/0956797617719950
View in ScopusGoogle Scholar

145. 145

F. Bianchi, E. Garnett, C. Dorsel, P. Aveyard, S.A. Jebb

Restructuring physical micro-environments to reduce the demand for meat: a systematic review and qualitative comparative analysis

Lancet Planet. Health, 2 (2018), pp. e384-e397, 10.1016/S2542-5196(18)30188-8
View PDFView articleView in ScopusGoogle Scholar

146. 146

F. Bianchi, C. Dorsel, E. Garnett, P. Aveyard, S.A. Jebb

Interventions targeting conscious determinants of human behaviour to reduce the demand for meat: a systematic review with qualitative comparative analysis

Int. J. Behav. Nutr. Phys. Activ., 15 (2018), p. 102, 10.1186/s12966-018-0729-6
View in ScopusGoogle Scholar

147. 147

WRAP

Portion Size Is the Main Reason for Plate Waste when We Eat Out

WRAP (2023)

https://wrap.org.uk/media-centre/press-releases/portion-size-main-reason-plate-waste-when-we-eat-out
Google Scholar

148. 148

Behavioural Insights Team

A Menu for Change: Using Behavioural Science to Promote Sustainable Diets Around the World

(2020)

Google Scholar

149. 149

C. Brown, A. Krishna

The Skeptical Shopper: A Metacognitive Account for the Effects of Default Options on Choice

J. Consum. Res., 31 (2004), pp. 529-539, 10.1086/425087
View in ScopusGoogle Scholar

150. 150

J.M.T. Krijnen, D. Tannenbaum, C.R. Fox

Choice architecture 2.0: Behavioral policy as an implicit social interaction

Behavioral Science & Policy, 3 (2017)

i–18

Google Scholar

151. 151

P.G. Hansen, M. Schilling, M.S. Malthesen

Nudging healthy and sustainable food choices: three randomized controlled field experiments using a vegetarian lunch-default as a normative signal

J. Public Health, 43 (2021), pp. 392-397, 10.1093/pubmed/fdz154
View in ScopusGoogle Scholar

152. 152

J. Meier, M.A. Andor, F. Doebbe, N. Haddaway, L.A. Reisch

Can Green Defaults Reduce Meat Consumption?

(2021), 10.2139/ssrn.3903160
Google Scholar

153. 153

A. Buxton

Tables Turned: Customers Had to Request Meat at Burger King Austria as Plant-Based Became the Default

Plant Based News (2022)

https://plantbasednews.org/lifestyle/food/burger-king-austria-meat-the-exception/
Google Scholar

154. 154

S. Wunderlich, M. Smoller

Consumer awareness and knowledge about food sources and possible environmental impact

Int. J. El., 2 (2019), pp. 85-96, 10.2495/EI-V2-N1-85-96
View in ScopusGoogle Scholar

155. 155

G. Borghesi, R. Stefanini, G. Vignali

Are consumers aware of products' environmental impacts? Different results between life cycle assessment data and consumers' opinions: the case study of organic Parmigiano Reggiano and its packaging

Int. J. Food Eng., 18 (2022), pp. 185-192, 10.1515/ijfe-2021-0025
View in ScopusGoogle Scholar

156. 156

B. Boardman

Carbon labelling: too complex or will it transform our buying?

Signif. (Oxf)., 5 (2008), pp. 168-171, 10.1111/j.1740-9713.2008.00322.x
View in ScopusGoogle Scholar

157. 157

F. Schaefer, M. Blanke

Opportunities and Challenges of Carbon Footprint, Climate or CO2 Labelling for Horticultural Products

Erwerbsobstbau, 56 (2014), pp. 73-80, 10.1007/s10341-014-0206-6
View in ScopusGoogle Scholar

158. 158

K.M.R. Taufique, K.S. Nielsen, T. Dietz, R. Shwom, P.C. Stern, M.P. Vandenbergh

Revisiting the promise of carbon labelling

Nat. Clim. Change, 12 (2022), pp. 132-140, 10.1038/s41558-021-01271-8
View in ScopusGoogle Scholar

159. 159

U.A. Schneider, L. Rasche, K. Jantke

Farm-level digital monitoring of greenhouse gas emissions from livestock systems could facilitate control, optimisation and labelling

Journal of Sustainable Organic Agricultural system, 69 (2019), pp. 9-12, 10.3220/LBF1580734769000
View in ScopusGoogle Scholar

160. 160

V.P. Gandhi, Z. Zhou

Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China

Food Res. Int., 63 (2014), pp. 108-124, 10.1016/j.foodres.2014.03.015
View PDFView articleView in ScopusGoogle Scholar

161. 161

J. Karstensen, G.P. Peters, R.M. Andrew

Attribution of CO2 emissions from Brazilian deforestation to consumers between 1990 and 2010

Environ. Res. Lett., 8 (2013), Article 024005, 10.1088/1748-9326/8/2/024005

View in ScopusGoogle Scholar

162. 162

J. Fassler

Lab-grown Meat Is Supposed to Be Inevitable. The Science Tells a Different Story

The Counter (2021)

Google Scholar

163. 163

M. Zurek, A. Hebinck, O. Selomane

Climate change and the urgency to transform food systems

Science, 376 (2022), pp. 1416-1421, 10.1126/science.abo2364
View in ScopusGoogle Scholar

164. 164

European Environment Agency

Greenhouse Gas Emissions from Transport in Europe

(2022)

Google Scholar

165. 165

IEA

World Energy Investment 2022

(2022)

Google Scholar

166. 166

OECD

Investing in Climate, Investing in Growth

(2017)

Google Scholar

167. 167

S. Cairns, L. Sloman, C. Newson, J. Anable, A. Kirkbride, P. Goodwin

Smarter Choices: Assessing the Potential to Achieve Traffic Reduction Using 'Soft Measures

Transp. Rev., 28 (2008), pp. 593-618, 10.1080/01441640801892504
View in ScopusGoogle Scholar

168. 168

P. Mock

Decoupling Emissions from Growing Traffic Volume

International Council on Clean Transportation (2012)

https://theicct.org/decoupling-emissions-from-growing-traffic-volume/
Google Scholar

169. 169

Department for Transport

Road Traffic Estimates: Great Britain 2021

(2022)

Google Scholar

170. 170

C. Brand, A. Jillian, M. Greg

The Role of Energy Demand Reduction in Achieving Net-Zero in the UK: Transport and Mobility

Centre for Research into Energy Demand Solutions (2021)

Google Scholar

171. 171

L. Castellazzi, P. Bertoldi, M. Economidou

Overcoming the Split Incentive Barrier in the Building Sector

Publications Office of the European Union (2017)

Google Scholar

172. 172

C. Moreno, Z. Allam, D. Chabaud, C. Gall, F. Pratlong

Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities

Smart Cities, 4 (2021), pp. 93-111, 10.3390/smartcities4010006
View in ScopusGoogle Scholar

173. 173

OECD

Teleworking in the COVID-19 Pandemic

(2021)

Google Scholar

174. 174

Office for National Statistics

Is Hybrid Working Here to Stay?

(2022)

Google Scholar

175. 175

J. Anable, B. Llinos, I. Docherty, G. Marsden

Less Is More: Changing Travel in a Post-pandemic Society

Centre for Research into Energy Demand Solutions (2022)

Google Scholar

176. 176

Bureau of Transportation Statistics

Transportation Statistics Annual Report 2021

US Department of Transportation (2021)

Google Scholar

177. 177

S. Kraus, N. Koch

Provisional COVID-19 infrastructure induces large, rapid increases in cycling

Proc. Natl. Acad. Sci. USA, 118 (2021), Article e2024399118, 10.1073/pnas.2024399118
View in ScopusGoogle Scholar

178. 178

A. Jáuregui, E.V. Lambert, J. Panter, C. Moore, D. Salvo

Scaling up urban infrastructure for physical activity in the COVID-19 pandemic and beyond

Lancet, 398 (2021), pp. 370-372, 10.1016/S0140-6736(21)01599-3
View PDFView articleView in ScopusGoogle Scholar

179. 179

A. Nelson

Riding in Riverside: The Rail-Bus Divide. Riding in Riverside

(2011)

http://ridinginriverside.blogspot.com/2011/08/rail-bus-divide.html
Google Scholar

180. 180

A. Shrikant

The Bus Gets a Lot of Hate. American Cities Are Trying to Change that

Vox (2018)

Google Scholar

181. 181

TFL

Congestion Charging: Impacts Monitoring

Second Annual Report (Transport for London) (2004)

Google Scholar

182. 182

H. Allcott

Social norms and energy conservation

J. Publ. Econ., 95 (2011), pp. 1082-1095, 10.1016/j.jpubeco.2011.03.003
View PDFView articleView in ScopusGoogle Scholar

183. 183

J. Carroll, S. Lyons, E. Denny

Reducing household electricity demand through smart metering: The role of improved information about energy saving

Energy Econ., 45 (2014), pp. 234-243, 10.1016/j.eneco.2014.07.007
View PDFView articleView in ScopusGoogle Scholar

184. 184

BEIS

Smart Meter Roll-Out: Cost-Benefit Analysis

(2019)

Google Scholar

185. 185

S. Oliveira, E. Prestwood, T. Chatterton, A. Poghosyan, B. Gething

Heating Controls: International Evidence Base and Policy Experiences

Department of Business, Energy and Industrial Strategy (2017)

Google Scholar

186. 186

T. Park

Evaluating the Nest Learning Thermostat-Four Field Experiments Evaluating the Energy Saving Potential of Nest's Smart Heating Control (Behavioural Insights Team)

(2017)

Google Scholar

187. 187

F. Wade, M. Shipworth, R. Hitchings

How installers select and explain domestic heating controls

Build. Res. Inf., 45 (2017), pp. 371-383, 10.1080/09613218.2016.1159484
View in ScopusGoogle Scholar

188. 188

F. Wade

Routinised heating system installation: The immutability of home heating

Energy Efficiency, 13 (2020), pp. 971-989, 10.1007/s12053-020-09867-3
View in ScopusGoogle Scholar

189. 189

C. Ahern, B. Norton

Energy savings across EU domestic building stock by optimizing hydraulic distribution in domestic space heating systems

Energy Build., 91 (2015), pp. 199-209, 10.1016/j.enbuild.2015.01.014
View PDFView articleView in ScopusGoogle Scholar

190. 190

Wunderflats

Green Living Index 2022

(2022)

Google Scholar

191. 191

Tado

UK Homes Losing Heat up to Three Times Faster than European Neighbours

Press Release (2020)

https://www.tado.com/gb-en/press/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours
Google Scholar

192. 192

J. Rosenow, N. Eyre

A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy

Energy Res. Social Sci., 21 (2016), pp. 141-144

View PDFView articleView in ScopusGoogle Scholar

193. 193

IEA

Solar PV

International Energy Agency (2022)

Google Scholar

194. 194

J. Jackman

Which Countries Are Winning the Heat Pump Race? the Eco Experts

(2021)

https://www.theecoexperts.co.uk/heat-pumps/top-countries
Google Scholar

195. 195

European Heat Pump Association

Market Data. European Heat Pump Association

(2022)

https://www.ehpa.org/market-data/
Google Scholar

196. 196

A.S. Gaur, D.Z. Fitiwi, J. Curtis

Heat pumps and our low-carbon future: A comprehensive review

Energy Res. Social Sci., 71 (2021), Article 101764, 10.1016/j.erss.2020.101764
View PDFView articleView in ScopusGoogle Scholar

197. 197

R. Khosla, N.D. Miranda, P.A. Trotter, A. Mazzone, R. Renaldi, C. McElroy, F. Cohen, A. Jani, R. Perera-Salazar, M. McCulloch

Cooling for sustainable development

Nat. Sustain., 4 (2020), pp. 201-208, 10.1038/s41893-020-00627-w
Google Scholar

198. 198

IEA

The Future of Cooling

International Energy Agency (2018)

Google Scholar

199. 199

Buildings Energy Efficiency Taskgroup

Minimum Energy Standards for Rented Properties: An International Review

Department of Climate Change, Energy, the Environment and Water (2020)

Australian Government)

Google Scholar

200. 200

S. Amelang

Germany Splits CO2 Price for Heating between Landlords and Tenants

Clean Energy Wire (2022)

Google Scholar

201. 201

Deutscher Bundestag

Act on the Allocation of Carbon Dioxide Costs (Carbon Dioxide Cost Allocation Act - CO2KostAufG)

(2022)

Google Scholar

202. 202

M. Meissner

Against accumulation: lifestyle minimalism, de-growth and the present post-ecological condition

Journal of Cultural Economy, 12 (2019), pp. 185-200, 10.1080/17530350.2019.1570962
View in ScopusGoogle Scholar

203. 203

A. Parriaux

Do single-use plastic bans work?

(2022)

https://www.bbc.com/future/article/20220711-do-single-use-plastic-bans-work

Google Scholar

204. 204

Ipsos Mori, and King's College London

Public Concern about Plastic and Packaging Waste Is Not Backed up by Willingness to Act

Ipsos (2018)

https://www.ipsos.com/en-uk/public-concern-about-plastic-and-packaging-waste-not-backed-willingness-act
Google Scholar

205. 205

E. Gray

Attitudes towards Single-Use Plastics (Ipsos)

(2022)

Google Scholar

206. 206

European Environment Agency

Paving the Way for a Circular Economy: Insights on Status and Potentials

(2019)

Google Scholar

207. 207

C.E. Cherry, N.F. Pidgeon

Is sharing the solution? Exploring public acceptability of the sharing economy

J. Clean. Prod., 195 (2018), pp. 939-948, 10.1016/j.jclepro.2018.05.278
View PDFView articleView in ScopusGoogle Scholar

208. 208

I. Murphy

Brands Need to Simplify Sustainability

RedC Research & Marketing (2021)

https://redcresearch.ie/sustainability-headlines-march-2021/
Google Scholar

209. 209

Competition and Markets Authority

Global Sweep Finds 40% of Firms' Green Claims Could Be Misleading. GOV.UK

(2021)

https://www.gov.uk/government/news/global-sweep-finds-40-of-firms-green-claims-could-be-misleading
Google Scholar

210. 210

R.A. Howell

Carbon management at the household level: a definition of carbon literacy and three mechanisms that increase it

Carbon Manag., 9 (2018), pp. 25-35, 10.1080/17583004.2017.1409045
View in ScopusGoogle Scholar

211. 211

W. Ejaz, M. Mukherjee, R. Fletcher, R.K. Nielsen

How We Follow Climate Change: Climate News Use and Attitudes in Eight Countries

(2022), p. 45

Google Scholar

212. 212

J.T. Carmichael, R.J. Brulle

Elite cues, media coverage, and public concern: an integrated path analysis of public opinion on climate change, 2001–2013

Environ. Polit., 26 (2017), pp. 232-252, 10.1080/09644016.2016.1263433
View in ScopusGoogle Scholar

213. 213

T. Deryugina, O. Shurchkov

The Effect of Information Provision on Public Consensus about Climate Change

PLoS One, 11 (2016), Article e0151469, 10.1371/journal.pone.0151469
View in ScopusGoogle Scholar

214. 214

Greenpeace

How to Talk about Climate Change with Friends and Family

Greenpeace UK (2021)

https://www.greenpeace.org.uk/news/how-to-talk-about-climate-change-family-friends-conversation/
Google Scholar

215. 215

World Economic Forum

Why We Need a New Social Contract for the 21st Century

World Economic Forum (2022)

https://www.weforum.org/agenda/2022/01/a-new-social-contract-for-21st-century/
Google Scholar

216. 216

The Nature Conservancy

How to Talk about Climate Change

(2018)

https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/can-we-talk-climate/
Google Scholar

217. 217

T. Hargreaves

Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change

J. Consum. Cult., 11 (2011), pp. 79-99, 10.1177/1469540510390500
View in ScopusGoogle Scholar

218. 218

C. Shaw, A. Corner

Using Narrative Workshops to socialise the climate debate: Lessons from two case studies – centre-right audiences and the Scottish public

Energy Res. Social Sci., 31 (2017), pp. 273-283, 10.1016/j.erss.2017.06.029
View PDFView articleView in ScopusGoogle Scholar

219. 219

C. Verfuerth, D. Gregory-Smith

Spillover of pro-environmental behaviour

Research Handbook on Employee Pro-Environmental Behaviour (2018), pp. 455-484

View in ScopusGoogle Scholar

220. 220

C. Verfuerth, D. Gregory-Smith, C.J. Oates, C.R. Jones, P. Alevizou

Reducing meat consumption at work and at home: facilitators and barriers that influence contextual spillover

J. Market. Manag., 37 (2021), pp. 671-702, 10.1080/0267257X.2021.1888773
View in ScopusGoogle Scholar

221. 221

A. Fenton

Millennials Are Looking for Greener Places to Work

Yahoo Finance (2019)

Google Scholar

222. 222

KPMG

Climate Quitting - Younger Workers Voting with Their Feet on Employer's ESG Commitments

KPMG (2023)

https://kpmg.com/uk/en/home/media/press-releases/2023/01/climate-quitting-younger-workers-voting-esg.html
Google Scholar

223. 223

A. Gaskell

Employees Demand that We Become More Sustainable

Forbes (2021)

https://www.forbes.com/sites/adigaskell/2021/10/31/employees-demand-that-we-become-more-sustainable/
Google Scholar

224. 224

OECD

Unemployment Rate (Indicator)

(2023)

https://data.oecd.org/unemp/unemployment-rate.htm
Google Scholar

225. 225

D. Sproull

New Study Shows Employees Seek and Stay Loyal to Greener Companies. swytchX

(2019)

https://medium.com/swytch/new-study-shows-employees-seek-and-stay-loyal-to-greener-companies-f485889f9a7f
Google Scholar

226. 226

I. Tharoor

Analysis | Bolsonaro, Trump and the Nationalists Ignoring Climate Disaster

Washington Post (2019)

Google Scholar

227. 227

C. Wolsko, H. Ariceaga, J. Seiden

Red, white, and blue enough to be green: Effects of moral framing on climate change attitudes and conservation behaviors

J. Exp. Soc. Psychol., 65 (2016), pp. 7-19, 10.1016/j.jesp.2016.02.005
View PDFView articleView in ScopusGoogle Scholar

228. 228

A. Corner, E. Markowitz, N. Pidgeon

Public engagement with climate change: the role of human values

WIREs Clim. Change, 5 (2014), pp. 411-422, 10.1002/wcc.269
View in ScopusGoogle Scholar

229. 229

L. Whitmarsh, A. Corner

Tools for a new climate conversation: A mixed-methods study of language for public engagement across the political spectrum

Global Environ. Change, 42 (2017), pp. 122-135, 10.1016/j.gloenvcha.2016.12.008
View PDFView articleView in ScopusGoogle Scholar

230. 230

S.J. O'Neill, N. Smith

Climate change and visual imagery

WIREs Climate Change, 5 (2014), pp. 73-87, 10.1002/wcc.249
View at publisherView in ScopusGoogle Scholar

231. 231

M.C. McGrath

Experiments on problems of climate change

Advances in Experimental Political Science, Cambridge University Press (2020), pp. 606-629

Google Scholar

232. 232

R. Borghesi

Employee political affiliation as a driver of corporate social responsibility intensity

Appl. Econ., 50 (2018), pp. 2117-2132, 10.1080/00036846.2017.1388911
View at publisherView in ScopusGoogle Scholar

233. 233

D.R. Fisher, S. Nasrin

Climate activism and its effects

WIREs Clim. Change, 12 (2021), p. e683, 10.1002/wcc.683
View at publisherView in ScopusGoogle Scholar

234. 234

T. Bolsen, M.A. Shapiro

The US News Media, Polarization on Climate Change, and Pathways to Effective Communication

Environmental Communication, 12 (2018), pp. 149-163, 10.1080/17524032.2017.1397039
View in ScopusGoogle Scholar

235. 235

UCL

"Let the People Decide" – Is Participatory Democracy the Answer to the Climate Crisis? Global Governance Institute

(2022)

https://www.ucl.ac.uk/global-governance/research/let-people-decide-participatory-democracy-answer-climate-crisis
Google Scholar

236. 236

R. Willis

Too Hot to Handle?: The Democratic Challenge of Climate Change

(1st ed.), Bristol University Press (2020), 10.2307/j.ctvz938kb
Google Scholar

237. 237

J. Boswell, R. Dean, G. Smith

Integrating citizen deliberation into climate governance: Lessons on robust design from six climate assemblies

Public Administration *n/a*., 101 (2022), pp. 182-200, 10.1111/padm.12883
Google Scholar

238. 238

E.A. Soto, L.B. Bosman, E. Wollega, W.D. Leon-Salas

Peer-to-peer energy trading: A review of the literature

Appl. Energy, 283 (2021), Article 116268

View PDFView articleView in ScopusGoogle Scholar

239. 239

R.D. Longa

Urban Infrastructure: Globalization/Slowbalization

Springer Nature (2023)

Google Scholar

240. 240

Sillito

Tuesday to Thursday Is the New Office Working Week, Data Suggests

BBC News (2023)

Google Scholar

241. 241

Behavioural Insights Team

How to Build a Net Zero Society: Using Behavioural Insights to Decarbonise Home Energy, Transport, Food, and Material Consumption

(2023)

Google Scholar

242. 242

J. Walenta

Climate risk assessments and science-based targets: A review of emerging private sector climate action tools

WIREs Clim. Change, 11 (2020), p. e628, 10.1002/wcc.628
View at publisherView in ScopusGoogle Scholar

Cited by (28)

- Current research practices on pro-environmental behavior: A survey of environmental psychologists
  2024, Journal of Environmental Psychology

Citation Excerpt :

For example, civic and leadership behaviors were almost exclusively measured with self-report. Without making any strong claims about typologies of pro-environmental behavior, the most frequently studied behaviors appear to be in the role of consumer rather than citizen or advocate (Hampton & Whitmarsh, 2023; Nielsen, Nicholas, Creutzig, Dietz, & Stern, 2021). All behaviors were considered relatively important to the wider environmental psychology community, Ms (SDs) = 3.5–6.0 (1.1–1.8).
Show abstract

- ## Carbon capability revisited: Theoretical developments and empirical evidence
  2024, Global Environmental Change

  Whereas previous CC scholarship has focused on individuals' adoption of low-carbon behaviours in their own lives (micro-scale), or direct engagement with systems of provision (macro-scale), our study has added to this by highlighting the importance of meso-scale practices, such as those relating to social influence and organisational membership. At this level, businesses are crucial actors in shaping choice environments through 'midstream' measures such as increasing the variety of low-carbon options, introducing low-carbon defaults or other 'nudges' (Behavioural Insights Team, 2023; Hampton and Whitmarsh, 2023). These help to establish low-carbon norms and build communities of CC.
  Show abstract

- ## Affective responses drive the impact neglect in sustainable behavior
  2023, iScience

  Citation Excerpt :

  In addition, a plethora of research studies and perspectives support the view that human behavior is central to how we mitigate the effects of climate change.2,3,4,5,6 Various human behaviors would reduce emissions such as consuming low-carbon products and services as well as supporting policies and technologies aimed at creating sustainable systems.7 Here, our focus lies on the former: mitigative human behaviors aimed at reducing emissions (e.g., purchasing low-carbon products, adopting a plant-based low-carbon diet, reducing air transport, and so forth).1

POLICY , MITIGATION AND LOW CARBON DEVELOPMENT

Policy and mitigation and low carbon development" refers to government strategies aimed at reducing greenhouse gas emissions (mitigation) by promoting economic development pathways that minimize carbon footprint, often achieved through policies that encourage renewable energy, energy efficiency, sustainable transportation, and responsible land use practices, all while considering the needs of economic growth and social development.

Key points about policy and mitigation in low carbon development:

- **Goal:**

  To transition towards a low-carbon economy by actively reducing emissions across various sectors like energy, industry, transportation, and agriculture while still enabling economic progress.
- **Policy instruments:**
- **Carbon pricing:** Implementing carbon taxes or cap-and-trade systems to incentivize emissions reductions.
- **Renewable energy mandates:** Setting targets for the percentage of electricity generated from renewable sources like solar and wind.
- **Energy efficiency standards:** Setting minimum efficiency requirements for appliances and buildings.
- **Investment in clean technologies:** Providing financial support for research and development of low-carbon technologies.
- **Sustainable transportation policies:** Promoting public transport, electric vehicles, and improved fuel efficiency standards.
  Mitigation strategies within low carbon development:
- **Shifting to renewable energy:** Investing in solar, wind, geothermal, and hydropower.
- **Improving energy efficiency:** Implementing measures to reduce energy consumption in buildings and industries.
- **Carbon capture and storage (CCS):** Technologies to capture CO_2 emissions from power plants and store them underground.
- **Sustainable land use practices:** Protecting forests, promoting reforestation, and managing agricultural practices to reduce emissions.
  Challenges and considerations:
- **Economic costs:** Balancing the need for emissions reduction with maintaining economic competitiveness.
- **Social equity:** Ensuring that low carbon policies do not disproportionately impact vulnerable populations.
- **International cooperation:** Addressing the global nature of climate change requiring coordinated efforts between countries.

The Overseas Development Institute (ODI) has reviewed the **low carbon growth and climate change response strategies** of a range of countries with differing economic characteristics to draw out the policy implications for developing countries at different stages of development (Ellis et al., 2009). The study, financed by the UK Department for International Development (DFID), selected a crosssection of high-, middle- and low-income countries to conduct a balanced review of low carbon growth policies. High-income countries (HICs) included Germany and the United Kingdom. Middleincome countries (MICs) included China, Brazil, Guyana, Mexico and Nigeria. Low-income countries included Bangladesh, and Ethiopia. Shorter 'snapshots' were also provided for South Korea, India, Malawi, Rwanda and South Africa. These countries were chosen because they indicate the range of activities being carried out. All have published official documents outlining their climate change policies, such as national strategy documents, National Adaptation Programme of Action (NAPA) reports to the UN Framework Convention on Climate Change (UNFCCC), and national communications to the UNFCCC. Growth has been, historically, highly correlated with carbon emissions. In light of the impact that this has had on climate change, new, low carbon growth strategies are being sought, i.e. policymakers are now seeking to achieve growth pathways that are associated with relatively low increases in carbon emissions. Many developing countries have struggled to achieve any kind of sustained growth however, and have contributed little to the problem of climate change. The question for them will be how to achieve growth at all, particularly in light of climate change and international mitigation policies and the impact these are having on their economies. These countries will need to find climate resilient growth strategies (i.e. growth strategies which are achievable despite the impact of climate change), and identify and manage opportunities (such as new markets) and risks (such as trade barriers) that arise from international mitigation efforts, in order to achieve growth in future. Having an appropriate policy framework in place (such as a NAPA or Nationally Appropriate Mitigation Actions (NAMA)), is likely to help countries secure public and private funding for adaptation and mitigation. Identification of future mitigation opportunities and low carbon growth trajectories could thus be important, even for countries that have achieved only low growth rates to date. This will allow such countries to position themselves to take maximum advantage of new opportunities that may arise. For this reason we have considered both low carbon and climate resilient growth strategies in this report, as well as strategies to maximise growth potential arising from international mitigation efforts going forward. The report draws on the case studies and other relevant literature to identify possible policy lessons and discuss the extent to which low carbon growth challenges traditional growth theory and policies. Achieving low carbon growth clearly has major implications for policy, and implies considerable adjustment of the traditional growth agenda. However, low carbon growth does not present a major challenge to traditional growth theory, it simply requires the internalisation of the environmental costs of growth through the appropriate pricing of goods and services. This can be achieved through a range of mitigation policies, such as taxes on the production or consumption of carbon intensive goods. Policies for Low Carbon Growth vii The potential impact of mitigation policies on growth is unclear. Constraints on emissions raise the cost of energy which, in turn, reduces the output that can be achieved with a given set of inputs. No consensus exists on the costs of mitigation however, which will depend on the efficiency and nature of the policies adopted, and the extent of technological innovation achieved. And mitigation could also generate new growth opportunities, which would offset those costs. This could be the case if, for example, there is fast growth in demand for environmental goods and services. Significant co-benefits associated with mitigation could also occur if there are strong synergies between green technology change and industrial technological progress, which is a key source of growth. Policies designed to promote green technological innovation and technology transfer could thus also potentially increase growth. In addition, some mitigation policies generate revenues (e.g. carbon taxes) and provide opportunities to stimulate growth through the judicious use of the revenues raised. Thus the design of national mitigation policies and the way incentive mechanisms for low carbon growth are created will determine overall growth effects. The literature on this is mixed however, and modelling results depend enormously on the particular assumptions that are used. While much of the literature on mitigation suggests an overall negative impact on growth, a recent report by The Climate Group finds that a global climate agreement could lead to an increase in global GDP of 0.8% by 2020 relative to projected GDP with no climate action. In addition to the overall impact of mitigation on global growth, the distribution of mitigation efforts will be important in determining the growth impacts in different parts of the world. Rich countries may need to accept lower rates of growth in future, if developing countries are to have the necessary space to grow their way out of poverty. The way that revenues from international mitigation efforts are used will also be important. For example, if auction revenue raised from permit sales in carbon cap-and-trade schemes is then used to finance mitigation or adaptation in developing countries, this could generate significant gains for recipient countries. Mitigation policies will affect different sectors in different ways and are likely to imply adjustments to the sectoral sources of growth enjoyed previously by some countries. For example, mitigation policies which drive down the price of oil will generate a net loss for oil exporting countries and net gain for oil importers. Air transport taxes might reduce demand for tourism or for air freighted exports such as fruit and vegetables. Carbon taxes may generate carbon leakage (i.e. the shift of dirty industry to pollution havens) and reduce income associated with carbon intensive products. The impact of these policies will vary significantly by country, depending on their sectoral composition. The analysis of the potential impact of different kinds of mitigation policies is fairly limited to date and the subject of a forthcoming ODI study. A key determinant of the impact of international efforts to mitigate climate change on developing countries' growth paths will be the policies adopted by developing countries to adapt, mitigate and strategically position themselves in order to benefit from these international mitigation responses. This is likely to include the pursuit of a low carbon growth path as a prerequisite for receiving finance either for mitigation or adaptation. Appropriate policies can help to position countries to take advantage of new economic opportunities that may arise and can also help protect countries from threats to their growth arising from climate change or its mitigation. Identifying policy implications To aid comparison across countries, and with conventional growth policies, the review has been structured around the following six key pillars: Policies for Low Carbon Growth 1. Finance for mitigation and adaptation; 2. Human capital; 3. Technological progress in energy, infrastructure and transportation; 4. Investment in agriculture and forestry; 5. Trade and private investment opportunities; 6. Incentives and regulation for low carbon growth. We have reviewed case studies and literature under each of these pillars and identified the following possible policy lessons. (A more detailed discussion of policy implications drawn from the country policy reviews is contained in the full version of this report.) Finance for mitigation and adaptation

• For the international policy community, the achievement of an international agreement on emissions reductions is a priority to help unlock private finance for mitigation.

• Countries can be strategic in how they position themselves to attract finance for mitigation and adaptation. For example, the development of a 'Climate Change Fund'/multi-donor trust fund, and an appropriate policy framework e.g. a NAPA, NAMA, and/or a low carbon growth strategy, can help to convince donors that climate change is taken seriously in that country, and that any funding will be spent transparently and effectively.

• Developing countries need to continue to lobby for financial support for mitigation and adaptation, and for reform that will help them benefit more from carbon markets, including the Clean Development Mechanism (CDM).

• For countries with carbon assets, strategic positioning, policy development, and lobbying for financial support for mitigation and adaptation, may help to both influence the international agenda, and the development of international mitigation mechanisms, such as Reduced Emissions from Deforestation and Forest Degradation (REDD) and CDM, in their favour, both in terms of scope and scale.

• Widening the scope of carbon markets to enable more LICs to benefit, and improving the investment climate in developing countries may also help them to maximise financial inflows of private finance for mitigation.

• Not all developing countries will be able to obtain private finance for mitigation and adaptation. Increasing the availability of public finance will also be important in supporting developing countries' low carbon growth efforts. Human capital

• Broad awareness-raising may help increase public understanding of climate change and its effects, and the implications for people's livelihoods and welfare going forward. This can be implemented formally, for example through schools, or informally, through public awareness campaigns.

• Training in skills relating to green technologies and industries can help position countries to take advantage of any new low carbon growth opportunities and markets.

• Targeted investments in health, water and sanitation may help increase climate resilience by protecting human capital from the potential negative health impacts of climate change. Technological progress in energy, infrastructure and transportation

• Infrastructure improvements and the development of clean energy options should be made as soon as possible to reduce emissions as well as adapt to potential impacts. This will avoid locking in high-carbon technologies and processes as demand for energy rises. The development of decentralised grids may offer co-benefits between greener energy production, and increased access to energy.

• Strategic thinking and strong policy management of patterns of urbanisation may be required to increase climate resilience and facilitate low carbon growth. Policies for Low Carbon Growth ix

• Government can play an important role in clarifying the future direction of policy and the key decisions that will be made on energy production and infrastructure development, to give business the confidence it needs to undertake low carbon investments.

• It is critical for low-income countries to receive international support and technology transfer to facilitate their transition to a low carbon economy. Greater efforts to promote international cooperation on research and development may help to promote technological diffusion. A re-examination of intellectual property provisions in the World Trade Organization (WTO) may also be needed.

• Countries should identify renewable resources that provide the greatest advantage in view of local conditions, resources, and state of development.

• The future development, demonstration and transfer of technology for carbon capture and storage will be very important for countries that continue to develop their large coal reserves.

• Governments in all countries can benefit from working with the private sector and civil society to scale up renewable technologies, from improved cook-stoves to large-scale wind and solar to hydropower.

• Transport is best approached holistically and should include public transport, clean, sustainable fuels, and efficient vehicles.

• Biofuels offer a potentially important new export opportunity for some developing countries, although major developed countries still impose protection on biofuel imports. Investment in agriculture and forestry

• Greater understanding and awareness of the impact of climate change on agricultural productivity, and shifts in demand for agricultural produce will help developing countries to improve climate resilience and take advantage of possible new growth opportunities. Education of farmers will be an important component in this.

• Comprehensive approaches that include improved agronomic practices; climate-resistant crop varieties; water, soil and fertiliser management, and better livestock management are needed.

• Adaptation efforts in agriculture may be most important in poor countries that rely disproportionately on agriculture and are likely to be most affected by climate change.

• Forestry payments present a significant potential financing opportunity for some countries, if international mechanisms such as REDD can be successfully developed.

• Countries that develop a rigorous, comprehensive, transparent and inclusive process around sustainable forest management may be more likely to secure international investments and future CDM benefits and turn them into successful alternative growth strategies and conservation of forests.

• Agriculture offers considerable potential sequestration benefits though there are significant barriers to attracting carbon finance for this sector. Trade and private investment opportunities

• Countries that identify, target and secure new green investment and growth opportunities stand to benefit more from the transition to a low carbon economy.

• There is a role for government leadership to identify low carbon growth sectors which may provide competitive advantage and employment growth.

• The development of new opportunities must be backed by sufficient support and funding from government and the international community. This includes the creation of an appropriate policy environment; provision of the necessary training/education; investment promotion and awareness raising; and collaborative partnerships between the public, private and NGO sectors. Policies for Low Carbon Growth x Incentives and regulation for low carbon growth

• Internationally coordinated action to mitigate climate change can help reduce the risk of a 'race to the bottom' in relation to the taxation and regulation needed to stimulate low carbon growth.

• Donor support for low carbon regulation and taxation could help build developing countries' capacity to implement such policies effectively.

• An ongoing review of the efficacy and cost-effectiveness of measures by different countries to incentivise the necessary changes in behaviour and stimulate low carbon growth, could help improve policy-making in this area.

• Many of the barriers to low carbon growth, mitigation financing and technological transfer in developing countries are the same as the barriers to growth and investment generally i.e. a poor investment climate and uncompetitive markets. Policies to tackle these remain important. Policy processes In our review, we also looked at the policy processes adopted in each country. Possible lessons include:

• Policy statements should go beyond 'statements of intent' to provide a roadmap for specific measures and an implementation plan.

• Policy is strengthened by underpinning studies.

• Consultations help to obtain ideas and include various stakeholder viewpoints; promote coordination and collaboration, and enhance transparency and trust in the process.

• The inclusion of civil society helps build support for policies and thus aids in implementation. Consulting and partnering with the private sector can help increase the feasibility and market-friendliness of policies that are proposed. This can facilitate greater private sector engagement in achieving low carbon growth and improve the sustainability and scale-up of green investments.

• Training and education can help with coordinating different government departments and policies.

• Providing strong policy guidance is crucial to implementation. Progress to date and lessons learned The countries we have reviewed have already taken steps to develop a climate change or low carbon development strategy, and thus are, to a greater or lesser degree, ahead of other countries, within their income category at least. However, there are still a number of issues that most countries either did not address or could not resolve in their policy documents. These include:

- Specification of a (potential) funding source for climate mitigation and adaptation activities;
- An implementation roadmap with specific measures;
- Anti-corruption and pro-transparency measures governing the use of mitigation/adaptation funds;
- A framework for macro management and measures to combat Dutch Disease;
- Identification of new green growth opportunities and the policies needed to achieve them;
- A rigorous consultation process;
- The need for policy alignment and intra-governmental cooperation. So, although many of these countries are, to some extent, ahead of the game in terms of policies to promote low carbon growth and climate resilience, it is clear that improvements can still be made. Policies for Low Carbon Growth Nonetheless, the policies they have set out and the processes they have pursued can provide valuable lessons for other countries only now beginning to think about how they will respond to climate change. While it is too early to judge the efficacy of many of these policies (and indeed many of them are still only being planned), ongoing monitoring of their impact will be important in ensuring that lesson are learned globally, thus speeding up the effective response to this most pressing of problems.

+ MODEL
ARTICLE IN PRESS
+ MODEL
Available online at www.sciencedirect.com
ScienceDirect
Advances in Climate Change Research xx (2016) 1−9
www.keaipublishing.com/en/journals/accr/

Approaches to low carbon development in China and India

Shailly KEDIA[a,b,*]

[a] The Energy and Resources Institute, New Delhi 110003, India
[b] Jawaharlal Nehru University, New Delhi 110067, India

Received 17 June 2016; revised 15 October 2016; accepted 28 November 2016

Abstract

Low carbon development has gained policy prominence and is a concern of both environment and development policy globally and in China and India. This paper discusses the role of China and India as important global actors in light of development imperatives in the two countries. The article then looks at emerging approaches in the two countries related to financing, science, technology & innovation policy, and sub-national actions. The objective is to review efforts in China and India for contributing to learning experiences for other countries. The final section discussed the ways forward in terms of examining the role of China and India in terms of national policy strengthening as well as in global agenda setting. Implementation of sub-national initiatives in both countries faces challenges due to lack of adequate financing as well as knowledge such as greenhouse gas inventories and disaggregated resource and socio-economic assessments. Both India and China are making efforts in technology and innovation domains to set foot on a trajectory of low carbon development with varying degrees of success. In finance, both China and India have experimented with various instruments—the key difference is that China has taken the support of regulation more while India has leaned on to market based instruments. Both China and India are moving on an encouraging track regarding low carbon development with fairly well-designed domestic policies and consistent international engagement.

Keywords: Low carbon development; China; India; Sustainable development; Climate change

1. Introduction

In an era where climate change has been acknowledged by the scientific community (IPCC, 2014), low carbon development has gained policy prominence and is a concern of both environment and development policy. The European Union (EU) was an early advocate of 'low carbon economy'. A 2003 white paper titled, 'UK energy white paper: Our energy future—creating a low carbon economy' by the Department of Environment, Food and Rural Affairs (DEFRA), was presented to the Parliament by the Secretary of State for Trade and Industry by Command of Her Majesty. The paper describes 'low carbon economy' as being characterized by higher resource productivity—producing more with fewer natural resources and less pollution—and contributing to higher living standards and a better quality of life (DEFRA, 2003). In climate change negotiations, the EU advocated the concept of 'low carbon pathways' to growth with an implied peaking point for carbon emissions.

China and India as developing countries have redefined the low carbon approach with the view of emphasizing harmony with the over-riding priority of poverty eradication and sustainable development. In China, the National Development and Reform Commission (NDRC) describes low carbon development as the development of the socio-economic system that can realize low carbon emissions. India's National Action Plan on Climate Change (NAPCC) highlights the co-benefit approach for low carbon activities that could in turn ensure energy security, reduced local pollution, and increased

* The Energy and Resources Institute, New Delhi 110003, India.
E-mail address: shailly.kedia@gmail.com.
Peer review under responsibility of National Climate Center (China Meteorological Administration).

ELSEVIER Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.accre.2016.11.001

access to energy through distributed and decentralized forms of energy systems (GoI, 2008).

This paper will first discuss the role of China and India as important global actors. The paper will then look at emerging approaches in the two countries related to financing, science, technology & innovation policy, and sub-national actions. The objective is to review efforts in China and India as these contribute to learning experiences for other countries around the world. The final section will discuss the ways forward in terms of examining the role of China and India in terms of post-2015 climate and development actions.

2. China and India as important global actors

The sustainability of development patterns followed by India and China has significant socio-economic and environmental implications for the two countries (CAEP-TERI, 2011). India and China, which together account for about 36% of the world's population, are responsible for more than 1/4 of the world's demand for primary energy, and about 1/3 of the world's CO_2 emissions. Both these countries are also witnessing structural shifts in their economies with an increasing share of Gross Domestic Product (GDP) coming from the services and manufacturing sectors. With India and China staying on their impressive economic growth trajectories, respectively, seen in recent years, their energy demand and CO_2 emissions will continue to grow, and the two countries together will account for more than 50% of the world's incremental energy demand and CO_2 emissions over the next two decades. Hence, in order to stabilize greenhouse gas (GHG) concentrations and achieve the 1.5−2 °C target globally, low carbon transitions in both countries are of significant importance to global efforts on tackling climate change and achieving sustainable development.

Though China's per capita income levels and human development performance is better than India, the two countries still have much ground to cover in terms of their development indicators as compared to the developed countries. Table 1 depicts key socio-economic development indicators for China and India and also shows the performance of the two countries when compared to the EU or Organisation for Economic Co-operation and Development (OECD). In terms of access to electricity, it is seen that China has achieved access to electricity while India still has to make progress with regard to ensuring electricity access to its population. Another area is with regard to non-solid fuel for household energy usages where both China and India have higher reliance to solid fuels when compared to the EU. China and India have both performed better in terms of improved water source for household. With regard to CO_2 emissions per capita, it is seen that both China and India have lower emissions per capita when compared to the OECD total.

Currently, at the aggregate level, China and India consume about 23.0% and 4.9% of the world's primary energy, respectively. China's primary energy consumption has risen at a compound annual growth rate (CAGR) of 6.3% in 1990−2014 and stands at 2792 Mtoe and was the largest energy consumer in the world in 2014. India's primary energy consumption has risen at a CAGR of 5.4% in 1990−2014 and stands at 638 Mtoe in 2014. In contrast, the world primary energy consumption increased at a rate of 1.94% during the same period (BP, 2015). As can be seen from Table 2, both China and India have high dependency on coal. Both China and India have also seen a high rate in growth of renewables in 1990−2014. It is also important to note that OECD has seen decline in coal and nuclear in 1990−2014.

India's NAPCC was adopted in 2008. NAPCC outlines policies directed at climate change mitigation and adaptation. China's National Climate Change Programme was approved in 2007 and includes measures to strengthen the energy legal system.

In the Twelfth Five-Year Plan, China has, for the first time, set for itself, a carbon-intensity reduction target of 17% by 2015. Similarly, the Government of India, in its Twelfth Five-Year Plan, recognized low carbon development and inclusive growth. Table 3 lists the policy objectives related to low carbon growth in China and India. It is seen that China and India have taken similar approaches at the multilateral foras as well as in domestic areas of action.

For both China and India, issues such as urbanization and industrial policy will continue to be relevant areas of low carbon development policies. The common areas for China

Table 2
CAGR according to fuel consumption (1990−2014)(unit: %).

	Renewable	Hydro	Nuclear	Coal	Gas	Oil
China	58.07	9.27	3.91	5.65	10.82	6.57
India	32.87	2.87	5.79	5.69	6.16	4.85
OECD	9.75	0.62	−0.86	−0.22	1.93	0.19
Total world	10.50	2.47	−0.13	2.33	2.32	1.20

Note: For nuclear, CAGR is considering the period 2000−2014.
Sources: Based on data from BP (2015).

Table 1
Key socio-economic indicators: China and India.

Indicator	India	China	Benchmark	Year	Notes
GDP per capita, PPP (constant 2011 international $)	5439	12599	34771	2014	EU as benchmark
Human Development Index (HDI) value	0.61	0.73	0.88	2014	OECD is used as benchmark
Access to electricity (% of population)	79	100	100	2012	EU as benchmark
Access to non-solid fuel (% of population)	36	55	99	2012	EU as benchmark
Improved water source (% of population with access)	94	96	100	2015	EU as benchmark
CO_2 per capita (t CO_2 per capita)	1.49	6.60	9.55	2013	OECD is used as benchmark

Sources: World Development Indicators, World Bank, data.workbank.org; UNDP HDR indicators, http://hdr.undp.org/en/data; International Energy Agency, https://www.iea.org/statistics/statisticssearch/.

Please cite this article in press as: KEDIA, S., Approaches to low carbon development in China and India, Advances in Climate Change Research (2016), http://dx.doi.org/10.1016/j.accre.2016.11.001

Table 3
Policy objectives and low carbon development in China and India.

Theme	China	India
Copenhagen accord target	40%−45% by 2020 in comparison to 2005 levels	20%−25% by 2020 in comparison to 2005 levels
INDC target (emission intensity)	60%−65% by 2030 in comparison to 2005 levels	33%−35% by 2030 in comparison to 2005 levels
INDC: peaking	2030 or earlier	−
INDC: non-fossil fuel	Non-fossil fuels in primary energy consumption to be around 20% by 2030	To achieve 40% cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030
INDC: forestry and land use	To increase the forest stock volume by around 4.5 billion m^3 on the 2005 level by 2030	Create additional carbon sink of 2.5−3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030
INDC: financing needs	−	US$ 2.5 trillion (at 2014−2015 prices) will be required for meeting India's climate change actions between now and 2030
National climate policy	China's Policies and Actions on Climate Change (2014) National Strategy for Climate Adaptation	National Action Plan on Climate Change (2008) National Adaptation Fund
Key national agency coordinating climate change	The National Development and Reform Commission	Ministry of Environment, Forest and Climate Change
Sub-national initiatives	Low carbon Pilot Projects in Provinces and Cities	State Action Plan on Climate Change
Emissions/energy trading	Carbon Emissions Trading Pilot Program	Energy Saving Certificate and Renewable Energy Certificates
Technology development	China's Science and Technology Actions on Climate Change	Climate Change Centres in states
South−South cooperation	Fund for South−South Cooperation on Climate Change	International Solar Alliance

and India, as clearly communicated in their national policies include renewable energy, energy efficiency in industry, energy efficiency in buildings, transportation and urban development. It is also important to make distinction between countries whose emissions have peaked and performance is assessed in terms of absolute emissions reductions and countries where emissions have yet to peak where performance will be measured through different indicators. Performance of developing and developed countries also takes into account their different capacity and levels of developments, which have already been achieved by developed countries. China and India both being developing countries, like other developing countries, have expressed intention not in terms of absolute emission targets but in terms of their development trajectories. China, with an ageing population, has expressed targets in terms of emission peaking and emission intensity of GDP. India, on the other hand, with a young workforce has expressed targets in terms of emission intensity of GDP.

Apart from similar stances at the domestic and multilateral policy levels, China and India have reaffirmed their commitment to work together on climate change at the bilateral level also. Climate change figured as an important element at high-level bilateral talks during the Chinese President's visit to India in September 2014 and during Prime Minister Modi's visit to China in May 2015. To strengthen the bilateral ties between the two countries the Indian government has set the goal of "INCH (India−China) towards MILES (Millennium of Exceptional Synergy)".[1] In May 2015, the two countries issued a Joint Statement on Climate Change between the Government of t India and the Government of China, promoting bilateral partnership on climate change and reaffirming their commitment to engage through the UNFCCC process.

In November 2014, United States and China had a joint announcement on climate change which the two countries expressed their intention to reduce emissions in a time-bound manner. United States expressed intention to achieve an economy-wide target of reducing its emissions by 26%−28% below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%. China intends to achieve the peaking of CO_2 emissions around 2030 and to make best efforts to peak early and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. It is observed that, while the United States had emissions reduction target in terms of absolute emissions, China had emission peaking targets as well as targets for enhancing share of renewable energy in the overall energy mix. India on the other hand has also had bilateral agreements with both China and the United States which emphasize on addressing the issue of climate change. Given India's priorities of commercial and other international issues, India's joint agreements have mainly focused on commercial aspects (including commercial aspects of addressing climate change) with China and the United States; India has also focused on international issues such as 'terrorism', an example is the "United States−India Joint Declaration on Combatting Terrorism" signed in September 2015. India communicated quantitative targets through the multilateral process of the UNFCCC involving intended nationally determined contributions. It is however clear that both China and India, through bilateral and multilateral forums, have communicated their intention to address the global issue of climate change.

3. Innovative financing mechanisms

The Addis Ababa Action Agenda of the Third International Conference on Financing for Development recognizes that

[1] Transcript of Prime Minister's Interaction with Chinese media organizations, September 16, 2014, Media Briefings, Ministry of External Affairs, Government of India. Available at www.mea.gov.in.

Please cite this article in press as: KEDIA, S., Approaches to low carbon development in China and India, Advances in Climate Change Research (2016), http://dx.doi.org/10.1016/j.accre.2016.11.001

Table 4
Examples of innovative financing mechanisms in India.

Public finance and fiscal Instruments	Tax revenue	Coal cess (indirect tax)
	Budgetary allocations and fiscal transfers	Annual budgetary allocations, centre-state fiscal transfers
	Subsidies	Example include subsidies on solar heaters, electric vehicles, energy efficient appliances
	Fiscal instruments	Property tax rebates on green buildings
Financing platforms	Special funds/institutions	National Clean Energy Fund, state energy conservation fund, IREDA, sub-national funds
	Markets innovations	Indices such as Greenex and Carbonex for Bombay Stock Exchange (BSE)
	Traditional market instruments	Green bonds for renewable energy, energy efficiency and green infrastructure projects
	Climate/energy market instruments	Clean Development Mechanism, Renewable Energy Certificates, Energy Saving Certificates
	Banking provisions	Special provisions for MSME, priority sector lending norms by the Reserve Bank of India for renewable energy
Risk management	Risk management mechanisms	The Partial Risk Guarantee Fund under the National Mission on Enhanced Energy Efficiency, Credit Guarantee Fund Trust for Micro and Small Enterprises
International sources	Grants	Bilateral and multilateral sources
	International climate finance	Green Climate Fund, Adaptation Fund

Source: Based on Kedia and Jain (2015).

"funding from all sources, including through public and private, bilateral and multilateral, as well as alternative sources of finance, will need to be stepped up for investments in many areas including for low carbon and climate resilient development". Finance is a very multi-faceted topic in low carbon development which encompasses public finance, banking, and market instruments. In the low carbon development space, financing is arguably the most critical challenge which has been greatly augmented in the wake of serious global macro-economic imbalances. While macro-economic decisions, including banking come from the policy side, finance decisions come from the investment side. Synchronization of macro-economic policy and finance mechanisms for sustainable development has become fairly arduous due conflicting interests. Macro-economic and banking regulations are moving towards safety while there are greater risks[2] attributed to sustainability projects. This section will discuss emerging practices related to finance in China and India.

3.1. Emerging practices in China

Following the global economic crisis in 2008, many governments announced stimulus measures for their respective governments. These included sets of policies to stimulate the private sector, boost consumer demand for goods and services, and provide greater public investment in various sectors. China's NDRC announced a variety of green stimulus measures. Over one-third of the massive Chinese stimulus package and nearly 27% of the 2009 budget was allocated to green themes, mostly rail, grids, and water infrastructure, along with spending on environmental improvement (Barbier, 2010).

The Chinese government announced its intent to establish domestic emissions trading markets in 2011, and moved quickly to establish seven regional emissions trading schemes: in the provinces of Guangdong and Hubei, and the cities of Beijing, Tianjin, Shanghai, Chongqing and Shenzhen. The pilot emission trading scheme (ETS) aimed to cover ~700 Mt of CO_2 emissions, which could make China the second-largest carbon trading market in the world. After one year's operation, all pilots basically run smoothly, but still have problems, such as the allowance allocation and the liquidity. Liquidity is another inherent challenge and future of the market is not optimistic. The price ranges between CN¥ 20−90 per ton, the high transaction concentration since most transaction occur in the last month for compliance and the lack of liquidity due to market structure, the scale and the participants' risk appetite are seen as the major challenges.

According to NDRC, a nationwide China ETS would test run was to in 2016, which may be postponed to 2018−2019. At present, China is at an initial stage, learning from pilots. To promote a "top-down" and "bottom-up" dual path, NDRC will set up ETS infrastructure cap setting, allowance allocation, trading infrastructure and a regulatory framework. Some challenges of the sub-national ETS market include lack of historical emission data at an enterprise level, need for third party verification, low market efficiency due to fluctuating prices, and limited[3] legal binding force.

As the key intermediary agents of indirect financing, banks are powerful forces to guide economic restructuring in China. China is the first country to establish the green credit policy system. Since 2007, China Banking Regulatory Commission has successively promulgated "Instructions to Energy Saving and Emission Reducing Credit Work" (2007), "Guidance to Green Credit" (2012) and "Instructions on Green Credit Work" (2013), which made rules for the credit extension for energy saving and emission reduction, and policy boundaries, managing styles, institutional arrangement, capacity building, procedure management, internal control, information disclosure and regulatory policies of green credit. These documents put forward not only the definition and key supporting industries of green credit, but also cautious loans to energy

[2] Also renewable energy or energy efficiency projects can have high initial capital costs which are usually offset by lower operations and maintenance costs.

[3] Shenzhen, Beijing and Chongqing passed legislations that fine defaulters. Others do not have a binding legal instrument, rely on government regulations.

Please cite this article in press as: KEDIA, S., Approaches to low carbon development in China and India, Advances in Climate Change Research (2016), http://dx.doi.org/10.1016/j.accre.2016.11.001

intensive and highly polluting enterprises. The policies encourage the establishment and improvement of environment and social risk assessment systems, and the measurement, reporting and verification (MRV) of green credits.

However, green credit still has broad room for development. According to statistics from China Banking Regulatory Commission, in terms of loans, green credits accounted for about 7.2% of the total amount loaned. There is need to further clarify the responsibility of different institutions related to environmental protection, financial regulators and profit-oriented banking institutions in the implementation of green credit policy. Currently the green credit policy is voluntary and market participation need to be enhanced for ensuring binding role of regulations alongside capacity building and internal incentives for banks.

3.2. Emerging practices in India

The report of the Expert Group on Low Carbon Strategies for Inclusive Growth by the erstwhile Planning Commission of India in 2014 noted that the shift to low carbon inclusive growth will require an additional investment equivalent to 1.5% of GDP over twenty years from 2011 to 2030, over and above the Baseline Inclusive Growth scenario. It is important to look at various financial mechanisms and the underlying policy environment for low carbon development in India. According to a stakeholder engagement by The Energy and Resources Institute, high cost of financing is the major bottleneck for financing sustainability projects. Also, inadequate subsidies, inadequate mechanisms for supporting low carbon development by financial institutions along with lack of awareness of low carbon projects impede the financial space for low carbon development.

There are various financial mechanisms for low carbon development in India including public finance, traditional finance, risk management instruments, market based tradable instruments, and international sources (Table 4). While there is no domestic carbon market developed in India, instruments such as renewable energy certificates are traded at the Power Exchange India Limited.

Public finance, including greater budgetary allocations, will be crucial in helping stimulate investments for low carbon development in India. Measures by the Reserve Bank of India such as sustainability guidelines for banking will be important. The Reserve Bank of India can play a role for spreading awareness regarding priority sector lending norms relevant to low carbon development among various stakeholders concerned. Also, sectors other than renewable energy which can also contribute potentially towards environmental sustainability, such as buildings, transport, agriculture, industry, waste and forestry should be given due consideration under the banking norms.

4. Science, technology & innovation

Science, technology and innovation (STI) does not follow a linear path that begins with research, moves through the processes of development, design, engineering, production, and ends with the successful introduction of new products and processes into the market, rather, it is an interactive (and cumulative) process that involves continuous feedback loops between the different stages. Innovation can push the frontier outward and help to decouple growth from the natural resource degradation. Innovation is thus key to developing the low carbon technologies required for transition to a low carbon economy, and make it affordable and accessible. Research and Development (R&D) and innovation activities in many low carbon development related technologies especially related to environment are characterized by low investment and slow diffusion. Incentives for low carbon innovation are further weakened by real and perceived uncertainties about lack of clear direction and policy instruments. It is thus important to understand emerging practices in China and India related to STI.

4.1. Emerging practices in China

The Ministry of Science and Technology (MOST) is responsible for R&D in China and is the major funder of public R&D. In 2006, MOST published the National Medium- and Long-Term Science and Technology Development plan[4] that sets out China's direction for R&D over the period 2006–2020. The plan included the specific target of investing 2.5% of GDP in R&D by 2020 in which developing technologies related to energy and environmental protection were among the top priorities including the development of efficient, clean and near-zero emissions fossil energy and Carbon Capture, Utilization and Storage, as well as other low carbon technologies. Examples of initiatives by MOST related to climate change include National Basic Research Programme on climate change and Global Change Research. Apart from MOST, other key organizations in China that have been promoting and financing basic research and applied research related to climate change include the National Science Foundation of China (directly affiliated to the State Council) and the Chinese Academy of Sciences.

Key policies that guide China's science technology and innovation systems include:

- National Medium- and Long-Term Program for Science and Technology Development (2006–2020) by State Council, 2006
- China's scientific actions on climate change, by MOST, 2007
- Twelfth National Scientific and Technological Plan on Climate Change by MOST, May 2012
- Work plan for Twelfth Five-Year National GHG Control by State Council, 2012
- S&T roadmap of China's CCUS development by MOST/ACCA21, 2011

[4] See http://english.gov.cn/2006-02/09/content_183426.htm.

Please cite this article in press as: KEDIA, S., Approaches to low carbon development in China and India, Advances in Climate Change Research (2016), http://dx.doi.org/10.1016/j.accre.2016.11.001

Table 5
Batches for low carbon pilots in China.

Batch	Year	Province	City
Batch 1	2010	Guangdong, Liaoning, Hubei, Shaanxi, Yunnan	Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding
Batch 2	2012	Hainan	Beijing, Shanghai, Shijiazhuang, Qinhuangdao, Jincheng, Hulunbuir, Jilin, Daxing'anling, Suzhou, Huai'an, Zhenjiang, Ningbo, Wenzhou, Chizhou, Nanping, Jingdezhen, Ganzhou, Qingdao, Jiyuan, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Kunming, Yan'an, Jinchang, Urumqi

- Special Plan for CCUS technology development by MOST, 2013

Some specific projects related to R&D in low carbon development include industrial energy-saving technologies and equipment for key industries, renewable energy and new energy development and utilization of technology, technologies of the smart grid, and low carbon economy of industrial development model and the integrated application of key technologies. Examples of dedicated initiatives in China on low carbon technology demonstration and deployment are also in place.

An example of an initiative in market based demonstration and deployment is for electric vehicles, LED bulbs and photovoltaic industry. “10 Cities, 1000 Vehicles” initiative is for energy-saving and new energy vehicle demonstration and extension of the pilot has been increased to 25 in 2010. “10 Cities, 10000 Lamps” is for LEDs and in the year 2010, there are more than 1.6 million LED lamps light applied in 21 pilot cities, saving more than 164 million kWh. “Golden Sun” initiative involves using a combination of financial assistance, technology support, and market driven approach to accelerate the development of photovoltaic industry.

The government in China is currently undertaking reforms of its STI systems to increase efficiency of input and maximize the use of funds. A council—with representatives from agencies such as MOST, MOF, NDRC—will be established to oversee fund allocation, aiming to increase communication among government sections.

4.2. Emerging practices in India

The Science, Technology and Innovation Policy of India, 2013 prepared by the Ministry of Science & Technology (MST), recognizes the role of STI system in the NAPCC. The document states that the STI system will “serve as a source of strategic knowledge to cope with the challenges of climate variability and change as well as to meet equity-based differentiated and shared responsibilities of India”.

According to the stakeholder consultation by TERI, adaption of imported technology to suit the local conditions emerged as an important aspect with regard to the transport, building and waste sector. Indigenous R&D and technology development was considered to be crucial for low carbon development in the agriculture sector. Technology demonstration has been perceived as the most important in the renewable energy, industry and non-renewable energy sector.

The Department of Science & Technology, Ministry of Science & Technology has been entrusted with the responsibility of coordinating two out of eight national missions launched under the NAPCC. These are National Mission for Sustaining Himalayan Ecosystem (NMSHE) and National Mission on Strategic Knowledge for Climate Change (NMSKCC). A brief description[5] of mission objectives is now discussed.

The NMSKCC has been launched with the broad objectives of mapping of the knowledge and data resources relevant to climate change and positioning of a data sharing policy framework for building strategic knowledge among the various arms of the Government. The mission envisages international cooperation on S&T for climate change agenda through strategic alliances and assistance to the formulation of policies within a responsive climate change framework and inputs to the Ministry of Environment and Forests and Ministry of External Affairs. Various arms of the Government have already earmarked large resources for climate change related actions leading to the development of strategic knowledge. Within the Ministry of Science and Technology and Earth Sciences such allocations are estimated over INR 2500 crores.

The broad objectives of NMSHE include understanding of the complex processes affecting the Himalayan Ecosystem and evolve suitable management and policy measures for sustaining and safeguarding the Himalayan ecosystem, creating and building capacities in different domains, networking of knowledge institutions engaged in research and development of a coherent data management systems. The government has created a fund of approximately INR 1650 crores for developing capacities for Sustaining Himalayan Ecosystem to serve the activities during the Eleventh and Twelfth Plan periods.

Linkages between different ministries such as human resource development, environment and finance among others, segments of the decision making fraternity of STI policy within India is lacking and needs to be established for low carbon development and innovation. Moreover there is a need to strengthen programmes related to demonstration and deployment. Transition to a sustainable development pathway could be accelerated by incentives through a national directive for R&D in low carbon development, setting up of low carbon technology incubation centres with strong industry–academia–government linkages, facilitation of technology

[5] Climate Change Programme, Department of Science & Technology; Available from http://www.dst.gov.in/climate-change-programme.

Please cite this article in press as: KEDIA, S., Approaches to low carbon development in China and India, Advances in Climate Change Research (2016), http://dx.doi.org/10.1016/j.accre.2016.11.001

transfer through existing and new technology transfer offices, a focus on low carbon innovations in the informal sector, among others. A clear vision and prioritization for R&D for development of low carbon technology need to be determined through structured analysis. This could be facilitated by using the tools of technology foresight, technology road-mapping, technology assessment and evaluation.

5. Sub-national actions

According to UNDP (2010), around 50%–80% of the investments for GHG mitigation (and up to 100% for climate change adaptation) happen at the sub-national and local levels. Regional and local governments lead the implementation of policies, programmes and fiscal instruments ‘in the areas of generation, supply and distribution of electricity, the regulation of the built environment, waste management, transport and land-use planning’. Engaging sub-national and local actors in climate action could promote cross-sector policy interventions and create ‘role models’ which could be replicated/up-scaled at the domestic and global levels. Further, in light of the wide socio-economic and climate-geographic variations across different regions, the relevance of active involvement of sub-national regions in policy formulation increases manifold. Sub-national regions can also differ in terms of mitigation potential and capacity, making it imperative in both China and India, that a more decentralized, bottom-up climate policy making, resulting in actions customized to local contexts and needs, drives national responses to climate change.

5.1. Emerging practices in China

In July 2010, the NDRC initiated a low carbon pilot province and city program including five provinces (Yunnan, Guangdong, Hubei, Shaanxi, and Liaoning) and eight cities (Tianjin, Baoding, Hangzhou, Chongqing, Nanchang, Guiyang, Xiamen and Shenzhen) across the country. In November 2012, another 29 provinces and cities have been selected as the second batch of low carbon pilots. All these pilot cities and provinces occupy 57% of China's GDP, 42% of China's population and 56% of energy related CO_2 emissions. Table 5 shows the two batches for low carbon pilots in China.

The pilot cities and provinces were expected to develop and propose a low carbon development plan, formulate supportive policies for low carbon green growth, establish low carbon industrial systems, establishing GHG emission statistics and data management systems, and encourage low carbon lifestyle and consumption patterns. Provinces/cities are given flexibility in setting sectoral priorities as well as target setting in terms of carbon emission target, carbon intensity, energy intensity, or peaking.

According to the performance evaluation conducted by the NDRC in 2013 of the target responsibility system for curbing the GHG emissions in 2012, the carbon intensity in the 10 pilot provinces and cities dropped by nearly 9.2% in 2012 compared with 2010, higher than the decline on the national level (NDRC, 2014). In addition, Guangdong, Hubei, Beijing, Tianjin, Shanghai and Yunnan provinces have surpassed their target in 2012 and the cumulative amount prescribed in the Twelfth Five-Year Plan. Other pilot regions have performed better in reducing carbon intensity than regions without similar conditions. While there is need for further strengthening of decision-support systems and financial systems, China's low carbon pilots are an important step in the right direction for integrating low carbon development planning at sub-national levels in accordance with local conditions to enable technological leap-frogging along with sustainable development.

5.2. Emerging practices in India

In June 2008, India launched its NAPCC that encompasses a multi-pronged, long-term and integrated framework for addressing climate change as a core development issue. In its eight missions, the NAPCC proposes an extensive range of measures focussing on renewable energy, energy efficiency, clean technologies, public transport, resource efficiency, afforestation/reforestation, tax incentives and research, and generation of strategic knowledge. As a corollary to NAPCC, in August 2009, the Prime Minister of India directed all the states to formulate their respective State Action Plan on Climate Change (SAPCC), guided by and consistent with the structure and strategies of the NAPCC. The individual SAPCCs should lay out sector-specific as well as cross-sector time-bound priority actions in light of state-specific risks, impacts and opportunities besides prioritizing areas for research and policy action in response to current and future vulnerabilities and projected impacts. The SAPCCs should also list indicative budgetary requirements, supplemented with details of the necessary institutional and policy infrastructure to support the operationalization of actions.

As of March 2016, the Ministry of Environment, Forests and Climate Change (MoEFCC) has endorsed 30 state action plans. As the next step, the SAPCCs endorsed by the National Steering Committee on Climate Change (NSCC) will be considered for integration in the respective state annual development plans and will seek financial support through various sources such as the Niti Ayog, MoEFCC and other national ministries and agencies.

Generally, the preparation of SAPCCs in India has witnessed line departments providing primary inputs to the nodal department (often the environment department), which in consultation with technical experts has sought to develop a coherent policy document. Cross-department integration of strategies has been attempted in varying ways: while in some states, presentation of the SAPCC before a high-level Committee of Secretaries has enabled quick iteration and consensus-building, in others, the process has been tedious and often superficial due to lack of funding.

In the state-specific SAPCCs, each state has come out with its own agenda of activities to address issues related to climate change in specific sectors in a manner that these activities also align with the eight missions listed under the NAPCC.

+ MODEL

However, the implementation of the SAPCCs is still in early stages—it is perceived that the progress of states towards achieving the goals listed in SAPCCs is likely to face challenges due to lack of adequate financing available for specific targets.

For strengthening the implementation of the State Action Plan on climate change data management systems around GHG inventories will need to be strengthened. To be better able to implement the SAPCCs, synergies between central expenditure and state finances and actions needs to be explored. The lack of adequate financing for the well-written SAPCCs also highlights the need for appropriate institutional mechanisms which can support centre-state disbursements of public funds. Especially for sectors like improving energy efficiency and promoting renewable energy, involvement of private sector funding needs to be encouraged. Most importantly, given the cross-cutting cross-sectoral nature of climate actions, it is essential to have a powerful coordinating government agency (perhaps associated with the Chief Minister's Office or Chief Secretary's Office), which can coordinate across different line departments.

6. Discussion

Globally, there is an increasing awareness of the need to move away from a carbon-intensive development model. This, however, requires fundamental policy changes in key sectors of the economy including, but not restricted to, the energy sector. For China and India, beyond the energy sector, factors such as overall level of development, governance structure and vulnerability to climate change will also determine a country's targets and strategies. There is no single low carbon development blueprint that can be universally applicable.

From the examples discussed in the preceding sections, it is clear that China and India have taken efforts to operationalize low carbon development strategies in areas of finance, innovation policy and sub-national actions.

In finance, both China and India have experimented with various instruments such as guidelines, regulation, special funds and market based instruments—thus offering a rich experience to other countries who are now formulating initiatives for low carbon development. The key difference in approach is that China has taken the support of regulation along with market transformation while India has leaned on to mainly market based instruments. Both countries have also used fiscal instruments and public finance allocation. In future, China and India will both have to play a leadership role to push the sustainable development community as a whole to recognize the importance of engaging with global financial regulatory frameworks such as the Bank for International Settlements, International Monetary Fund and International Accounting Standards Board. Moreover, China and India will both have to voice for a more effective international finance architecture. While international climate finance has sought to leverage and attract private finance, according to Climate Funds Update, as of the beginning of 2012, globally, for every US$ 1 spent between 2010 and 2012, only US$ 0.25 of private finance had been drawn (ODI, 2013). Green Climate Fund should be able to boost this gap.

In terms of innovation policy, differences between developed and emerging world markets are leading to reinvention of products and reduction of costs and have fostered innovation in distribution, commercialization, and marketing chains in countries like India and China. Both India and China are making efforts in technology and innovation domains to set foot on a trajectory of low carbon development with varying degrees of success. According to the Paris Climate Agreement,[6] global technology mechanisms and the Climate Technology Centre and Network will need to be further strengthened to further work relating to technology research, development and demonstration, and for enhancement of endogenous capacities and technologies. To further climate actions in the post-2015 climate and development agendas, it will be vital that China and India, based on domestic experiences, play a role in global agenda shaping. China and India can give impetus to through national directives for R&D in low carbon development, setting up of low carbon technology incubation centres with strong industry–academia–government linkages, facilitation of technology transfer through existing and new technology transfer offices (TTOs), a focus on low carbon innovations in the informal sector, among others.

In terms of sub-national actions, both China and India have experimented with different implementation frameworks—low carbon pilots for China and the SAPCCs in case of India. However, the implementation of sub-national initiatives in both countries face challenges due to lack of adequate financing as well as knowledge such as GHG inventories and disaggregated resource and socio-economic assessments. The scientific basis of sub-national actions in both China and India need strengthening. With regard to policies for incubation and knowledge sharing, there are learning for other countries from the experiences of China and India. In terms of implementation, it will not be exaggerating to say that climate actions at sub-national (local, state/province, agro climatic regions) will contribute to climate change mitigation and adaptation. In the post-2015 climate and development agendas, the main theatre of actions will be at sub-national and local levels. It will be crucial to see how China and India strengthen engagement and capacity at all levels—global, national and sub-national.

Both China and India are moving on the right track regarding low carbon development with strong political willingness, fairly well-designed domestic policies, and consistent international engagement. The key to China's and India's low carbon technology future is through innovation, development, and commercialization of new technologies and focusing on indigenous solutions. In addition, technology transfer from developed countries and joint R&D with developed countries can also help the two countries leapfrog to cleaner development patterns and become leaders in rapidly emerging economic sectors like renewable energy. However, both China and

[6] Para 67 of FCCC/CP/2015/L.9/Rev.1.

+ MODEL

India need to overcome a series of social and economic barriers in order to achieve a low carbon future. For instance, meeting poverty reduction needs, expanding energy services, ensuring energy security, maintaining and increasing employment rate, reducing environmental pollution, protecting biodiversity, have to be kept in mind while moving down a low carbon development path.

Difficulties for both China and India, as emerging economies, in developing, deploying, and adopting low carbon technologies is mostly due to the additional cost associated with it and in some cases technical barriers to implementation. Besides, collaboration and open stakeholder involvement from various sectors including government, industry, academic, and civil society between the two countries is essential in framing and coordinating policies and measures, so that low carbon development policies can be implemented to promote sustainable development, spur innovative business, and meet the over-riding priority of poverty eradication in the two largest developing countries in the world.

Acknowledgment

Contents in this article has majorly drawn on the outputs of the project "Collaborative Initiative on Low Carbon Development for China and India" supported by Shakti Sustainable Energy Foundation (Ref No 121100545). The seed funding for the project was provided by the United Nations Development Programme. The implementing partners include The Energy and Resources Institute, National Centre for Climate Change Strategy and International Cooperation, Central University of Finance and Economics, and Zhejiang University. The China component was coordinated under the guidance of the National Development and Reform Commission. The collaborative study on low carbon development for China and India is directed towards developing specific strategies for low carbon development in crosscutting areas such as financing, technology and innovation policy, and subnational initiatives. The intended outcome of the collaborative project on low carbon development for China and India is supporting policy development by facilitating south−south cooperation, creating relevant knowledge and building capacities through exchange of experiences and ideas. Project webpage: http://www.teriin.org/projects/locci/

References

Barbier, E.B., 2010. A Global Green New Deal: Rethinking the Economic Recovery. Cambridge University Press, Cambridge and New York.

BP, 2015. BP Statistical Review of World Energy. British Petroleum.

CAEP-TERI, 2011. Environment and Development: China and India. Joint Study by the Chinese Academy for Environmental Planning (CAEP) and the Energy and Resources Institute (TERI), Commissioned by the CCICED and ICSD. TERI Press, New Delhi.

DEFRA, 2003. Our Energy Future: Creating a Low Carbon Economy. Department for Environment, Food and Rural Affairs European Environmental Agency.

GoI, 2008. National Action Plan on Climate Change. Government of India, New Delhi.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

Kedia, S., Jain, N., 2015. Financing for low carbon development in India (policy brief). http://www.teriin.org/projects/locci/pdf/res/Policy_Brief_LCD_Finance.pdf.

NDRC, 2014. China's Policies and Actions on Climate Change (2014). The National Development and Reform Commission, China.

ODI, 2013. Ten Things to Know About Climate Finance in 2013. Overseas Development Institute. http://www.odi.org/ten-things-know-climate-finance-2013.

UNDP, 2010. Down to earth: a territorial approach to climate change, low carbon and climate resilient strategies at the sub-national level. http://www.nrg4sd.org/sites/default/files/default/files/content/public/29-climatechange/background/tacc/down_to_earth_donor_proposal-version_1_mars_2010.pdf.

Please cite this article in press as: KEDIA, S., Approaches to low carbon development in China and India, Advances in Climate Change Research (2016), http://dx.doi.org/10.1016/j.accre.2016.11.001

Linking sustainable development with climate change adaptation and mitigation

Article · July 2010

DOI: 10.1017/CBO9780511762475.011

4 authors:

Livia Bizikova
International Institute for Sustainable Development

Sarah Burch
University of Waterloo

Stewart Cohen
Independent

John B Robinson
University of Toronto

IN PRESS: O'Brien K. and A. L. Claire (Eds.), 2009. Clair Shifting the Discourse: Climate Change as an Issue of Human Security. Springer, Berlin, Heidelberg, New York.

A Participatory Integrated Assessment Approach to Local Climate Change Responses: Linking Sustainable Development with Climate Change Adaptation & Mitigation

Bizikova Livia*, Burch Sarah [#], Cohen Stewart [+] and John Robinson[#]

[+] Adaptation and Impacts Research Division (AIRD), Environment Canada; Department of Forest Resources Management, Faculty of Forestry, The University of British Columbia
* Adaptation and Impacts Research Division (AIRD), Environment Canada; Institute for Resources, environment and Sustainability, University of British Columbia
[#] Institute for Resources, environment and Sustainability, University of British Columbia

Abstract
Recent advances in the study of climate change impacts and responses have indicated the great value of integrated assessment methods. Traditional integrated assessment, however, is plagued by the lack of thorough integration of social and institutional domains, which must occur if integrated assessment is to serve its purpose of facilitating decision-making under conditions of uncertainty. These domains are especially relevant to an exploration of the linkages between Sustainable development and climate change responses (Adaptation and Mitigation) and related policies. We suggest that a participatory integrated assessment (PIA) framework can be used as a platform for organizing SAM studies, providing an ongoing learning opportunity for both researchers and practitioner/stakeholder partners. Within the PIA, scenario and backcasting tools could be used in conjunction with other case-specific methods (e.g. from forestry, water management and urban planning), as well as dialogue support methods such as visualization and decision-support models. We outline some key elements of a methodology which uses backcasting and scenario development to envision a locally sustainable future, explicitly considers tradeoffs and synergies between adaptation and mitigation, links climate change and sustainable development, and generates an integrated 'SAM' scenario.

Explicit incorporation of capacity in the PIA process reveals a set of indicators that must be included so that climate change can be placed in the context of broader development priorities and responsible policy decisions can be made. Examining capacity in this context reveals the resources with which any response to climate change can be built and it draws our attention to the underlying development path which simultaneously begets both capacity and barriers to action. The ultimate result is the generation of locally-significant climate change response strategies constructed upon a foundation of multi-stakeholder dialogue and scientifically robust scenario development.

1. Introduction

Climate change impacts, and potential adaptive and mitigative responses, have been the subject of major assessments by the Intergovernmental Panel on Climate Change (IPCC), including the recently released 4th Assessment Report, which was published in 2007. Throughout this assessment process, increased attention was being focused on linkages between climate change responses and sustainable development in part because climate change adds to the list of stressors that challenge our ability to achieve the ecologic, economic and social objectives that define sustainable development. Development choices, furthermore, can inadvertently result in altered vulnerabilities to climate, changed patterns of energy and material consumption, and consequently, emissions of carbon dioxide and other pollutants. Risks to human security could increase because of global climate change interacting with specific regional stresses, including ecosystem degradation, economic difficulties, high climate-related exposure, low response capacities and weak governance systems at sub-national and national scales (Barnett and Adger, 2007).

Klein et al. (2005) suggest that climate policy can evolve to facilitate the successful embedding of climate change within broader development goals to help reduce vulnerability and insecurity, but the integration of adaptation and mitigation at different operational scales remains a challenge (Jones et al., 2007) Although these responses are widely regarded as complements rather than substitutes, gaps in our understanding of the various capacities that are required to carry out these responses have prevented a truly integrated assessment of response options.

In this paper, we build on a series of case studies published in the Climate Policy special issues [Bizikova et al. (eds.), 2007] that partially addressed linkages between climate change responses and sustainable development. In this paper, we explore in more detail a possible methodology for linking sustainable development (S) and climate change adaptation (A), mitigation (M), herein referred to as "SAM". We seek an approach that enables the explicit consideration of climate change as part of the search for development paths that achieve the three pillars of economic, environmental and social sustainability in the particular local context. The specific objectives for conducting such local studies could be the following:

1. To explore ways of transitioning to sustainable futures at the local level that anticipate mitigation and adaptation needs;
2. To assess ways of strengthening necessary capacities for effective responses to climate change that can be fabricated into development activities that promote win–win policy solutions while addressing trade-offs;
3. To explore opportunities for the engagement of local stakeholders in a way that fosters collaboration, encourages creative thinking and promotes shared learning in addressing future development challenges;
4. To provide long-term guidance for local policies by strengthening the linkages between current local situations and future development options in the context of climate change impacts.

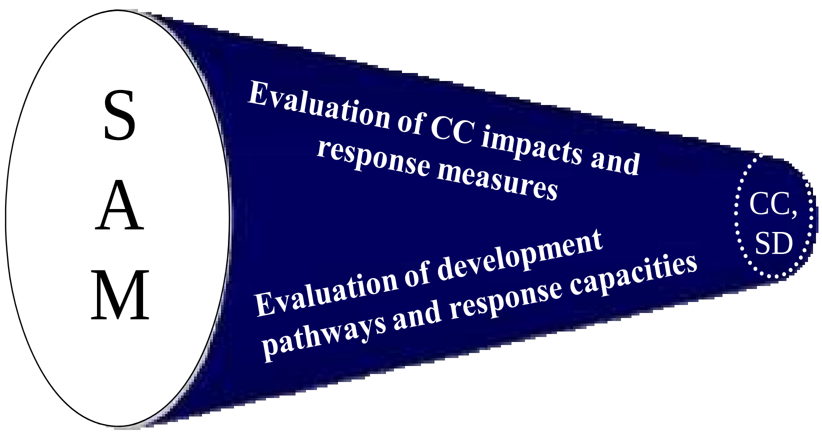
The proposed methodology will incorporate a merging of model-based and participatory approaches for information gathering, analysis, and communication, as part of a shared learning experience, engaging researchers and stakeholders. We furthermore propose that an integration of the concept of capacity to respond to climate change and an explicit consideration of barriers to responses will add value to previous Participatory Integrated Assessment approaches to climate change.

This paper elucidates one way in which these objectives can be achieved by first introducing a novel conceptual framework for SAM studies, describing key components of the proposed assessment framework (section 3 and 4), and finally section 5 outlines a key elements of methodological approach for conducting SAM case studies broadly characterized as participatory integrated assessment.

1. 1 Conceptual framework

As noted in Robinson et al. (2006), two ways to think about the linkages between adaptation, mitigation, and sustainable development are to view sustainability as a possible consequence of climate policies (seeing sustainability through a climate change lens) and to view climate change mitigation and adaptation as rooted in and the consequence of different socioeconomic and technological development paths (seeing climate change through a sustainability lens). Given these two approaches, Bizikova et al. (2007) have proposed a two pronged or "combined lens" approach to SAM, in which climate change and sustainable development goals are explicitly articulated (Figure 1), and simultaneously considered. This means that climate change responses become part of a portfolio of measures that represent a new, more sustainable, development pathway. This could include, for instance, specific actions designed to reduce consumption of fossil fuels, and to avoid high intensity development in vulnerable areas such as high risk zones for flooding or drought. In practice, however, it has not been easy to "mainstream" climate change measures into broader development decisions (e.g. Beg et al., 2002; Agrawala, 2005; Schipper and Pelling, 2006), so an SAM assessment must consider potential barriers, constraints and trade-offs that could affect the implementation of such measures. We suggest that many of these barriers are deeply rooted in path dependent development trajectories, which have, in this context, been given scant analytical and theoretical attention in the past.

Figure 1. Climate change and sustainable development through a SAM lens. *This "combined lens" builds on the climate change (CC) and sustainable development (SD) lenses from Robinson et al. (2006).*



The combined SAM lens represents an acknowledgement that entry points are needed in order for development paths and climate change measures to be linked in the assessment process (figure1). Development paths are created within a societal context that varies for each location, and give rise to the pools of resources, or capacity, that are available to be utilized in response to risks such as climate change. Climate change response measures, however, have at times been portrayed as inhibitors of the development aspirations of certain regions and countries. In the process of the design and implementation of the Kyoto Protocol, the concern has arisen that emissions reduction would be harmful to economic growth, or that various unequal commitments would create an unfair advantage for those countries that have negotiated relatively easily-achieved emission reduction targets, or none at all (Shimada, 2004). These arguments reveal the importance of wisely selected, contextually appropriate, response measures which take into consideration locally significant development priorities.

The search for entry points for the SAM assessment requires identification of key variables that can influence the results of both quantitative analyses and dialogue. For example, does the structure of a land use model include explicit usage of a climate parameter (temperature, precipitation, etc.), or of a variable that can be derived from climate information (e.g. water supply, crop growth, forest pest risk, malaria risk) so that climate change can be factored into decision making? Similarly, if a climate impacts model does not include parameters that represent adaptation capabilities, including human behaviour and the incorporation of trade-offs between alternative decisions, how can the effects of a change in the local development path be evaluated?

These issues suggest the need for a framework of integrated assessment which: is flexible enough to be able to incorporate a range of quantitative and qualitative inputs, builds on the learning opportunities that can be generated by backcasting and scenario-based approaches to exploring alternative futures, explicitly examines the various capacities required for climate change responses, and investigates the path-dependent institutional, technological, and socio-cultural barriers to effective responses.

1. 2. Linkages to capacity

Recent discussions of the potential implications climate change have led researchers to consider the resources and tools that provide the foundations upon which climate change responses are built. The concepts of mitigative and adaptive capacity were introduced in the Third Assessment Report of the Intergovernmental Panel on Climate Change (McCarthy, Canziani et al. 2001; Metz, Davidson et al. 2001) and further developed in the recent Fourth Assessment Report (Metz, Davidson et al. 2007; Parry, Canziani et al. 2007). Adaptive capacity, or the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change (Schneider, Sarukhan et al. 2001), was argued to be determined by factors such as the range of technological options, the availability and distribution of resources, the structure of critical institutions, and the stocks of human and social capital (Yohe and Tol, 2002). Similarly, mitigative capacity represents the ability of a group to "reduce anthropogenic emissions of greenhouse gases or enhance natural sinks," (Winkler et al., 2006) and has, in the past, consisted of a set of determinants that are virtually identical to those of adaptive capacity (Yohe, 2001).

Since the development of these concepts, it has been noted that many of the proposed determinants of capacity are simply features of a highly developed, often industrialized nation that is rich in all forms of capital and possesses highly complex institutions (Burch and Robinson, 2007). Thus, we see that many of the determinants of mitigative capacity are in fact part of some broader pool of resources that can be utilized in response to a multitude of risks, and that are closely linked to the underlying development path of a nation or community. This broader pool of resources has been called 'response capacity' and represents the human ability to respond to any risk with which it is faced (Burch and Robinson 2007), including the management of greenhouse gases and the consequences of their production (Tompkins and Adger, 2003). Mitigative and adaptive capacities, therefore, are better thought of as the institutions and policies, derived from the underlying response capacity (and thus the group's level of development), which are geared specifically towards either the mitigation of, or adaptation to, climate change. For example, the creation of a government agency aimed at managing climate change adaptation, or passage of an energy efficiency policy, represent the conversion of generalized response capacity into, respectively, adaptive and mitigative capacity.

These concepts provide insights into the ways in which responses to climate change are rooted in the underlying development path of a group or nation, by way of response capacity. Furthermore, institutional, technological, and socio-cultural barriers to effective climate change action, which grow out of complex path dependent processes, are revealed. These barriers may inhibit the translation of capacity into action on climate change, and as such require special attention throughout the PIA process. Incorporating capacity into this analysis is crucial for two reasons: it reveals the resources with which any response to climate change can be built, and it draws our attention to the underlying development path which simultaneously begets both capacity and barriers to action.

3. Assessment framework

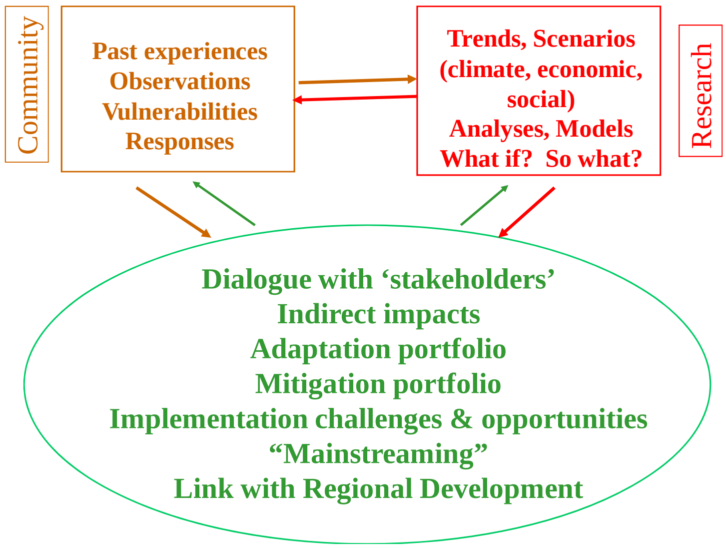
Although the ways in which participatory processes are useful in integrated assessments are manifold, one especially relevant use is the capacity of participatory process to frame problems and support the policy process by designing and facilitating policy debate and argumentation (Hisschemöler, Tol et al. 2001). In its simplest terms, an assessment of a complex problem like climate change can involve researchers and stakeholders. If an "integrator" can bring together the suppliers of the science information with those that are demanding a particular kind of information, then between the two groups it may be possible to obtain what Rotmans (1998) calls an integrative narrative, which helps to define the problem, leading to a consensus building process, and a sense of joint ownership in the process. This relationship becomes more complex with the involvement of sponsors of research and independent organizations, as well as the interested public and researchers mentioned above. The knowledge that emerges from these exchanges creates what has been called 'interactive social science' (Caswill and Shove, 2000).

The following sections will introduce a framework with which interactive social science can be operationalized in the context of SAM.

3. 1. Participatory Integrated Assessment

As a complement or alternative to all-inclusive integrated models, the participatory integrated assessment (PIA) approach is a framework that utilizes dialogue as a research tool. Dialogue may be used to provide the 'scaffolding' with which participants can relate new experiences to existing knowledge (Chermack and van der Merwe, 2003) The purpose of this dialogue is not simply for outreach, nor even simply for one-way teaching. Instead, this is intended to be two-way or multi-voice teaching. A PIA can create a shared learning experience for scientists, business interests, community representatives, aboriginal peoples, resource managers, governments, or any stakeholder with knowledge to share and a reason to be part of the process (Figure 2). In other words, the knowledge that is created during the process of PIA is an emergent property of the interactions among multiple actors (Robinson and Tansey, 2006), and the use of participatory process in integrated assessment can be seen as a 'learning machine' rather than a 'truth machine' (Berkhout *et al.*, 2002).

Figure 2. Framework for SAM shared learning involving researchers and communities of interest.



PIA is an umbrella term describing approaches in which non-researchers play an active role in integrated assessment (Rotmans and van Asselt, 2002), and can be used to facilitate the integration of biophysical and socio-economic aspects of climate change adaptation and development (Hisschemöller et al., 2001). Van Asselt and Rijkens-Klomp (2002) identify several approaches, including methods for mapping out diversity of opinion (e.g. focus groups, participatory modeling), and reaching consensus (e.g. citizens' juries, participatory planning). Huitema et al. (2004) have reported on a recent exercise on water policy that employed citizen's juries. PIA has also been used to facilitate the development of integrated models (e.g. Turnpenny, et al., 2004) and to use models to facilitate policy dialogue [e.g. van de Kerkhof, 2004).

In a PIA, individuals agree to participate in a process that allows them to use dialogue to approach a complex problem. Throughout the PIA process, issues often arise, and must be overcome, when bringing together people with potentially disparate points of view on an issue. Confrontations or contradictory information may also arise through this process, which requires reconciliation. The dialogue is intended to find a way to navigate through these issues without the process taking on the atmosphere of a judicial inquiry or other form of legal proceeding.
PIA has evolved in part from Participatory Action Research (PAR), which is a well-known approach that social scientists have used in studies of traditional practices and environmental knowledge of aboriginal communities (see, for example Krupnik and Jolly, 2004; Reid et al., 2006).

Dialogue and models can be mutually reinforcing (Tansey et al. 2002), and together, can improve decision-making by integrating knowledge from a variety of sources (Hisschemöller et al., 2001). For instance, dialogue can support model building through the process of participatory modelling, including, for example, mediated modelling (van den Belt 2004; Tansey and Robinson, 2006). Still, the success of a PIA is heavily dependent on the presence of the following elements: sufficient time, subject matter of the dialogue that is relevant to the participants, and the explicit presentation of uncertainty and disagreement (Hisschemöller et al., 2001). Time is especially important, as evidenced the Netherlands' COOL project (Climate OptiOns for the Long term), which focused on Dutch national policy for reducing emissions (van de Kerkhof 2004) and extended over several years.

Part of what distinguishes PIA from traditional construction of integrated models is the application of dialogue techniques. Dürrenberger et al. (1997) provide a categorization of various dialogue techniques according to two criteria:

1) Embeddedness, which is related to the level of activity within a decision making process, ranging from low (information gathering) to medium (advice) to high (decision), and
2) Level of conflict, which ranges from absent to latent to acute.

In a situation with acute conflict and high embeddedness, the technique most likely to be used is mediation. In a research situation, with low to medium embeddedness, there are other options, such as focus groups, planning cells, and consensus conferences. Climate change research, dialogue, or negotiation can include situations that cover much of this range of embeddedness and conflict. But, the choice of dialogue exercise really depends on what the objective is. For example, policy exercises and focus groups are techniques that are designed to bring out the range of positions, rather than to force a consensus. In other words, in these exercises, the task here is not to reach agreement, but rather to find out what all the positions really are.

Returning to the example of the COOL project, van de Kerkhof (2004) explored a number of dialogue exercises and attempted to measure how well these different exercises worked. This was determined through several indicators. Two of these were *distance* and *involvement*.

In the case of *distance*, the question is, does the approach enable participants to distance themselves from short-term concerns and focus on wider long-term issues? For example, consider a situation in which researchers want to discuss climate change with a business owner or a manager of a reservoir, who have their particular planning horizon. Can the exercise enable them to think outside of a near-term operational frame and think in terms of 30 to 50 years in the future?

Involvement is a measure of whether there was successful transfer of information to the dialogue participants from the scientists or the technical staff that were providing the background information. In other words, did the technical or background materials teach new concepts or knowledge to the participants? Also, is there a balance between distance and involvement?

Other indicators of learning include:

- encouragement of debate and argument;
- use of scientific knowledge being offered;
- homogeneity or heterogeneity in the makeup of the group and in the sources of information; and
- commitment, trust, fairness, and transparency, in the dialogue process.

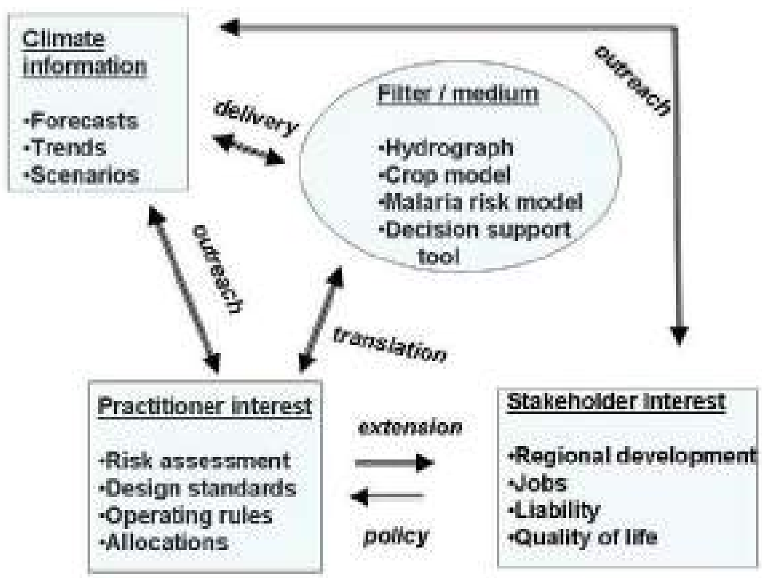
In the Georgia Basin Futures Project, a five year PIA, the focus was explicitly on the co-production of knowledge, whereby 'expert' knowledge was combined with partner knowledge at multiple stages of the project in order to give rise to an emergent understanding of sustainability options at a regional scale. The focus was much less on the communication of technical knowledge to stakeholders than to the co-production of understanding about the choices and consequences facing the region (Tansey et al. 2002; Robinson et al, 2006). Such work brings to the fore complex question about power, trust, and the nature and status of different forms of understanding (Robinson and Tansey, 2006).

3.2. Models as dialogue starters

Success in a PIA or any dialogue process will ultimately depend on convincing stakeholders to agree to remain committed to the process. In that respect, it will likely be more difficult to organize and sustain dialogue within a PIA than for a modelling group to construct an integrated model on its own, because response rates can be influenced by many external factors (e.g. participants' other commitments to their jobs and families). At the same time, however, PIA can include group-based model construction (van den Belt, 2004), in which stakeholders contribute directly to model construction, within a modelling process that includes incremental development of codes and functions, tested and evaluated by local practitioners and other local knowledge holders. This offers an exercise in shared learning, which is important for providing a sense of ownership in the process, as well as the results (Rotmans and van Asselt, 1996). Furthermore, the output of the process is fundamentally a product of the involvement of 'users' of the research, rather than strictly the result of design and execution by researchers in isolation from other actors.

What then is the role of models (including group-based models) in initiating and maintaining a dialogue between researchers and stakeholders? In the context of climate variability and change, one important function is the translation of information from one base of knowledge (such as scientific information or traditional environmental knowledge) into other forms of knowledge (Figure 3). The role of local professionals and technical support staff (i.e. practitioners, such as engineers and resource managers working for local/regional governments) is an important element of this translation process for decision makers.

Figure 3. Role of models as 'filters' to translate basic climate information into indicators of interest to practitioners and stakeholders (from Cohen and Waddell, in press).



The long-term sustainability of dialogue processes is critical to the success of participatory approaches. Models can play an important role as dialogue starters, and can offer interactive learning opportunities. For such processes to be successful as shared learning experiences, they have to be inclusive and transparent. Haas (2004) describes examples of experiences in social learning on sustainable development and climate change, noting the importance of sustaining the learning process over the long term, and maintaining distance between science and policy while still promoting focused science-policy interactions. Applications of focus group and other techniques for stakeholder engagement are described for several studies in Europe (Welp et al., 2006) and Africa (Conde and Lonsdale, 2004).

Group-based model building was used to study water resources in the Okanagan region of Canada. A systems dynamics model of stocks and flows of water was used to explore various response options for adapting to climate change and population growth (Langsdale *et al.*, 2006). Other participatory examples are case studies of agriculture in the UK (Lorenzoni *et al.,* 2001), adaptation to worst-case sea level rise in Europe (Toth and Hiscnyk, 2005), options for greenhouse gas mitigation in the Netherlands (van de Kerkhof, 2004), and the application of the QUEST model series in support of stakeholder engagement on regional sustainability in the Georgia Basin Futures Project (Tansey *et a l.*, 2002; Robinson and Tansey, 2006). It incorporates a backcasting approach (see section 4.2 below), which enables model users to explore pathways for producing desirable outcomes.

Despite the host of benefits associated with PIA methods, there can be difficulties in reaching consensus on identifying and engaging participants (Parkins and Mitchell, 2005), and in interpreting the results of dialogue within different communities (e.g. Huntington et al., 2006). There are also challenges inherent in measuring the quality of dialogue, the transparency of process, the promotion of learning, and indicators of influence (Rowe and Frewer, 2000; van de Kerkhof, 2004). Furthermore, there is the danger that such processes will add to the stress already being felt by local scale decision makers and institutions, as external pressures from national and international scales are downloaded onto their jurisdictions (Burton *et al.,* 2007). Allen (2006) notes that increased responsibility without increased capacity could create a barrier to successful participation in shared learning exercises on long term climate and sustainability, and indeed lead to of the disempowerment of local participants. A related issue is the potential for claims of oppressive or patronizing research that may result from improperly acknowledged distribution of power (Orme, 2000; Cooke and Kothari, 2001).

4. Operationalizing the assessment framework

In this section, we review the opportunities and challenges associated with scenarios and backcasting. The former offers a picture of changes evolving from current conditions to various future states. The latter involves a subset of scenarios which are the result of a process that begins with defining futures, ideal or otherwise, and then works backwards to current conditions.

4. 1. Scenarios

Climate change is a long-term problem in which the past may not be the only or best guide to the future. Scenarios represent an excellent opportunity to begin an exploration of different futures in which climate can be treated as a variable condition, rather than as a constant state with regular oscillations. There is a growing interest in the use of scenarios as heuristic tools that make mental maps more explicit (Berkhout *et al.,* 2002), as aids to social and organizational learning (Chermack and van der Merwe, 2003), as tools for scanning the future in a rigorous, creative, and policy relevant way that explicity incorporates normative elements (Swart *et al.*, 2004), and as a means by which we may explore the effects of alternative course of action for future problems involving multiple actors, risk and uncertainty (Mayer *et al.*, 2004). The three most commonly-used types of scenarios are exploratory scenarios, which posit a range of underlying socioeconomic conditions upon which alternative futures may be constructed; extrapolatory scenarios, which provide forecasts based on baseline trends; and normative scenarios, or backcasting, which are built on positive and negative visions of the future, and explore pathways of change that might lead to them (Berkhout *et al.*, 2002). This section will first consider the broad umbrella of scenarios in general, and will then focus on backcasting as a subset of scenarios that may be particularly useful for SAM analyses.

Assessments of future scenarios can lead to the realization by researchers and local partners that current operational and planning practices may need to be re-examined, and current vulnerabilities reconsidered, as part of a larger process of defining and implementing local-scale sustainable development paths. As such three questions become especially important:

a) *What if*? In a scenario of climate change and development, what kinds of local impacts may occur? Without absolute certainty regarding future climate conditions, can a damage report be provided for various combinations of climate change and local development choices?

b) *So what*? Does the damage scenario make a difference? As the damage scenario is presented to interested parties, such as irrigation purveyors, municipal planners, business leaders or engineers, the dialogue can turn to whether the damage scenario makes a difference to their vision of the future. Current planning processes may consider population growth or changes in important industries or market conditions. The climate change impacts scenario represents a new set of climate statistics translated into a physical (and possibly an economic) impact. Could this scenario hinder long-term efforts to meet local development goals?

c) *What can be done*? How can a sustainable development pathway be defined for the study area? What adaptation measures should be considered? How could these become "mainstreamed" into a sustainable development pathway? How could emission reduction measures become part of this without creating a new vulnerability? If climate change scenarios can be translated into parameters that are relevant to stakeholders in their planning context, then it should be possible to start a dialogue about adaptation, mitigation, and development that would be different from the initial planning scenario, but still be plausible.

A scenario-based SAM case study would ideally try to address these critical questions. Ultimately, the goal is to move away from the simplifying assumption that everything else remains equal, and towards the notion that the ground is moving under our feet while the atmosphere is changing over our heads. In order to do this, we must consider that a search for the most likely future, which is the most common approach of scenarios, may be misguided or counterproductive, since the future remains to be created (Höijer *et al.*, 2006). Furthermore, the goals of a SAM approach, as articulated above, include the integration of human responses to climate change within the broader context of sustainable development paths. Thus, we seek to explore and articulate the path that we wish to take, rather than the path that is most likely. In doing so, we are explicitly incorporating a normative element into the more traditional use of scenarios in Participatory Integrated Assessment. Backcasting is a scenario approach that attempts to accomplish this goal, and will be briefly introduced in the following section.

4. 2. Backcasting

Backcasting is a method of analyzing alternative futures (Robinson, 1994; Dreborg, 1996). Unlike predictive forecasts, backcasts are not intended to reveal what the future will likely be, but to indicate the relative feasibility and implications of different policy goals. It is thus explicitly normative, involving working backwards from a particular desired future end-point or set of goals to the present, in order to determine the physical feasibility of that future and the policy measures that would be required to reach it.

While the value and quality of a predictive forecast depend upon the degree to which it accurately suggests what is likely to happen under specified conditions, backcasting is intended to suggest the implications of different futures, chosen not on the basis of their likelihood but on the basis of other criteria defined externally to the analysis (e.g. criteria of social or environmental desirability). No estimate of likelihood is possible since such likelihood would depend upon whether the policy proposals resulting from the backcast were implemented. Thus, while the emphasis in forecasts is upon discovering the underlying structural features of the world that would cause the future to come about, the emphasis in backcasts is upon determining the freedom of action, in a policy sense, with respect to possible futures.

In order to undertake a backcasting analysis, future goals and objectives are defined, and then used to develop a future scenario. Analyzing the technological and physical characteristics of a path that would lead toward the specified goals specifies the scenario. The scenario is then evaluated in terms of its physical, technological and socio-economic feasibility and policy implications. Iteration of the scenario is usually required in order to resolve physical inconsistencies and to mitigate adverse economic, social and environmental impacts that are revealed in the course of the analysis.

In what have been called first order backcasting methods, the general nature of the desired end-point is specified by the research team in advance of the backcasting analysis itself, which focuses on the detailed characteristics of the end-point future and/or the path between that end-point and the present. Second order backcasting is based on a view of backcasting as a social learning process, whereby not just the analysis of the feasibility of a scenario, but also the choice of the goals themselves, should be part of the analysis (Robinson, 2003). The decision as to what is a desirable scenario is thus an emergent property of the process of analysis. This in turn requires the development of iterative and participatory modeling tools and processes quite different from those usually used (Quist and Vergracht, 2006). The type of participatory integrated assessment described above, however, is well-suited to the goals of backcasting, and the combination of these two approaches can yield creative, open, and reasonable solutions to problems, while explicitly acknowledging the challenges presented by uncertainty, contradiction and ambivalence (Höijer *et al.*, 2006).

Since backcasting approaches explicitly introduce the question of policy choice, they serve to re-focus the use of analysis away from responding to inevitable futures and toward exploring the nature and feasibility of alternative directions of policy. This helps to put the onus for choosing back where it belongs: in the policy arena. Furthermore, the explicitly normative approach built into backcasting methods parallels the norms and values that are embedded within an integrated SAM research agenda.

5. Key elements of SAM case studies linking climate change and sustainable development

Addressing such complex questions as sustainable development and climate change requires a coordinated effort building on linkages between research and practice. As stated earlier, the ultimate goal of the SAM case study is to assist in moving policy-making at the local level toward sustainability, given new challenges arising from changing climate. Information available from climate impact/adaptation assessment needs to be integrated with local development priorities, including mitigation of GHG emissions, in order to inform the policy process, take action and strengthen capacities. We can accomplish this aim if we move towards integrated assessments based on the interaction with stakeholders, enhancing interdisciplinary work and producing outcomes that can be included in the decision-making processes. The below discussed key elements for conducting the case study builds upon PIA and utilizes scenario-based models developed though public dialogue processes (van Asselt and Rijkens-Klomp, 2002).

Defining preferred local sustainable development scenario

A scenario focused on describing a sustainable future for the location of interest and in this way providing the context for climate change impacts is a crucial element of any SAM case study. By creating a context for climate impacts we no longer impose future climatic conditions on present-day socio-economic conditions, an approach taken by many climate impacts studies that appears insufficient. Scenarios can provide heuristics that enable policy makers to identify possible future vulnerabilities to climate change and to assess the capacity of future societies to adapt to its impacts—impacts that only have meaning in their social context (Berkhout *et al.,* 2002). Approaches focusing on anticipating future development should capture the long-term and dynamic nature of local goals and challenges arising from efforts to achieve sustainability.

At an operational level, planners are more concerned about the local development questions than global-scale climate change (Gupta and van Asselt, 2006). Therefore, by creating the local scenario, the stakeholders get an opportunity to identify local development goals, such as large-scale reforestation, urban densification, expanding the transportation network, building new energy facilities, agricultural change, or other unexplored options that they are concerned about and if the goals are designed properly they may help to move to a sustainable future. This goal can be seen as a local problem, addressing a single dimension of sustainability, but analysed under different time frames (Swart et al., 2004).

Earlier in this paper, we discussed second-order backcasting as a way to explore the nature and feasibility of alternative directions of achieving certain desired future development goals in collaboration with stakeholders. In the case of urban infrastructure development, Ruth and Coelho (2007) showed that stakeholders can be strongly biased towards pre-existing notions of development, and consequently, the selected method needs to allow stakeholders to distance themselves from past and current trends that may restrict opportunities to move towards a more sustainable path. Using backcasting to generate scenarios gives the opportunity to challenge current development pathways.

Finally, the scenario evolution is complemented with the analysis of an identified set of indicators. It is important, that these indicators must include barriers to action on sustainable development, such as institutional capacity, social capital, technological path dependences and modes of environmental governance. In the realm of adaptation research, scholars have developed a number of indicators that are closely related to the original set of adaptive and mitigative capacity determinants developed by Yohe (2001). Especially useful as a starting point are measures of the number of deaths incurred by a natural disaster, the number of people affected by the disaster, the amount of damage done, further development on floodplains, coasts and other vulnerable areas (Yohe and Tol, 2002). This gives us some idea of the vulnerability of a region in the event of future, climate-related disasters, and thus the adaptive response that is required. Other indicators of adaptive capacity, as defined above to be much more specific than previous definitions of the concept, would include the number of institutions and policies created to deal with the impacts of climate change, and the perceived efficacy and feasibility of these policies. Shepherd et al. (2006) have identified specific components related to feasibility, such as institutional and technical enabling factors and barriers to implementation. Generally speaking, these indicators assist in an integrated assessment of climate change response options. Furthermore, both future scenarios and backcasting, discussed below, can utilize these indicators to formulate visions of the future that are desirable to PIA participants.

Applying PIA offers integration of the biophysical and socio-economic aspects of development, by creating opportunities for shared experiences in learning, problem definition, and design of potential solutions[1]. Researchers should carefully design the scenario development exercise by giving sufficient time for problem definition, knowledge base development, building trust and gaining a shared appreciation of critical development questions articulated by the participants (Swart *et al.,* 2004).

[1] Welp et al. (2006) suggested that for issues such as climate change, science needs to open up for new ways of framing problems and in such a process stakeholder dialogues play a vital role.

Linking local development and impacts of changing climate

The importance of defining a local scenario and elaborating it within the local scenarios first is rooted in the premise that climate change could create additional vulnerabilities (Reid *et al.*, 2006). We see the role of the scenarios as helping local communities move towards a sustainable pathway at the early stage of planning, while addressing complexity and risk arising from climate change. Scenarios provide a context to identify information on broader social and environmental consequences of climate change (UK CIP, 2001) from often narrowly defined climate change impacts assessments.

In defining the measures required to achieve the outline 'future' scenario, here we focus on whether climate change makes a difference in being able to achieve this sustainable future (i.e. does climate change impose any additional constraints, technical, environmental or social). Here, models/tools specifically developed to address climate-related concerns, such as water, forests, food production, fish, property exposure/risk, health, etc can be applied. This may also include group-based or mediated model building of the STELLA tradition (van den Belt, 2004). This PIA approach has been used in a series of studies on climate change and water management in the Okanagan region of British Columbia, using a range of population growth scenarios (Cohen et al., 2006; Cohen and Neale, 2006; Langsdale *et al.,* 2007). However, linkage with a sustainable development scenario has not yet been attempted.

Lorenzoni et al. (2001) shows that stakeholders in farmer communities in the UK were more concerned when climate change was presented as an increase in rainfall rather then changes in temperatures, due to the higher sensitivity of agricultural production to rainfall then temperature. Collaborating with stakeholders in assessing potential climate change damage, as well as the performance of adaptation measures, is crucial for translating outcomes of models often presented as changes in temperature, precipitation or sea level rise to units that matter to local stakeholders. For example, changes in biomass accumulation, changes in length of the growing season or water availability can be seen as relevant information for stakeholders. Estimating the impacts of climate change is a task for researchers applying their expertise within an interdisciplinary team[2] and communicating the results to the stakeholders (for details see figure 3). This provides a challenge for natural scientists dealing with downscaling climate predictions and linking them with changes in natural resources, but also creates opportunities for interdisciplinary scholars to deepen their understanding of social implications of climate change impacts (e.g. cost and benefit assessments).

Assessing the relationship between adaptation and mitigation at the local level

Viewing adaptation and mitigation responses as part of broader development strategies on the path towards sustainability offers a new way of thinking about climate change response and creates opportunities for innovative approaches. In a climate change context, for example, this would involve near-term objectives for both adaptation and mitigation alongside objectives which characterize an improved capacity or ability to address adaptation and mitigation in the future (Wilson and McDaniels, 2007). Adaptation options can include a diversity of measures, which can also strengthen response capacities. Examples include new regulations for infrastructure development, revised allocation principles for water, introduction of new agricultural crops or ways of production, changed zoning to avoid vulnerable sites, heat alert systems and new flood management systems. Similarly, a diversity of mitigation options can be promoted as feasible in a local context to reduce emissions such as renewable energy production, support for low emission

[2] PIA of climate change strongly centred on participation, however showed that distinct step could be conducted by scientists (Welp *et al*., 2006).

and clean technologies, increasing energy efficiency, recycling and re-use, urban densification and zoning for multiple use, carbon sequestration, and lowering emissions from agriculture.

Here, there are opportunities for scientists to articulate examples of adaptation and mitigation measures, but it also gives members of the collaborative group the opportunity to address their own experiences[3]. The main focus should be on creating an inventory of specific adaptation and mitigation measures, including the assessment of performance through various indicators of development (e.g. vulnerability/risk exposure, economic performance, and environmental indicators including GHG emission rates). Specific attention would be given to identifying measures with potential synergies that we are trying to avoid, such as adaptive emissions and new vulnerabilities emerging from mitigation. Here, the dialogue should also include specific coverage of barriers to implementation (municipal policy, high-level policy, and technical, economic and social/ethical concerns) or enabling factors based on current and potential changes in local response capacity. This helps to deepen the understanding of policy makers on how to promote efficient use of limited resources by identifying synergies between adaptation and mitigation at the early planning stage of development activities.

The inventory of measures should be drawn from diverse economic sectors involved in the local development scenario. For example, local transportation network development can minimize vulnerability from extreme weather events, but at the same time create opportunities for emission reduction and co-benefits (e.g. public transportation, car pools). Energy system development can strike a balance between increased use of renewable sources that might be affected by climate change (e.g. changes in precipitation may impact hydropower or climate impacts on forestry as a source of biomass) and decreasing dependency on coal and oil. Co-benefits such as less local air pollution and associated human health benefits and job opportunities should be considered. Similar examples can be recognized in the forestry sector, in which the selection of planted species needs to address potential changes in pest dispersion and occurrence of fires. But, increased forest planting also provides other benefits such as flood protection, carbon sequestration, and carbon stored in long-life wood products or using wood as a source of energy (Dang et al., 2003; Swart et al. 2003).

Local dialogue processes have the potential to identify synergies among local measures that could be utilized actively to mobilize local actors (Næss et al., 2006). Deliberation during the PIA is focused on identifying potential synergies and trade-offs between adaptation and mitigation identified in the previous step, which requires an identification of capacities and actions, their cost and benefits for various sectors (e.g. diversification of energy sources, water resources management, forestry, agriculture and consequences for ecosystems), and their interaction in the development scenario. This creates a dialogue about the feasibility of the responses, how they can be incorporated into the development initiatives at the early stage of development planning. Participants would therefore gain a better appreciation of the need to balance competing priorities, preferences and decisions using limited resources.

Indentifying measures to promote sustainable development pathway with embodied responses to climate change

The centre of the SAM case study is the **i**ntegration of local sustainable development goals and the climate change 'damages and opportunities' report. Long-term iterative scenarios would be the product of this integration. Similar to Næss et al. (2006), we see local problems as 'door openers' or entry points for the evolution of local climate policies and the possibility of creating mutual legitimization within the mitigation and adaptation policy areas. Here we should focus on

[3] Shepherd et al. (2006) describes early adapters to climate change.

informing community-level decision-makers and other relevant stakeholders to allow them to adjust their long-term priorities to the threats (also opportunities) from a changing climate. Defining of the local development scenario, with embodied climate change responses, can lead to identification of a broader set of measures than targeting the responses solely as a mitigation and/or adaptation response (Swart et al., 2004). This would require answering question, such as, does the inclusion of identified adaptation and mitigation measures fit with local sustainability priorities, or create additional problems, requiring a second iteration? For example, do 'green' buildings require legislative protection of solar access?

Developing a local sustainable development scenario, identifying impacts of climate change and adaptation and mitigation measures are meant to facilitate “learning by planning” within the group of practitioners by developing key elements of the SAM case study. Here we focus on creating venues to operationalize the responses in the institutional context by identifying measures to promote “learning by doing” at the policy levels (Wiek et al., 2006). Examples with collaborative development of climate change impacts assessment showed that local decision-makers involved during the whole assessment can internalize the results (UK CIP, 2001). Similarly, Moser (2005) showed that cases of successful linkages between information produced by scientists, and actually used in decision making, occurred in those cases in which ongoing interaction and mutual understanding of practitioner information needs vis-à-vis scientific capability was already further along. Consequently, the suggested outcomes can be internalized more easily if there is already an expressed need to address impacts of climate change based on past negative experiences such as floods (Penning-Rowsell, 2006).

Although we emphasize the importance of the participatory process throughout the case study, it does not necessary imply success in transforming the integrated SAM scenario to actual policies. However, the value of this stakeholder-driven approach goes beyond guiding further scientific inquiry. Such direct stakeholder engagement increases the likelihood that the decision-makers will find subsequent research salient, credible, and legitimate, insofar as the underlying assumptions are derived in part from their observations (Cash et al., 2003). Moreover, this type of research product provides immediate educational benefits in a process of social learning for all participants, including researchers (Moser, 2005). Through the learning that will occur during the case study, we can create a collective process in which the policy makers, scientists, and other stakeholders generate new insights into, and a better understanding of, the different perceptions, ideas, interests, and considerations that exist with regard to the nature of the development goal in the context of climate change (Kerkhof and Wieczorek, 2005). This process will deepen their understanding of the appropriate strategies to induce the transition towards the preferred local scenario, and to facilitate the changes identified in the scenario. Policy recommendations could include new rules and standards, building codes, revised principles of natural resources management, and policy incentives for using new technologies. This type of collaboration between the stakeholders also creates important outcomes in the form of new relationships, and social capital built among players who would not ordinarily interact, much less do so constructively (Hajer, 2005).

A SAM case study requires that stakeholders identify institutional constraints, and promote institutional partnerships that can foster the implementation as well as the monitoring of identified responses. Innes and Booher (2004) showed that collaborative planning processes addressing developmental priorities are essential ways to build societal capacity and institutional capacity. It is important to create partnerships between institutions targeting climate change and sustainable development, in order to establish a platform for the successful implementation of the outcomes of the case study[4].

Finally, the outlined approach should be applicable in diverse local contexts with their own challenges. Local initiatives depend not only on the decisions made at the local level, but also respond to trends occurring and policies being adopted at the regional, national, and international scale. Many responses to climate change, especially those focused on mitigation, are developed at the international level, and then translated into commitments at national and regional levels. However, there are examples of local initiatives emerging from shared learning experiences which offer useful models for carrying out SAM studies with PIA, such as the guidebook for adaptation based on experiences in King County, Washington, in the US (Snover et al., 2007). Future initiatives need to focus on conducting local case studies, strengthening transfer of lessons learned between cases, and facilitating collaborative work of diverse groups of stakeholders including local decision-makers as well as participants from other level of governance. These studies should also address technical and institutional aspects of adopting development decisions involving both climate change adaptation and mitigation, which could provide useful insights for development of an integrated global climate change adaptation and mitigation agenda.

Acknowledgements

We also gratefully acknowledge the continuous support of the Adaptation and Impacts Research Division of Environment Canada for the research involved in this paper and for the SAM initiative.

References

Agrawala, S. (ed.), 2005. *Bridge over Troubled Waters: Linking Climate Change and Development.* Organization for Economic Co-Operation and Development, OECD Publishing, Paris.

Allen, K.M., 2006. Community-based disaster preparedness and climate adaptation: local capacity-building in the Philippines. *Disasters* 30, 81-101.

Barnett, J., and W.N. Adger. 2007. Climate change, human security and violent conflict. *Political Geography*, 26, 639-655.

Beg, N., J. Corfee-Morlot, O. Davidson, Y. Afrane-Okesse, L. Tyani, F. Denton, Y. Sokona, J.P. Thomas, E.L. Rovere, J. Parikh, K. Parikh and A. Rahman, 2002. Linkages between climate change and sustainable development. *Climate Policy* 2, 129-144.

Berkhout, F., Hertin, J., Jordan, A., 2002. Socio-economic futures in climate change impact assessment: using scenarios as 'learning machines. *Global Environmental Change* 12, 83 – 95.

Bizikova L., J. Robinson and S. Cohen (eds.), 2007. Integrating climate change actions into local development. Climate Policy special issue, vol 4. pp. 105.

Burch, S. and J. Robinson 2007. Beyond Capacity: A Framework for Explaining the Links between Capacity and Action in Response to Global Climate Change. Climate Policy 4, 304 – 316.

Burton, I, Bizikova L., T. Dickinson and Y. Howard (2007) . Upscaling the results of local research on adaptation, mitigation and sustainable development', Climate Policy, 4, 353 – 370.

[4]Example from the UK shows, that creating local climate change impacts scenarios within the socio-economic development path in collaboration with local development bodies promoted greater local ownership of regional policies and increased commitment to heir implementations (UK CIP, 2001).

Cash, D. W., W. C. Clark, et al., 2003. Knowledge systems for sustainable development. *PNAS* 100, 8086–8091, www.pnas.org_cgi_doi_10.1073_pnas.1231332100.
Caswill, C., and E. Shove, 2000. Introducing interactive social science. *Science and Public Policy* 27, 154-157.
Chermack, T.J., and L. van der Merwe, 2003. The role of constructivist learning in scenario planning. *Futures* **35**, 445-460.
Cohen, S. and T. Neale (eds.). 2006. *Participatory integrated assessment of water management and climate change in the Okanagan Basin, British Columbia.* Final report, Project A846, submitted to Natural Resources Canada, Ottawa, Environment Canada and University of British Columbia, Vancouver.
Cohen, S. and M. Waddell. In press. *Climate Change in the 21st Century*. McGill-Queen's University Press, Montreal.
Cohen, S., D. Neilsen, S. Smith, T. Neale, B. Taylor, M. Barton, W. Merritt, Y. Alila, P. Shepherd, R. McNeill, J. Tansey, and J. Carmichael, 2006. Learning with Local Help: Expanding the Dialogue on Climate Change and Water Management in the Okanagan Region, British Columbia, Canada, *Climatic Change* 75, 331-358.
Cohen, S., Demeritt, D., Robinson, J., Rothman, D., 1998. Climate change and sustainable development: towards dialogue. *Global Environmental Change* 8, 341 – 371.
Conde, C. and K. Lonsdale, 2004. Engaging stakeholders in the adaptation process. In Lim, B. and E. Spanger-Siegfried (eds.), *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures.* Cambridge University Press, Cambridge, 47-66.
Cooke, B. and U. Kothari (eds.) 2001. *Participation: The New Tyranny?* Zed Books, London, 207 p.
Dang, H. H., Michaelowa, A., Tuan, D. D., 2003. Synergy of adaptation and mitigation strategies in the context of sustainable development: the case of Vietnam. *Climate Policy* 3, S81–S96.
Dreborg, K., 1996. Essence of Backcasting. *Futures* 28**,** 813-828.
Dürrenberger, D., J. Behringer, U. Dahinden, A. Gerger, B. Kasemir, C. Querol, R. Schüle, D. Tabara, F. Toth, M. van Asselt, D. Vassilarou, N. Willi, and C. Jaeger, 1997. '*Focus groups in integrated assessments: A manual for a participatory tool'*, ULYSSES working paper, WP-97-2, Darmstadt University of Technology, Darmstadt.
Gupta, J., Asselt, van H., 2006. Helping operationalise Article 2: A transdisciplinary methodological tool for evaluating when climate change is dangerous. *Global Environmental Change* 16, 83–94.
Haas, P. M., 2004. When does power listen to truth? A constructivist approach to the policy process. *Journal of European Public Policy* 11, 569-592.
Hajer, A. M., 2005. Setting the stage, a dramaturgy of policy deliberation. *Administration &* Society 36, 624-647.
Hisschemöller, M., R.S.J.Tol, and P. Vellinga, 2001. The relevance of participatory approaches in integrated environmental assessment. *Integrated Assessment* 2, 57-72.
Höijer, B., R. Lidskog, and Y. Uggla, 2006. Facing dilemmas: Sense-making and decision-making in late modernity. *Futures* 38, 350-366.
Huitema, D., M. van de Kerkhof, R. Terweij, M. Van Tilburg, and F. Winsemius, 2004, '*Exploring the future of the Ijsellmeer: Report of the river dialogue project on the Dutch citizen's juries*, Institute for Environment Studies, Vrije Universitat, Amsterdam, 94p.
Huntington, H.P., S.F. Trainor, D.C. Natcher, O.H. Huntington, L.DeWilde and F.S. Chapin III, 2006. In: 'The significance of context in community-based research: understanding discussions about wildfire in Huslia, Alaska'. *Ecology and Society* 11, article 40 [online] http://www.ecologyandsociety.org/vol11/iss1/art40/
Innes, J. E., Booher, E. D., 2004. Reframing Public Participation: Strategies for the 21st Century. *Planning Theory & Practice* 5, 419 – 436.

Jones R. N., P. Dettmann, G. Park, M. Rogers[4] and T. White (2007). The relationship between adaptation and mitigation in managing climate change risks: a regional response from North Central Victoria, Australia. Mitigation and Adaptation Strategies for Global Change 12, 685 – 712.

Klein, R.J.T., E.L.F. Schipper and S. Dessai. 2005. Integrating mitigation and adaptation into climate and development policy: three research questions. *Environmental Science & Policy* 8, 579-588.

Krupnik, I., Jolly, D. (eds.). 2002.*The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change.* ARCUS: Washington, D.C.

Langsdale, S., A. Beall, J. Carmichael, S. Cohen and C. Forster. 2007. An exploration of water resources futures under climate change using system dynamics modeling. *The Integrated Assessment Journal*, 7, 1, 51-79.

Lorenzoni I., Jordan, A., O'Riordan T., Turner, K. and Hulme M., 2000. A co-evolutionary approach to climate change impact assessment: Part II. A scenario-based case study in East Anglia (UK). *Global Environmental Change* 10, 145-155.

Mayer, I.S., L. Carton, M. de Jong, M. Leijten, and E. Dammers, 2004. Gaming the future of an urban network. *Futures* 36, 311-333.

McCarthy, J. J., O. F. Canziani, et al., Eds. (2001). Climate Change 2001: Impacts, Vulnerability and Adaptation; Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, U.K., Cambridge University Press.

Metz, B., O. Davidson, et al., Eds. (2001). Climate Change 2001: Mitigation; Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, Cambridge University Press.

Metz, B., O. R. Davidson, et al., Eds. (2007). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press.

Moser, 2005. "Impacts assessments and policy responses to sea-level rise in three U.S. states: An exploration of human dimension uncertainties." Global Env. Change 15: 353-369.

Naess L. O., I. T. Norland, W. M. Laffertyb, C. Aall (2006) Data and processes linking vulnerability assessment to adaptation decision-making on climate change in Norway. Global Environmental Change 16, 221–233

Orme, J., 2000. Interactive social sciences: patronage or partnership? *Science and Public Policy* 27, 211-219.

Parkins, J.R. and R.E. Mitchell, 2005. Public participation as public debate: a deliberative turn in natural resource management. *Society & Natural Resources* 18, 529-540.

Parry, M. L., O. F. Canziani, et al., Eds. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press.

Penning-Rowsell, E., Johnson, C. and Tunstall, S., 2006. Signals' from pre-crisis discourse: Lessons from UK flooding for global environmental policy change? *Global Environmental Change* 16, 323–339.

Quist, J. and P. Vergragt, 2006. Past and future of backcasting: The shift to stakeholder participation and a proposal for a methodological framework. *Futures* 38, 1027-1045.

Reid, W.V., F. Berkes, T. Wilbanks and D. Capistrano (eds.), 2006. *Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment*. Island Press, Washington.

Robinson, J., 1994. Backcasting. In R. Raehlke, (Ed.) *The Encyclopedia of Conservation and Environmentalism*. New York, Garland Publishing Inc.

Robinson, J., 2003. Future Subjunctive: Backcasting as Social Learning. *Futures* 35, 839-856.

Robinson, J., and J. Tansey, 2006. Co-production, emergent properties, and strong interactive social research: The Georgia Basin Futures Project. *Science and Public Policy* 33, 151-160.
Robinson, J., Bradley M., Busby, P., Conor, D., Murray, A., Sampson, B., Soper, W., 2006. Climate change and sustainable development: realizing the opportunity. *Ambio* 35, 2-9.
Rotmans, J. 1998. Methods for IA: The challenges and opportunities ahead. *Environmental Modeling and Assessment* 3, 155-179.
Rotmans, J., and M. van Asselt, 1996. Integrated assessment: A growing child on its way to maturity. *Climatic Change* 34, 327-336.
Rowe, G. and L.J. Frewer 2000. Public participation methods: a framework for evaluation, *Science, Technology & Human Values* 25, 3-29.
Ruth, M. and D. Coelho, 2007. Managing the Interrelations Among Urban Infrastructure, Population, and Institutions. Climate Policy 4, 317 – 336.
Schipper, L. and M. Pelling. 2006. Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters* 30, 19-38.
Schneider, S., J. Sarukhan, et al. (2001). Overview of impacts, adaptation, and vulnerability to climate change. Climate Change 2001: Impacts, Adaptation, and Vulnerability. J. McCarthy, O. Canziani, N. Leary, D. Dokken and K. White. Cambridge, Cambridge University Press.
Shepherd, P., Tansey J. and Dowlatabadi, H., 2006. Context matters: What shapes adaptation to water stress in the Okanagan. *Climatic Change* 78, 31 – 62.
Shimada, K. 2004. The legacy of the Kyoto Protocol: its role as the rulebook for an international climate framework. *International Review for Environmental Strategies* 5, 3-14.
Smith, B. and Wandel J., 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 3, 282-292.
Snover, A.K., L. Whitely Binder, J. Lopez, E. Willmott, J. Kay, D. Howell and J. Simmonds. 2007. Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. In association with and published by ICLEI – Local Governments for Sustainability, Oakland, 172 p.
Swart, R., Raskin P. and Robinson J., 2004. The problem of the future: sustainability science and scenario analyses. *Global Environmental Change* 14, 137 – 146.
Swart, R., Robinson, J., Cohen, S., 2003. Climate change and sustainable development: expanding the options. *Climate Policy* 3, S19-S40.
Tansey, J., Carmichael, J., Van Wynsberghe, R., Robinson, J., 2002. The Future is not what it used to be: participatory integrated assessment in the Georgia Basin. *Global Environmental Change* 12, 97-104.
Tol, R.S.J., (1998). Socio-Economic Scenarios. In: Feenstra, J.F., Burton, I., Smith, J.B., and Tol, R.S.J., (eds.) (October 1998, Version 2), *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies.* United National Environment Programme and the Institute for Environmental Studies, Vrije Universiteit Amsterdam
Toth, F.L. E. Hizsnyik, 2005. Managing the inconceivable: participatory assessments of impacts and responses to extreme climate change. *Climatic Change*, submitted.
Turnpenny, J., A. Haxeltine and T. O'Riordan, 2004. A scoping study of user needs for integrated assessment of climate change in the UK context: Part 1 of the development of an interactive integrated assessment process. *Integrated Assessment* 4, 283-300.
UK Climate Impacts Programme, 2001. Socio-economic scenarios for climate change impact assessment: a guide to their use in the UK Climate Impacts Programme. UKCIP, Oxford.
van Asselt, M.B.A. and N. Rijkens-Klomp, 2002. A look in the mirror: reflection on participation in integrated assessment from a methodological perspective. *Global Environmental Change* 12, 167-184.
van de Kerkhof M., Wieczorek, A., 2005. Learning and stakeholder participation in transition processes towards sustainability: Methodological considerations. *Technological Forecasting & Social Change* 72, 733–747.

van de Kerkhof, M., 2004. *Debating climate change: A study of stakeholder participation in an integrated assessment of long-term climate policy in The Netherlands*. Utrecht: Lemma Publishers.
van den Belt, M, 2004. *Mediated modeling: A system dynamics approach to environmental consensus building*. Washington, Island Press.
Welp, M., A. de la Vega-Leinert and S. Stoll-Kleeman, 2006. Science-based stakeholder dialogues: theories and tools. *Global Environmental Change*, 16, 170-181.
Wilson C. and McDaniels T. 2007. Linking Climate Change Adaptation, Mitigation and Sustainable Development with Structured Decision-making Tools: The Gateway Program Example. Climate Policy 4, 353 – 370.
Winkler, H., K. Baumert, O. Blanchard, S. Burch, and J. Robinson, 2006. What factors influence mitigative capacity? *Energy Policy* 35, 692-703.
Yohe, G., and R. Tol, 2002. Indicators for social and economic coping capacity: Moving toward a working definition of adaptive capacity. *Global Environmental Change* 12, 25-40.
Yohe, G.W., 2001. Mitigative capacity: the mirror image of adaptive capacity on the emissions side. *Climatic Change* 49, 247-262.

The Science of climate change

ATMOSPHERE OF THE EARTH:

What Is Atmosphere?

An atmosphere is a blanket of gases that surrounds Earth. It is held near the surface of the planet by Earth's gravitational attraction. Argon, oxygen and nitrogen from the three main constituents of the atmosphere.

Definition

"Atmosphere is a protective layer of gases that shelters all life on Earth, keeping temperatures within a relatively small range and blocking out harmful rays of sunlight."

Features of the Atmosphere:

- Helps retain the sun's heat and prevents it from escaping back into space.
- Protects life from harmful radiation from the sun.
- Plays a major role in Earth's water cycle.
- Helps keep the climate on Earth moderate.

There is no boundary between the atmosphere and outer space. The atmosphere gets less dense and denser until it "blends" into outer space.

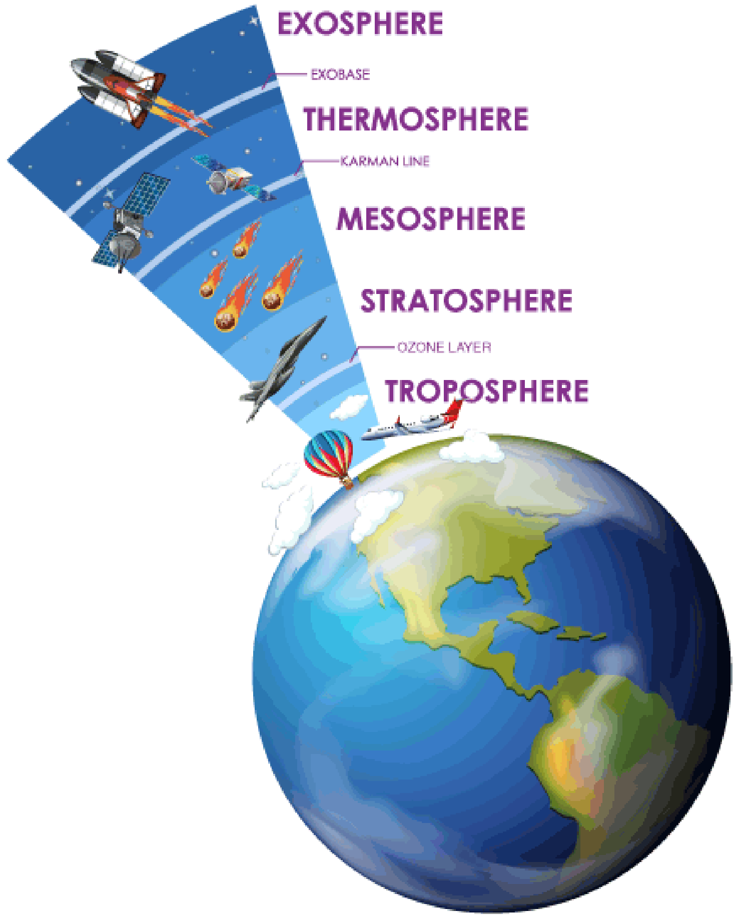
Layers of Atmosphere

What do you see when you stand outside and look up? A blue sky? A group of clouds? At night you might see a crescent moon, stars, a satellite. What you are not seeing, however, is the complexity of our atmosphere.

The atmosphere has five distinct layers that are determined by the changes in temperature that happen with increasing altitude. Layers of Earth's atmosphere are divided into five different layers as:

- Exosphere
- Thermosphere
- Mesosphere
- Stratosphere
- Troposphere

Let us find out more about the layers of atmosphere and their importance.



The hierarchical arrangement of various layers of the Earth's atmosphere

Troposphere

The troposphere is the lowest layer in the atmosphere. It extends upward to about 10 km above sea level starting from ground level. The lowest part of the troposphere is called the boundary layer and the topmost layer is called the tropopause. The troposphere contains 75% of all air in the atmosphere. Most clouds appear in this layer because 99% of the water vapour in the atmosphere is found here. Temperature and air pressure drop as you go higher in the troposphere. When a parcel of air moves upwards it expands. When air expands it cools. Due to this reason, the base of the troposphere is warmer than its base because the air in the surface of the Earth absorbs the sun's energy, gets heated up and moves upward as a result of which it cools down.

Stratosphere

Above the troposphere lies the stratosphere which extends from the top of the troposphere to about 50 km (31 miles) above the ground. The ozone layer lies within the stratosphere. Ozone molecules in this layer absorb high-energy ultraviolet (UV) light from the Sun and convert it into heat. Because of this, unlike the troposphere, the stratosphere gets warmer the higher you go!

Mesosphere

Above the stratosphere is the mesosphere and it extends to a height of about 85 km (53 miles) from the ground. Here, the temperature grows colder as you rise up through the mesosphere. The coldest parts of our atmosphere are located in this layer and can reach –90°C.

Thermosphere

Thermosphere lies above the mesosphere and this is a region where the temperature increases as you go higher up. The temperature increase is caused due to the absorption of energetic ultraviolet and X-ray radiation from the sun. However, the air in this layer is so thin that it would feel freezing cold to us! Satellites orbit Earth within the thermosphere. Temperatures in the upper thermosphere can range from about 500° C to 2,000° C or higher. The aurora, the Northern Lights and Southern Lights, occur in the thermosphere.

Exosphere

Exosphere is the final frontier of the Earth's gaseous envelope. The air in the exosphere is constantly but gradually leaking out of the Earth's atmosphere into outer space. There is no clear cut upper boundary where the exosphere finally fades away into space.

Ionosphere

The ionosphere isn't a distinct layer unlike other layers in the atmosphere. The ionosphere is a series of regions in parts of the mesosphere and thermosphere where high-energy radiation from the Sun has knocked electrons loose from their parent atoms and molecules.

Summary of Layers of Atmosphere			
Region	**Altitude Range (km)**	**Temperature Range(0°C)**	**Important Characteristics**
Troposphere	**0-11**	**15 to -56**	**Weather occurs here**
Stratosphere	**11-50**	**-56 to -2**	**The ozone layer is present here**
Mesosphere	**50-85**	**-2 to -92**	**Meteors burn in this layer**
Thermosphere	**85-800**	**-92 to 1200**	**Auroras occur here**

Watch this video to know everything about the air around us. Although, technically we call it the atmosphere – the circle of air. Learn how this atmosphere arranges itself in 4 layers above earth – troposphere, stratosphere, mesosphere, thermosphere, how the ozone layer protects us from the harmful UV rays of the sun, and why it feels cold when we go up high in the air.

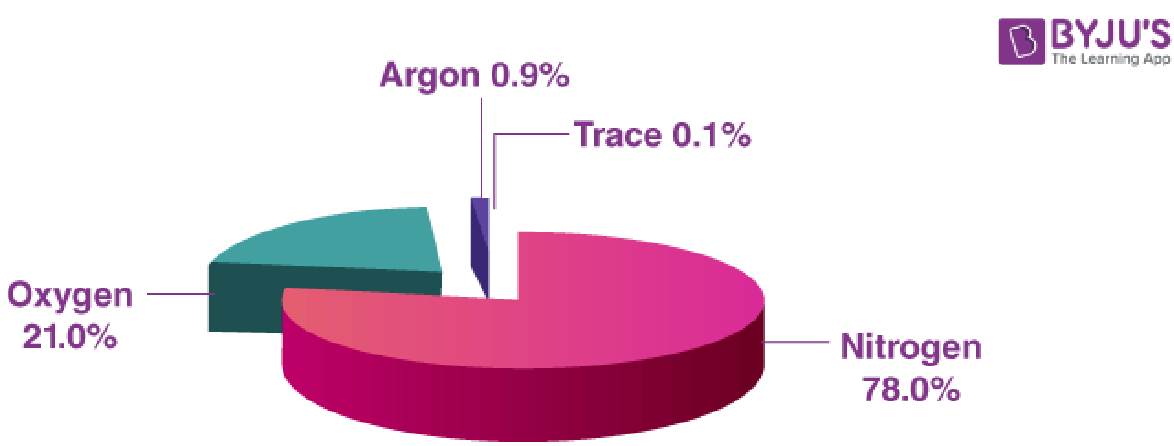
What Would Happen if the Earth's Atmosphere Disappeared?

Have you ever wondered what would happen if the Earth lost its atmosphere? Here is a breakdown of what could happen:

- Birds and planes would fall from the sky. Although we can't see air, it has a mass that supports flying objects.
- The sky would turn black. The sky gets its colour blue due to the atmosphere. Gases and particles in Earth's atmosphere scatter sunlight in all directions. Blue light is scattered more than other colours because it travels as shorter, smaller waves. This is why we see a blue sky most of the time.
- There would be no sensation of sound. Although you could feel vibrations from the ground you wouldn't hear anything. Sound requires a medium to travel.
- All the water bodies such as rivers, lakes and oceans would boil away. Boiling occurs when the vapour pressure of a liquid exceeds external pressure. In a vacuum, the water readily boils.
- Organisms that breathe air to survive would die.

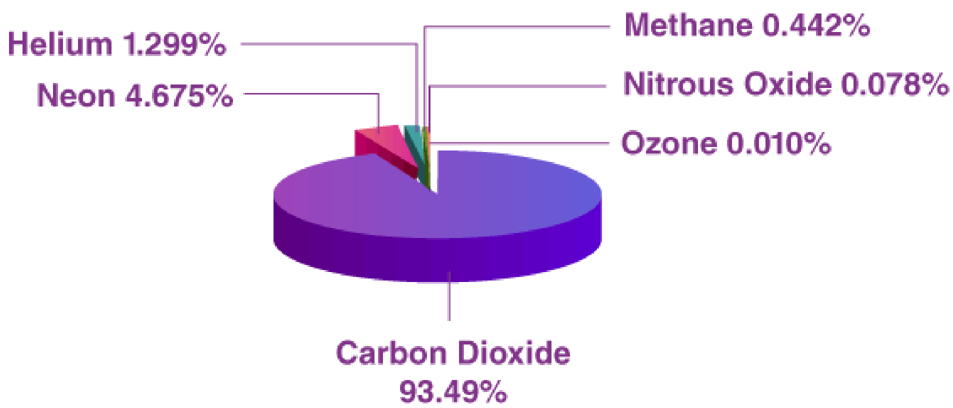
Composition of Atmosphere – Gases in the Atmosphere

The atmospheric composition of gas on Earth is largely conducted by the by-products of the life that it nurtures.



Dry air from earth's atmosphere contains 0.038% of carbon dioxide, 20.95% of oxygen, 78.08% of nitrogen and 0.93% of argon.

Traces of hydrogen, neon, helium, nitrous oxide, ozone and other “noble” gases, but generally a variable amount of water vapour is also present, on average about 1% at sea level.



GLOBAL TEMPERATURE-PAST AND PRESENT TREND:

Climate Change: Global Temperature

BY REBECCA LINDSEY AND LUANN DAHLMAN REVIEWED BY JESSICA BLUNDEN

PUBLISHED JANUARY 18, 2024

HIGHLIGHTS

- Earth’s temperature has risen by an average of 0.11° Fahrenheit (0.06° Celsius) per decade since 1850, or about 2° F in total.
    - The rate of warming since 1982 is more than three times as fast: 0.36° F (0.20° C) per decade.
- 2023 was the warmest year since global records began in 1850 by a wide margin.
    - It was 2.12 °F (1.18 °C) above the 20th-century average of 57.0°F (13.9°C).
    - It was 2.43 °F (1.35 °C) above the pre-industrial average (1850-1900).
- The 10 warmest years in the historical record have all occurred in the past decade (2014-2023).
- 2023 global summary

Related Content

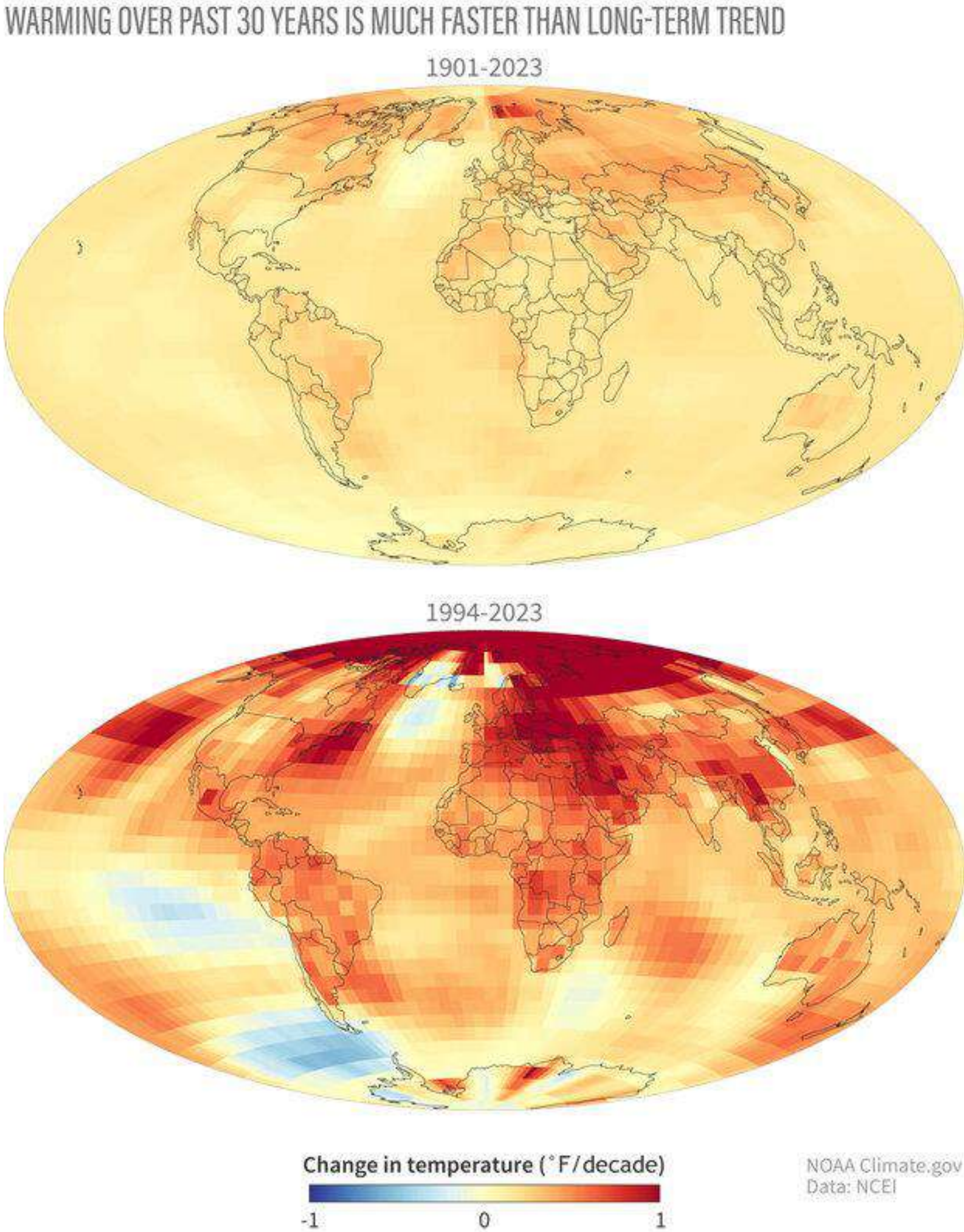
18801900192019401960198020002020−1.2−0.8−0.400.40.81.2

GLOBAL AVERAGE SURFACE TEMPERATUREYearDifference from 1901-2000 average (°C)

Yearly surface temperature from 1880–2023 compared to the 20th-century average (1901-2000). Blue bars indicate cooler-than-average years; red bars show warmer-than-average years. NOAA Climate.gov graph, based on data from the National Centers for Environmental Information.

Given the tremendous size and heat capacity of the global oceans, it takes a massive amount of added heat energy to raise Earth’s average yearly surface temperature even a small amount. The roughly 2-degree Fahrenheit (1 degrees Celsius) increase in global average surface temperature that has occurred since the pre-industrial era (1850-1900 in NOAA's record) might seem small, but it means a significant increase in accumulated heat.

That extra heat is driving regional and seasonal [temperature extremes](), reducing [snow cover]() and [sea ice](), intensifying [heavy rainfall,]() and changing habitat ranges for [plants]() and [animals]()—expanding some and shrinking others. As the map below shows, most land areas have warmed faster than most ocean areas, and the Arctic is warming faster than most other regions. In addition, it's clear that the rate of warming over the past few decades is much faster than the average rate since the start of the 20th century.



Trends in annual surface temperature in the past few decades (1994-2023, bottom) compared to the trend since the start of the 20th century (1901-2023, top). Recent warming is much faster than the longer-term average, with some locations warming by 1 degree Fahrenheit or more per decade. Differences are most dramatic in the Arctic, where the loss of reflective ice and snow amplifies the rate of warming. NOAA Climate.gov, based on data provided by NOAA National Centers for Environmental Information.

About surface temperature

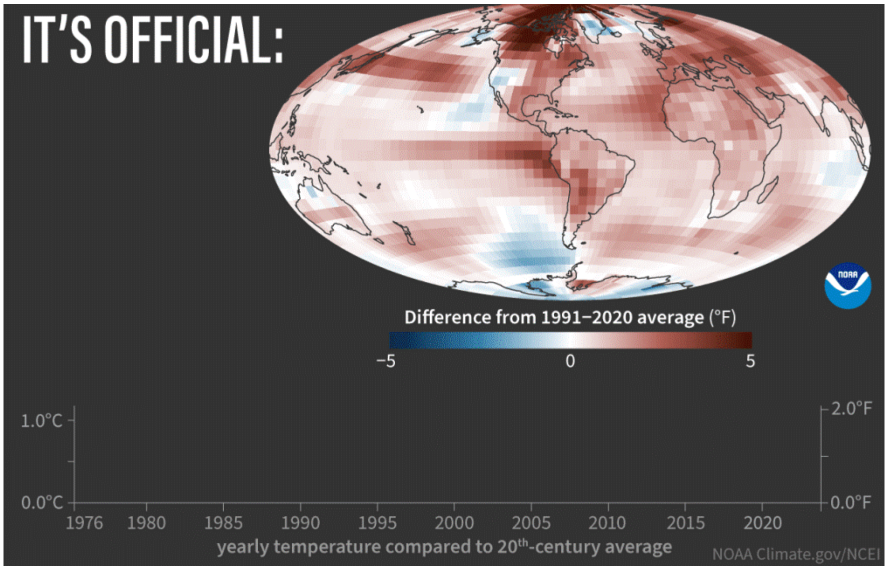
The concept of an average temperature for the entire globe may seem odd. After all, at this very moment, the highest and lowest temperatures on Earth are likely more than 100°F (55°C) apart. Temperatures vary from night to day and between seasonal extremes in the Northern and Southern Hemispheres. This means that some parts of Earth are quite cold while other parts are downright hot. To speak of the "average" temperature, then, may seem like nonsense. However, the concept of a global average temperature is convenient for detecting and tracking changes in Earth's energy budget—how much sunlight Earth absorbs minus how much it radiates to space as heat—over time.

To calculate a global average temperature, scientists begin with temperature measurements taken at locations around the globe. Because their goal is to track *changes* in temperature, measurements are converted from absolute temperature readings to temperature anomalies—the difference between the observed temperature and the long-term average temperature for each location and date. Multiple independent research groups across the world perform their own analysis of the surface temperature data, and they all show a similar upward trend.

Across inaccessible areas that have few measurements, scientists use surrounding temperatures and other information to estimate the missing values. Each value is then used to calculate a global temperature average. This process provides a consistent, reliable method for monitoring changes in Earth's surface temperature over time. Read more about how the global surface temperature record is built in our Climate Data Primer.

Global temperature in 2023

According to the 2023 Global Climate Report from NOAA National Centers for Environmental Information, every month of 2023 ranked among the 7 warmest for that month, and the months in the second half of the year (June-December) were each their hottest on record. In July, August, and September, global temperatures were more than 1.0°C (1.8°F) above the long-term average—the first time in NOAA's record any month has breached that threshold.



Map of global average surface temperature in 2023 compared to the 1991-2020 average. Warmer-than-average areas are shades of red, and cooler-than-average areas are shades of blue. The darker the color, the bigger the difference from average. The animated bar graph shows global temperatures each year from 1976 (left) to 2023 (right) compared to the 1901-2000 average. 1976 (blue bar at far left) was the last time a year was cooler than the 20th-century average. 2023 (far right) set a new record for warmest year. NOAA Climate.gov image, based on data provided by NOAA National Centers for Environmental Information.

Other 2023 rankings included...

- warmest year on record for land and ocean areas individually;

- warmest year on record for both the Northern and Southern Hemispheres (land and ocean areas combined),
    - warmest year for land and ocean individually in the North,
    - 2nd-warmest year for land and warmest year for ocean in the South;
- 40th-warmest year for the Antarctic,
- 4th-warmest year for the Arctic.

For more regional details and 2023 climate statistics, see the 2023 Global Climate Report from NOAA's National Centers for Environmental Information.

Past and future change in global temperature

Though warming has not been uniform across the planet, the upward trend in the globally averaged temperature shows that more areas are warming than cooling. According to NOAA's 2023 Annual Climate Report the combined land and ocean temperature has increased at an average rate of 0.11° Fahrenheit (0.06° Celsius) per decade since 1850, or about 2° F in total. The rate of warming since 1982 is more than three times as fast: 0.36° F (0.20° C) per decade.

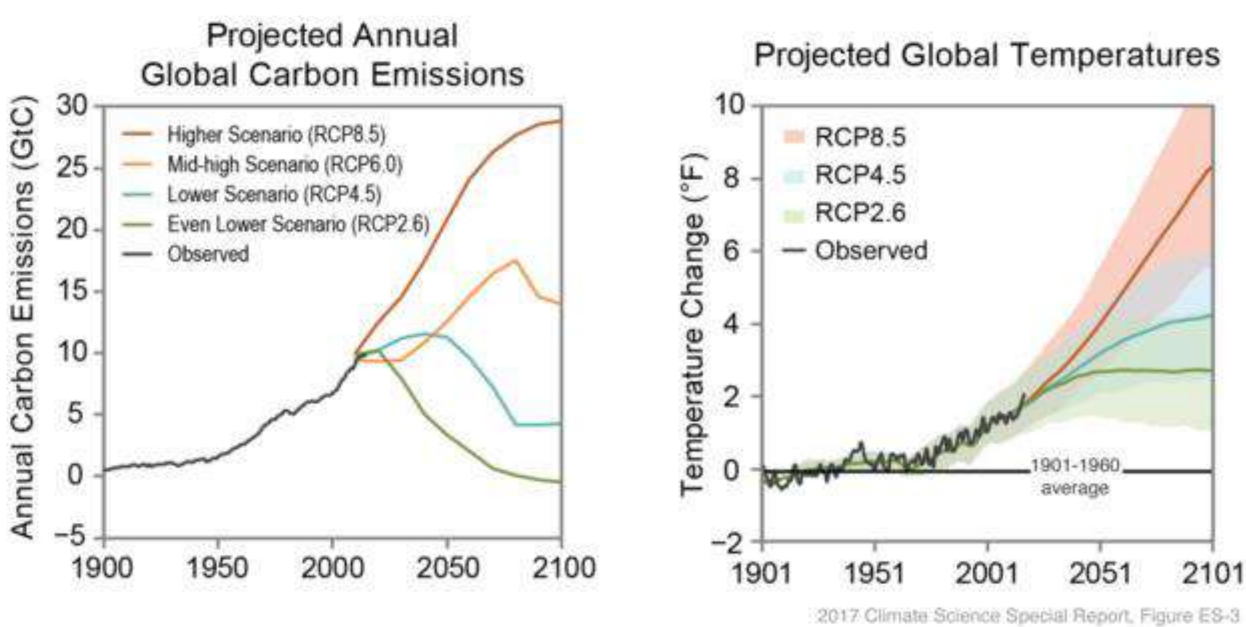
According to the latest Synthesis Report (pdf) from the Intergovernmental Panel on Climate Change, there is no debate about the cause of this warming trend:

Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020.

In the IPCC's Sixth Assessment Report on the Physical Basis of Climate Change, experts summarized the relative influence of all things known to affect Earth's average surface temperature:

The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C [2.01 ˚F]. Over this period, it is *likely* that well-mixed greenhouse gases (GHGs) contributed a warming of 1.0°C to 2.0°C, and other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural (solar and volcanic) drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C.

The amount of future warming Earth will experience depends on how much carbon dioxide and other greenhouse gases we emit in coming decades. Today, our activities—burning fossil fuels and to a lesser extent clearing forests—add about 11 billion metric tons of carbon (equivalent to a little over 40 billion metric tons of carbon dioxide) to the atmosphere each year. Because that is more carbon than natural processes can remove, atmospheric carbon dioxide amounts increase each year.



(**left**) Hypothetical pathways of carbon emissions ("representative concentration pathways," or RCPs) throughout the twenty-first century based on different possible energy policies and economic growth patterns. (**right**) Projected temperature increase relative to the 1901-1960 average depending on which RCP we eventually follow. Image by Katharine Hayhoe, from the *2017 Climate Science Special Report* by the U.S. Global Change Research Program.

According to the 2017 U.S. Climate Science Special Report, if yearly emissions continue to increase rapidly, as they have since 2000, models project that by the end of this century, global temperature will be at least 5 degrees Fahrenheit warmer than the 1901-1960 average, and possibly as much as 10.2 degrees warmer. If annual emissions increase more slowly and begin to decline significantly by 2050, models project temperatures would still be at least 2.4 degrees warmer than the first half of the 20th century, and possibly up to 5.9 degrees warmer.

GREEN HOUSE EFFECTS ,GREEN HOUSE GASSES AND AEROSOLS:

Greenhouse gases (GHGs) control energy flows in the atmosphere by absorbing infra–red radiation. These trace gases comprise less than 1% of the atmosphere. Their levels are determined by a balance between "sources" and "sinks". Sources are processes that generate greenhouse gases; sinks are processes that destroy or remove them. Humans affect greenhouse gas levels by introducing new sources or by interfering with natural sinks.

- **The largest contributor to the natural greenhouse effect is water vapour.** Its presence in the atmosphere is not directly affected by human activity. Nevertheless, water vapour matters for climate change because of an important "positive feedback". Warmer air can hold more moisture, and models predict that a small global warming would lead to a rise in global water vapour levels, further adding to the enhanced greenhouse effect. On the other hand, it is possible that some regions may become drier. Because modelling climate processes involving clouds and rainfall is particularly difficult, the exact size of this crucial feedback remains unknown.
- **Carbon dioxide is currently responsible for over 60% of the "enhanced" greenhouse effect, which is responsible for climate change.** This gas occurs naturally in the atmosphere, but burning coal, oil, and natural gas is releasing the carbon stored in these "fossil fuels" at an unprecedented rate. Likewise, deforestation releases carbon stored in trees. Current annual emissions amount to over 7 billion tonnes of carbon, or almost 1% of the total mass of carbon dioxide in the atmosphere.
- **Carbon dioxide produced by human activity enters the natural carbon cycle.** Many billions of tonnes of carbon are exchanged naturally each year between the atmosphere, the oceans, and land vegetation. The exchanges in this massive and complex natural system are precisely balanced; carbon dioxide levels appear to have varied by less than 10% during the 10,000 years before industrialization. In the 200 years since 1800, however, levels have risen by almost 30%. Even with half of humanity's carbon dioxide emissions being absorbed by the oceans and land vegetation, atmospheric levels continue to rise by over 10% every 20 years.
- **A second important human influence on climate is aerosols.** These clouds of microscopic particles are *not* a greenhouse gas. In addition to various natural sources, they are produced from sulphur dioxide emitted mainly by power stations, and by the smoke from deforestation and the burning of crop wastes. Aerosols settle out of the air after only a few days, but they are emitted in such massive quantities that they have a substantial impact on climate.
- **Aerosols cool the climate locally by scattering sunlight back into space.** Aerosol particles block sunlight directly and also provide "seeds" for clouds to form, and often these clouds also have a cooling effect. Over heavily industrialized regions, aerosol cooling may counteract nearly all of the warming effect of greenhouse gas increases to date.

- **Methane is a powerful greenhouse gas whose levels have already doubled.** The main "new" sources of methane are agricultural, notably flooded rice paddies and expanding herds of cattle. Emissions from waste dumps and leaks from coal mining and natural gas production also contribute. The main sink for methane is chemical reactions in the atmosphere, which are very difficult to model and predict.
- **Methane from past emissions currently contributes 15–20% of the enhanced greenhouse effect.** The rapid rise in methane started more recently than the rise in carbon dioxide, but methane's contribution has been catching up fast. However, methane has an effective atmospheric lifetime of only 12 years, whereas carbon dioxide survives much longer. This means that the relative importance of methane versus carbon dioxide emissions depends on the "time horizon". For example, methane emitted during the 1980s is expected to have about 80% of the impact of that decade's carbon dioxide emissions over the 20–year period 1990–2010, but only 30% over the 100–year period 1990–2090 (see figure).
- **Nitrous oxide, chlorofluorocarbons (CFCs), and ozone contribute the remaining 20% of the enhanced greenhouse effect.** Nitrous oxide levels have risen by 15%, mainly due to more intensive agriculture. CFCs increased rapidly until the early 1990s, but levels of key CFCs have since stabilised due to tough emission controls introduced under the Montreal Protocol to protect the stratospheric ozone layer. Ozone is another naturally-occurring greenhouse gas whose levels are rising in some regions in the lower atmosphere due to air pollution, even as they decline in the stratosphere.
- **Humanity's greenhouse gas emissions have already disturbed the global energy budget by about 2.5 Watts per square metre.** This equals about one percent of the net incoming solar energy that drives the climate system. One percent may not sound like much, but added up over the earth's entire surface, it amounts to the energy content of 1.8 million tonnes of oil every minute, or over 100 times the world's current rate of commercial energy consumption. Since greenhouse gases are only a by-product of energy consumption, it is ironic that the amount of energy humanity actually uses is tiny compared to the impact of greenhouse gases on natural energy flows in the climate system.

EFFECT ON GLOBAL WARMING:

Greenhouse gases primarily contribute to warming the environment by trapping heat from the sun in the atmosphere, while aerosols can either cool or warm the planet depending on their composition, with most types of aerosols generally having a cooling effect by reflecting sunlight back into space; essentially, greenhouse gases cause warming while many aerosols counteract this warming to a degree by reflecting sunlight.

Explanation:

- **Greenhouse gases:**

  These gases, like carbon dioxide and methane, absorb infrared radiation emitted from the Earth's surface, preventing it from escaping into space and thus warming the planet.

- **Aerosols:**

  These are tiny particles suspended in the air, which can either absorb or reflect sunlight depending on their characteristics.

- **Cooling effect of aerosols:**

  Many types of aerosols, like sulfate particles from burning coal, reflect sunlight back into space, creating a cooling effect.

- **Warming effect of aerosols:**

  Some aerosols, like black carbon (soot), can absorb sunlight, contributing to warming.

  Key points to remember:

- **Overall impact:** While greenhouse gases generally have a warming effect, aerosols can partially offset this warming by reflecting sunlight.
- **Type matters:** The impact of aerosols on climate depends on their composition and size.
- **Cloud interactions:** Aerosols can also influence cloud formation, further impacting the Earth's energy balance.
- 3. Greenhouse gases and aerosols - UNFCCC
  18 Jul 2000 — Warmer air can hold more moisture, and models predict that a small global warming would lead to a rise in global water ...
  UNFCCC
- Basics of Climate Change | US EPA
  7 Nov 2024 — Unlike greenhouse gases, the climate effects of aerosols vary depending on what they are made of and where they are emit...
  U.S. Environmental Protection Agency (.gov)
- Aerosols: Small Particles with Big Climate Effects
  12 Jun 2023 — Aerosol air pollution has made the planet about 0.7° F (0.4 °C) cooler than it otherwise would be, according to the 202...

Aerosols can also be produced naturally from a number of natural processes e.g. forest fires, volcanoes and isoprene emitted from plants. We know that greenhouse gases provide a warming effect to Earth's surface, but aerosol pollution in the atmosphere can counteract this warming effect

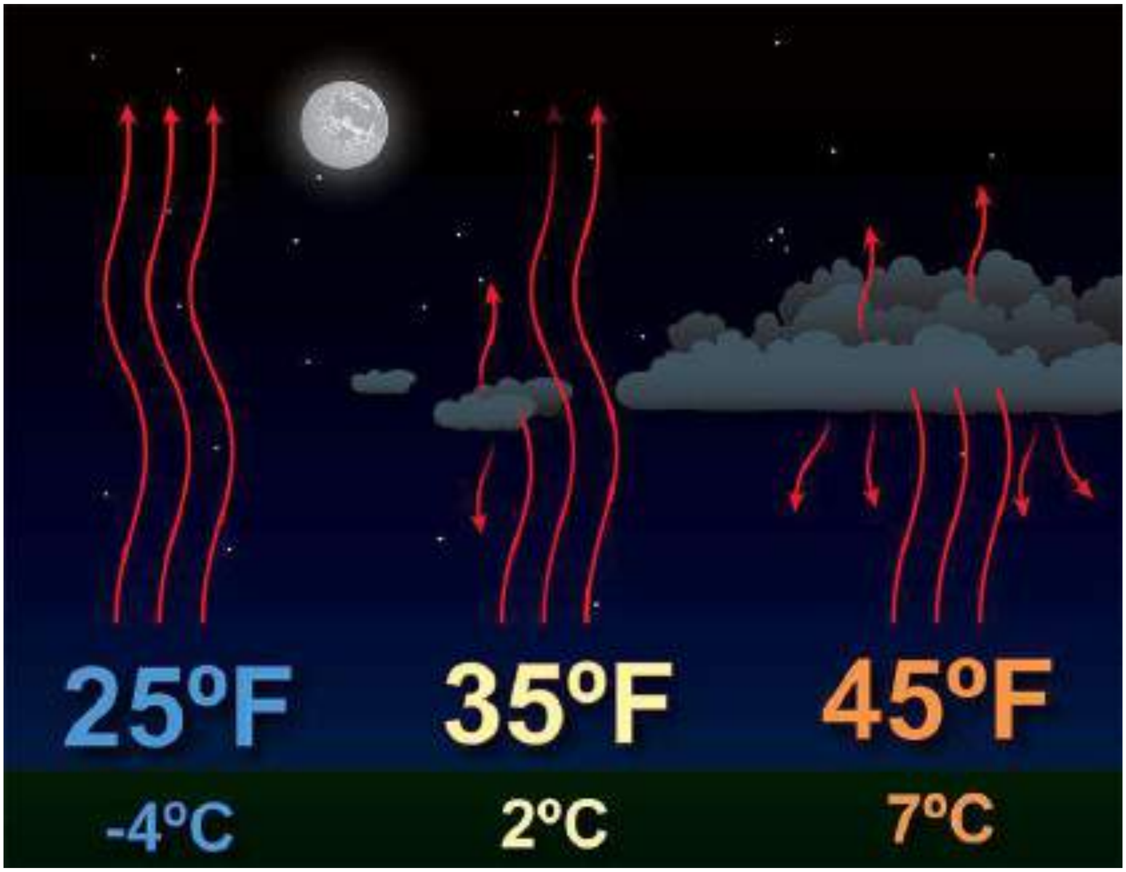
GLOBAL ENERGY BALANCE:

The Earth-Atmosphere Energy Balance

The earth-atmosphere energy balance is the balance between incoming energy from the Sun and outgoing energy from the Earth. Energy released from the Sun is emitted as shortwave light and ultraviolet energy. When it reaches the Earth, some is reflected back to space by clouds, some is absorbed by the atmosphere, and some is absorbed at the Earth's surface.

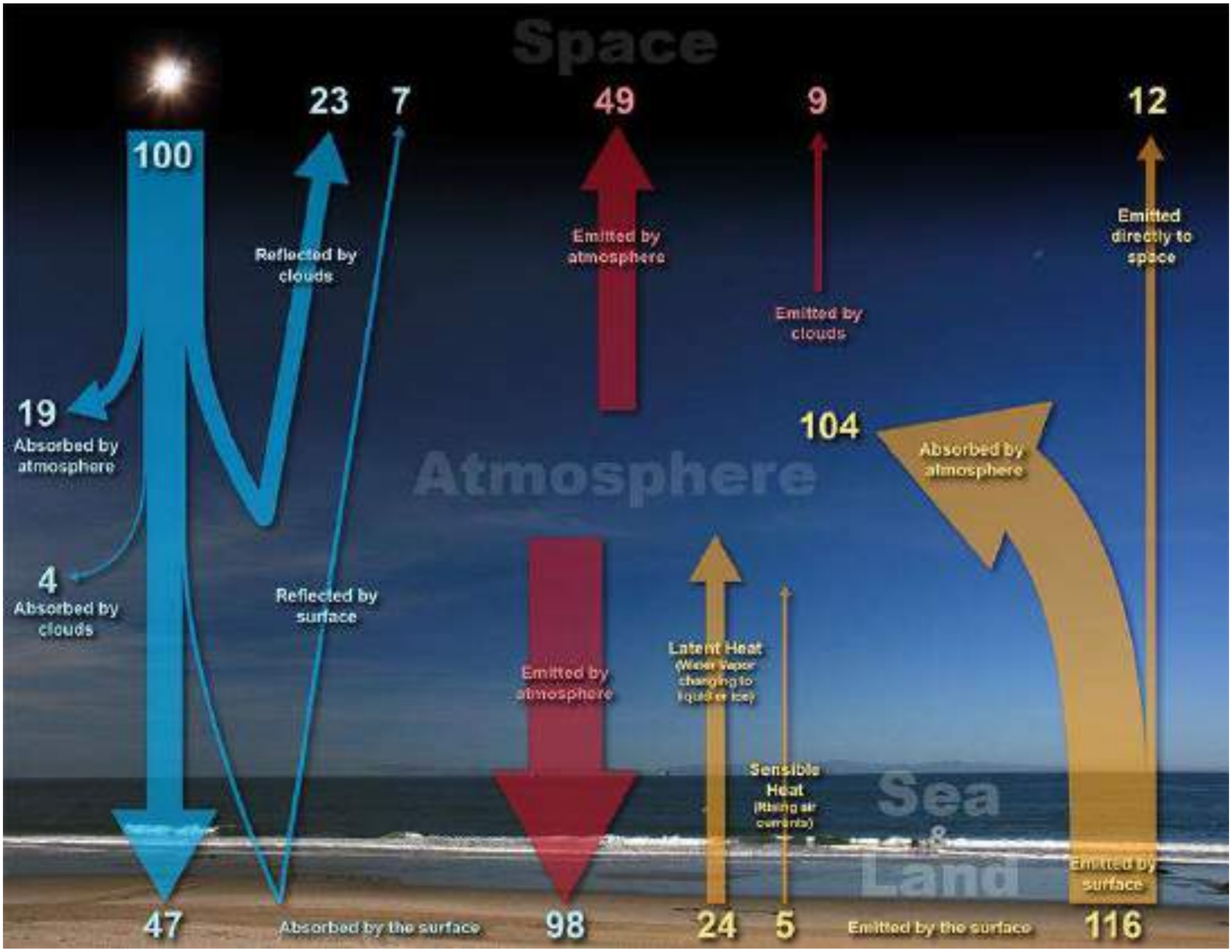
Learning Lesson: Canned Heat

However, since the Earth is much cooler than the Sun, its radiating energy is much weaker (long



wavelength) infrared energy. We can indirectly see this energy radiate into the atmosphere as heat, rising from a hot road, creating shimmers on hot sunny days.

The earth-atmosphere energy balance is achieved as the energy received from the Sun *balances* the energy lost by the Earth back into space. In this way, the Earth maintains a stable average temperature and therefore a stable climate. Using 100 units of energy from the sun as a baseline the energy balance is as follows:



<table>
<tr><td colspan="2">At the top of the atmosphere - Incoming energy from the sun is balanced with outgoing energy from the Earth.</td></tr>
<tr><td>INCOMING ENERGY</td><td>OUTGOING ENERGY</td></tr>
</table>

UNITS	SOURCE	UNITS	SOURCE
+100	Shortwave radiation from the sun.	-23	Shortwave radiation reflected back to space by clouds.
		-7	Shortwave radiation reflected to space by the earth's surface.
		-49	Longwave radiation from the atmosphere into space.
		-9	Longwave radiation from clouds into space.
		-12	Longwave radiation from the earth's surface into space.
+100	Total Incoming	-100	Total Outgoing

The atmosphere itself - Energy into the atmosphere is balanced with outgoing energy from atmosphere.			
INCOMING ENERGY		**OUTGOING ENERGY**	
UNITS	**SOURCE**	**UNITS**	**SOURCE**
+19	Absorbed shortwave radiation by gases in the atmosphere.	-9	Longwave radiation emitted to space by clouds.

The atmosphere itself - Energy into the atmosphere is balanced with outgoing energy from atmosphere.			
INCOMING ENERGY		**OUTGOING ENERGY**	
UNITS	**SOURCE**	**UNITS**	**SOURCE**
+4	Absorbed shortwave radiation by clouds.	-49	Longwave radiation emitted to space by gases in atmosphere.
+104	Absorbed longwave radiation from earth's surface.	-98	Longwave radiation emitted to earth's surface by gases in atmosphere.
+5	From convective currents (rising air warms the atmosphere).		
+24	Condensation /Deposition of water vapor (heat is released into the atmosphere by process).		
+156	Total Incoming	-156	Total Outgoing

At the Earth's surface - Energy absorbed is balanced with the energy released.			
INCOMING ENERGY		**OUTGOING ENERGY**	
UNITS	**SOURCE**	**UNITS**	**SOURCE**

At the Earth's surface - Energy absorbed is balanced with the energy released.			
INCOMING ENERGY		**OUTGOING ENERGY**	
UNITS	**SOURCE**	**UNITS**	**SOURCE**
+47	Absorbed shortwave radiation from the sun.	-116	Longwave radiation emitted by the surface.
+98	Absorbed longwave radiation from gases in atmosphere.	-5	Removal of heat by convection (rising warm air).
		-24	Heat required by the processes of evaporation and sublimation and therefore removed from the surface.
+145	Total Incoming	-145	Total Outgoing

The absorption of infrared radiation trying to escape from the Earth back to space is particularly important to the global energy balance. Energy absorption by the atmosphere stores more energy near its surface than it would if there was no atmosphere.

The average surface temperature of the moon, which has no atmosphere, is 0°F (-18°C). By contrast, the average surface temperature of the Earth is 59°F (15°C). This heating effect is called the greenhouse effect.

CLIMATE CHANGE AND ITS EFFECTS

INTRODUCTION

*Corresponding Author: Amrik Singh Ahluwalia, Eternal University, Baru Sahib, Sirmour - 173 101, Himachal Pradesh, India. Email: amrik.s511 @ gmail.com Ajar Nath Yadav, Department of Biotechnology, Dr. Khem Sigh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmour, Himachal Pradesh, India. Email: ajarbiotech @ gmail.com

The super challenges of the 21st century are climate change, energy supply, health and disease invasion, and sustainable environment. The world's climate continues to change at a rate expected to be unprecedented in recent human history.

The increase of about 0.6°C in global average surface temperature has been observed during the twentieth-century. In recent years, human activity and natural factors have led to rapid increase in greenhouse gas (GHG) emissions. The influence of emitted GHG on future climate is estimated due to its capability of absorbing available infrared radiation and its persistence in the atmosphere [1]. The effects of global warming are broader which may include arctic shrinkage, glacial retreat, and worldwide sea level rise. The changing precipitation patterns will result in more floods and drought. The changes will also occur in agricultural yields, there may be addition of new trade routes, vast extinction of species and increase in disease vectors range [2]. In fact, the climate change is not only an environmental issue nor is it the only threat to global prosperity rather is a threat multiplier for diverse other urgent concerns including global security, disease and habitat loss. Climate change is unique in its scale and enormous risks it poses. Climate change, if remained unchecked, possibly will redraw the map of the planet. It can create global living conditions beyond the range, humanity has ever experienced in history. The influence of climatic change is much broader, such as increased frequency of hypoxic events, storm activity, altered rainfall patterns, and flow regimes of freshwater streams and rivers [3]. There is a discernible global pattern of the effects of climate change on crop productivity, which may have implications for food availability. Climate change may jeopardize the stability of entire food systems. The demand for agricultural products has been estimated to increase with increase in global population, which may require a shift toward sustainable intensification of food systems [4]. Rising concentration of atmospheric carbon dioxide is one of the most critical problems as its effects are globally persistent and irreversible on ecological timescales [5]. The primary direct consequences are increasing ocean temperatures [6]. Rising temperatures create additional changes such as increase in ocean stratification, increasing sea levels, reduced sea ice extent, altered ocean circulation patterns, precipitation and freshwater inflows. Acidification is another direct impact of rising CO2 concentrations on oceans [7]. Climate change also affects global biodiversity in several ways. Movement is an integral part of ecology of many animals, which can affect the fitness of individuals and population survival by enabling foraging and predation, behavioral interactions, and migration [8]. Migration may also be observed in fishes in search of suitable conditions due to increase in temperature. Arrival and hatching date in migrating birds can be strongly affected by global warming [9]. Numerous changes occur in animals due to rising temperature such as increased respiration, decrease in the efficiency of nutrient utilization, decrease in milk production reproductive performance especially in dairy cows [10]. Climate is a major factor determining plant physiology, distribution, and interactions [11]. There might be changes in phenological phases of plants which will lead to prolonged growing season and affect the plant fitness. Evidences are in favor of global climate change and its consequences on different aspects of environment. There is a greater need to develop conservation strategies to respond to such global challenges. This review deals with the influence of climate change on biodiversity and impact on environment.

2. IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

Climate change is increasingly recognized as the serious and widespread threat to biodiversity. The alterations in the environment which will be brought up by the climatic changes will be too rapid for many species to adapt to, and ultimately lead to extensive extinctions. Climate change may lead to migrations which in turn will affect biological diversity at regional and global scales. Stress on populations of whales, ringed seals, and polar bear will continue as a result of changes in critical sea-ice habitat interactions. Crops will fail more often, especially on land at lower latitudes where food supply is scarce [12]. The changes in occurrence of drought, strong winds, and winter storms will bring massive loss to commercial forestry [13]. The species must adapt, move, or face extinction with climate change.

2.1. Animal Biodiversity Animals had been already subjected to major shifts in the Earth's climate in the past. Some species perished, while others adapted and thrived. Climate change is already having a negative impact on animal life, and the consequences are likely to be disastrous in the future. Climate change is considered a major threat to the survival of many species in changing ecosystems [14-16]. Many studies have taken into account the economic impact of day by day changing climate on livestock production [17]. In general, a combination of rising temperatures and changing rainfall patterns will certainly affect animal husbandry. Feed is an important constraint for livestock production in the tropics, and will continue to be, and crop productivity is a useful proxy for feed availability in most regions. Crop productivity at mid-to high latitudes may increase slightly for local mean temperature increases while at the lower latitudes, it may decrease for even relatively small local temperature increases. In general climate change may affect the animal agriculture in different ways by influencing livestock [18], nammely, the availability and price of feed grain, quality, and production of forage, reproduction, growth and health, as well as distribution of diseases and pests. These changes can lead to redistribution of livestock in an area. There may be shifts in animal types used for instance change from cattle to buffalo, camels, goats, or sheep; there may be genotype shifts which mean the use of breeds which can well handle adverse conditions. Furthermore, there may be changes in housing of animals [17]. Temperature is likely to become hotter in several places and different species due to their physiological differences will show variations in their susceptibility to changing temperatures [19]. Holstein-Friesian dairy cows are primarily susceptible to heat stress as the ambient temperature exceeds 25°C [20]. The first sign of heat stress is an increase in body temperature and rate of respiration ultimately reducing feed intake and milk output [21,22]. Sheep when exposed to high temperatures, weight loss, decrease of average daily gain, growth rate, and total body solids reflected by impaired reproduction have been observed. When the ambient air temperature is high, appetite decreases and growth of pigs is affected [23]. Further, in such changes, some species of animals may expand their ranges whereas others may move towards the poles or upward in elevation. An example of such a shift is population of red fox in

Canada which have been advancing north and, on the other hand, population of Arctic fox has been retreating [24]. High temperatures and precipitation have been known to decline the population of British ring ouzel which is a shy species of thrush with a high chirping call. The decline in Arctic sea ice have a significant impact on Arctic vertebrate populations including polar bears, seals, and walruses which are adapted to live in sea ice for significant periods of the year [25]. If the sea ice breaks and drifts as a result of polar warming, polar bears will have to move north to find a stable platform. Pregnant females will leave the ice to find their preferred land den area have to swim long distances. In case, the pregnancy of malnourished mothers is successful under sub-optimal habitats, the chances of survival of cubs will be greatly reduced [26]. Climate change has a profound impact on the oceans. The upper ocean is warming [27], potentially affecting invertebrate populations including krill, which are important food sources for whales, seabirds, seals, and penguins [28]. Changes in upper ocean temperatures may alter the range of many species, especially marine mammals. Studies show the expansion in the range of common dolphins common in northwest Scotland which are warmer water species whereas contractions in the range of white-beaked dolphins which are a colder water species [29]. Relatively small changes in temperature alter the metabolism and physiology of fishes, affecting their growth, reproduction, feeding behavior, distribution, migration, and abundance [30].

2.2. Bird Biodiversity Birds are one of the most studied organisms on the planet, and they serve as an important group of indicators for learning about the effects of climate change. The choice of birds for studying climatic changes offer certain advantages such as they are the most well-known kind of organism for climate studies and second, millions of citizen scientists Kour, .: Journal of Applied Biology & Biotechnology 2024;12(2):1-12 et al Kour, et al.: Effect of climate change on biodiversity and environment 2024;12(2):1-12 3 track birds all over the world, contributing to massive datasets [31]. Bird distribution changes have been well described and linked to climate change [32-34]. The vulnerability of species of tropical birds to climate change in particular has been increasingly recognized [35-37]. The weather not only affects the metabolic rate of the birds (e.g., in cold weather where energy expenditure must increase to maintain the body), but also their behavior directly or indirectly [38]. Climate change has been shown to impact breeding. Extreme weather events, such as prolonged freezing spells and droughts, can have catastrophic effects on bird populations, including long-term effects on entire cohorts [39]. The study of Pied Flycatchers Ficedula hypoleuca showed increase in their egg size with warmer springs in Germany and Finland [40]. In Siberia, reproductive success in the planktivorous auklets including crested Aethia cristatella and parakeet Cyclorhynchus psittacula increases at lower sea-surface temperatures. On the other hand, better reproductive success has been observed in the piscivorous puffins such as horned Fratercula corniculata and tufted Lunda cirrhata at higher, sea-surface temperatures. Long-term changes in sea-surface temperatures can affect the viability of each species' population in different ways and change the seabird population in that area [41]. Storms and snowpack have a significant impact on the reproductive schedules of birds breeding at high altitudes. Climate change is expected to have an impact on reproduction as well as the entire annual cycle of birds. The species that mainly adjust the annual cycle and multiply according to rainfall, temperature, and food supply will face fewer difficulties as compared to those that coordinate their annual cycle by a rigid Zeitgeber, like photoperiod [42]. Migration in birds is affected by changes in climatic conditions. It is expected that the greater the distance of migration of the species, the more likely one or more aspects of the annual cycle may become mistimed with local weather and food supplies on the summering grounds. An advancement of 14 days over 47 years in the timing of egg laying in Parus major population in the United Kingdom due to increased spring temperature has been reported [43].

2.3. Plant Biodiversity Climate change is also affecting the life cycles and distributions of the world's vegetation. The combination of the changes in air quality and composition and climate are producing new bioclimate for food production systems. There is extensive evidence that plant seasonal biological events have changed in recent decades along with the global climate change [44]. Some medicinal and aromatic plants have begun to flower earlier. In Britain, the first flowering date for approximately 385 plant species advanced by 4.5 days on average over the previous four decades [45]. Temperature range between 45°C and 65°C can cause severe damage and even death of crop plants. For instance, rice is most sensitive to temperature change at anthesis stage. Exposure for few hours at flowering can reduce floral reproduction [46]. In medicinal plants, the damaging effects of climate change may include decrease in availability and most dramatically in the extinction of species [47]. A study reported extinction of about 600 plant species in the past 250 years [48].Valuable medicinal plants are likewise one of those species that experience dramatic phenological change [49]. In addition to endangering population growth, phenological changes may have an impact on the predictable or consistent availability of medicines to those who rely on them [50,51]. The medicinal plants of arid zone may also be at special risk. The nival or subnival species in montane ecosystems are most vulnerable to habitat loss [52], and future climate change is expected to be most severe in northern latitude mountains [53]. Alpine meadows are once again among the most threatened plant communities [54], and they are shrinking due to warming-induced upslope shrub encroachment [55]. It is thought that species growing at the highest altitudes are most vulnerable to extinction because they will have nowhere to go if they are outcompeted by lower elevation species that are now expanding their ranges to higher elevations [56]. In a survey of plant distribution in Arizona mountains local extinction of 15 species of plants including Muhlenbergia porter, Quercus gambelii and Urochloa arizonica, in comparison with 50 years earlier has been observed [57]. In the alpine Himalayas of Sikkim 75 species of plants, including Rhododendron nivale, Potentilla fruticosa and Lepidium capitatum were observed to be locally extinct in comparison with 1850 [58]. Deserts and arid shrublands are expected to experience the fastest rates of climate change, making compensatory migration difficult [59]. For instance, a significant degradation has been observed in the desert steppe habitat of one of the most widely used wild medicinal plants Glycyrrhiza uralensis, attributed to increasing climate change and anthropogenic disturbance [60]. Sea grasses are declining globally at a rate of about 7% per year, and global climate change is expected to have a negative impact on them, posing a pressing challenge for coastal management [61]. Water temperature greatly influences the physiology, growth rates and reproduction in sea grasses and determines their geographic distribution based on their temperature tolerance [62]. The species of tropical sea grasses including Thalassia testudinum and Syringodium filiforme in the Gulf of Mexico showed reduction in their productivity when summer temperatures were higher [63]. In an investigation in Australia, the leaf growth rates of Thalassia hemprichii, Halodule uninervis, and Cymodocea rotundata were reduced at water temperature above 40°C [64]. Warming is occurring quickly in the Arctic [65]. The fluctuations in ranges of temperature and changes in ice covers and snow patterns are affecting the distribution of Arctic vegetation. It has been observed that the changes in climate possibly will affect the chemical constituents and thus the survival of the aromatic and medicinal plants in Arctic. Certain reports have revealed the impact of the temperature fluctuations on bioactive compounds of the plants [66,67].

2.4. Microbial Biodiversity Microbes inhabiting soil play significant roles in nutrient cycling and protecting plants from environmental stresses [68]. The organisms inhabiting the soil interact with each other and plants in many ways that shape and maintain the ecosystem. Climate change is altering the distribution and diversity of species and at the same time affecting the interactions between organisms [69,70]. Numerous studies have shown that changes in species interactions in response to climate change chain alter biodiversity and function of terrestrial ecosystems [24,71]. There are some reports on soil microbial communities (SMCs) and their diversity and distribution during climatic change [72,73]. Alterations in relative abundance and function of soil communities due to climatic changes has been observed as the members of SMCs vary in their physiology, temperature sensitivity, and growth rates [74,75]. A study observed changes in the relative abundances of soil bacteria and increased the bacterial to fungal ratio of the community due to warming by 5°C [76]. Further, the acceleration in fermentation, methanogenesis and respiration among the microbial communities has also been observed in response to increase in temperature. The microbial community composition (MCCs) of soil constantly changes as they respond to changing resource availability. Certain communities grow quickly and utilize the resources as they are available and some 4 communities adapt and grow slowly and utilize more chemically complex substrates. Guo et al. [77] carried out study on climate warming accelerates temporal scaling of grassland soil microbial biodiversity. The study suggested that the strategies of soil biodiversity preservation and ecosystem management may need to be adjusted in a warmer world. The study of Wu et al. [78] concluded detrimental effects of biodiversity loss might be more severe in a warmer world. Recently, a study has been conducted to measure the effect of climate change in Antarctic microbial communities. The study proposed that climate change studies in Antarctica should consider descriptive studies, shortterm temporary adaptation studies, and long-term adaptive evolution studies and concluded that this will help in understanding and managing the effects of climate change on the Earth [79]. A study investigated the effect of temperature on microbes in dry land soil, boreal, temperate, and tropical soil and response of microbial communities to different temperatures. The study concluded that the rates of respiration per unit biomass were lower in the soils collected from the environments having higher temperature and suggested that thermal adaptation of the microbial communities may lessen positive climate feedbacks [80]. Another study reported increased soil biomass and fungal abundance with higher atmospheric CO2 . The study showed a limited effect on bacterial diversity with higher atmospheric CO2 [81]. Drought conditions have been shown to influence fungi and bacteria, but fungi are known to be more sensitive than bacteria. It has been observed that during drought fungal growth increases [82]. Another study observed the effects of elevated levels of CO2 and precipitation on soil microorganisms. The study suggested that bacterial growth was negatively affected whereas fungal biomass was observed to show an increase with increasing precipitation [83]. On the other hand, it has been suggested that global warming increases the abundance of bacteria and fungi and leads to the alteration of the soil food web. The rise in temperature also makes changes in the physiology of decomposing microorganisms also [84]. Climate change is known to favor the growth of cyanobacteria [85]. Many bloom-forming cyanobacteria grow at high temperatures [86]. The growth of

Microcystis sp. has been observed to increase at elevated CO2 levels [87]. Generally as the environmental conditions change, the resident microbial communities either adapt, become dormant or die [88].

3. BIODIVERSITY RESPONSES TO CLIMATE CHANGE

Climate change is expected to change the diversity of species, the distribution of human pathogens, and ecosystem services around the world. Estimating these changes and designing suitable management strategies for future ecosystem services will need a predictive model that includes the most basic biological responses. One of the key questions in the debate over climate change's ecological impact is whether species can adapt quickly enough to keep up with the rapid pace of climate change [89,90]. Species can, in theory, change in response to climate change, and changes have already been observed. The species can track and follow suitable conditions in space, which is typically accomplished through dispersion. Spatial movement of species tracking appropriate climatic conditions on a regional scale is the best documented response from palaeontological records and recent observations. Over 1000 species of marine invertebrates, insects, and birds have already shown latitudinal and altitudinal range shifts [91], resulting in a decrease in range size, primarily in mountain top and polar species [92]. Furthermore, in order to keep up with abiotic factors that represent cyclic variation, such as on a daily or yearly basis, species may respond to changes by shifting time from daily to seasonal. A meta-analysis of a wide range of plant and animal species found that the average response to climate change was a shift in key phenological events occurring 5.1 days earlier per decade over the last 50 years [93]. The advancement in flowering by more than 10 days per decade has also been observed in some species [91]. Another approach is species may adapt themselves to the changing climate in their local range. Thus, there are multiple responses of the species to cope up with the changing climatic conditions and unable to adapt to new conditions, the species may go extinct either locally or globally [94]. As a result of numerous human-caused changes in the global environment, global biodiversity is changing at an unprecedented rate [95,96]. Quantitative scenarios are emerging as tools to assess the impact of future socio-economic development pathways on biodiversity and ecosystem services. Global marine, freshwater, and terrestrial biodiversity scenarios are analyzed through different measures including change in the abundance of the species, habitat loss, extinction, and distribution shifts [97]. The risk of species extinction address the irreversible component of biodiversity change [98,99]; however, species extinctions have weak links to ecosystem services and respond less rapidly to global change than other factors. Quantitative global extinction scenarios for freshwater and marine organisms are, however, uncommon. According to one of the proposed models based on the relationship between fish diversity and river discharge, 4–22% extinction of fish by 2070 in about 30% of the world rivers, due to reduced river discharge from climate change and increased water withdrawals [100]. Habitat loss and degradation in terrestrial ecosystems encompass a wide range of human-caused changes in natural and semi-natural ecosystems. The distribution shifts are expected to cause the reorganization of ecosystems, including the establishment of novel communities [96]. Scenarios constantly indicate the decline of the biodiversity over the 21st century. The most important factors identified so far to induce changes in biodiversity at global scale includes the changes in the concentration of carbon dioxide, land use, deposition of nitrogen, and on purpose or accidental introduction of alien animals, plants, and microbes in an ecosystem [101]. CLIMATE The changing temperature and precipitation patterns are expected to interact with other drivers to influence an array of biological processes and distribution of species. Alarming predictions about the potential consequences of future climate change are prompting policy responses ranging from the local to the global [102]. To date emission of greenhouse gases are driving earth to significant climate change in the coming decades [103]. The annihilation of evolutionary potential, possible loss of biodiversity and disturbance of ecological services must be taken seriously. Many countries have conservation plans for threatened species, but these plans have generally been developed without taking into account the potential impacts of climate change. Climate change is greatly influencing the biodiversity and represents a significant future challenge for biodiversity conservation strategies [94].The interaction between climate and land use provides opportunities for adaptation to climate change that increase the ability of species to adapt [104]. Preventing detrimental consequences for biodiversity requires immediate action and strategic conservation

4. GLOBAL BIODIVERSITY SCENARIO FOR THE YEAR 2100 5. CONSERVATION OF BIODIVERSITY IN CHANGING Kour, .: Journal of Applied Biology & Biotechnology 2024;12(2):1-12 et al Kour, et al.: Effect of climate change on biodiversity and environment 2024;12(2):1-12 5 plans for years and decades to come [105]. Integration of different approaches and perspectives is required for more accurate information on which species and habitats, which places and how conservation managers can make the most of natural systems' adaptive capacity. In many cases, existing conservation policies and practices are already encouraging measures to reduce vulnerability to climate change such as restoration or creation that improves the functional connectivity of landscapes and habitat management. The assessment of impact of climate change on biodiversity has been especially based on empirical niche models [106]. These models for most species indicate large geographic displacements and widespread extinction. Assessing the biodiversity consequences of climate change is really a multifaceted issue and all aspects of vulnerability such as adaptive capacity, exposure, and sensitivity must be considered for implementation of conservation strategies [Figure 1] [107]. 6. IMPACT OF CLIMATE CHANGE ON ENVIRONMENT In recent years, extensive efforts have been made to monitor and predict climate change in response to fears of global warming. Attention has been focused on the diverse environments including soil and water, and the imminent socio-economic and environmental consequences of rising global temperatures. The fluctuations in temperature will leave a negative impact on organic matter of soil, and diverse physical and chemical properties of soil. Water resources will be greatly affected under changing climate [Figures 2 and 3]

6.1. Soil Health and Fertility Healthy soil is the foundation of agriculture and a basic resource for meeting human needs in the twenty-first century. It is a critical component of ecosystems and earth system functions that helps to deliver primary ecosystem services [108]. The most recent report of the intergovernmental panel on climate change point outs the average rise in the global temperature between 1.1 and 6.4°C by 2090–2099. The changes in the climate will have impact on precipitation patters at global level and will alter both the amount of precipitation received and the distribution of precipitation over the course of an average year in many locations [109]. Each of these factors will affect soil which is of major importance for the food security [110-112]. Food security will be threatened through its effects on soil processes and different properties [113]. Soil moisture is another important component of the hydrological cycle that regulates precipitation partitioning between runoff, evapotranspiration, and deep infiltration [114]. Fluctuations in temperature will influence moisture content of the soil which in turn may impact infiltration and runoff amounts and rates [115]. Further, as a link between the biosphere and the edaphic zone, soil water is fundamental requirement for the terrestrial ecosystems which determines plant growth. Water stress occurs when the soil water level falls below a critical species-specific threshold, which will then lead to morphological and physiological disturbances in plants [116]. Soil erosion is another phenomenon experienced in different parts of the world under changing climate. It is one of the major threats to the economy and society affecting agriculture. The most common reason predicted for soil erosion is the change in the erosive power of rainfall and changes in plant biomass [117]. Although soil erosion is a natural and inevitable process, the accelerated rates of soil loss, is really a serious environmental issue. Theloss due to erosion is estimated to be 30–40 t/ha/year [125,126]. Microorganisms present in the soil play important role in nutrient cycling and thus the decrease in MCCs in soil due to climate change affect the soil health and fertility. Increasing challenges and concerns on global warming and changing climate have led to special attention to soil and its capability in carbon sequestration. In a study, the effect of climate change on soil organic carbon storage using the Rothamsted C model in the agricultural lands of Golestan province has been studied. The results suggested that with increasing temperature, the rate of decomposition of soil organic carbon will increase [127]. Soil organic carbon is an important carbon pool which can alleviate the increasing concentration of atmospheric carbon dioxide as part of the carbon cycling process. A study on the basis of Rothamsted C model concluded soil organic carbon will in general decline during the next decades. Further the rate of decrease of soil organic carbon will be higher over time if there is no addition of organic matter is adopted in China [128]. Another study focused on impact of global climate change on terrestrial soil CH4 emissions. The meta-analysis in the study suggested that future climate change will decline the natural buffering capability of terrestrial ecosystems on CH4 fluxes [129].

6.2. Water Resources Climate change is expected to pose negative impact on water resources and freshwater ecosystems in almost every part of the world. However, the intensity and characteristics of the impact can vary widely from region to region. There may be water shortages in some regions. A study concluded that climate change will lead to water scarcity to meet the rising demand for food. It is estimated to be 60% higher in Africa by 2030, which will spike food prices and worsen food scarcity [130]. The shorter rainy periods and seasonality shifts might affect water resources by reducing water availability with wide ranging consequences for local societies and ecosystems [131].

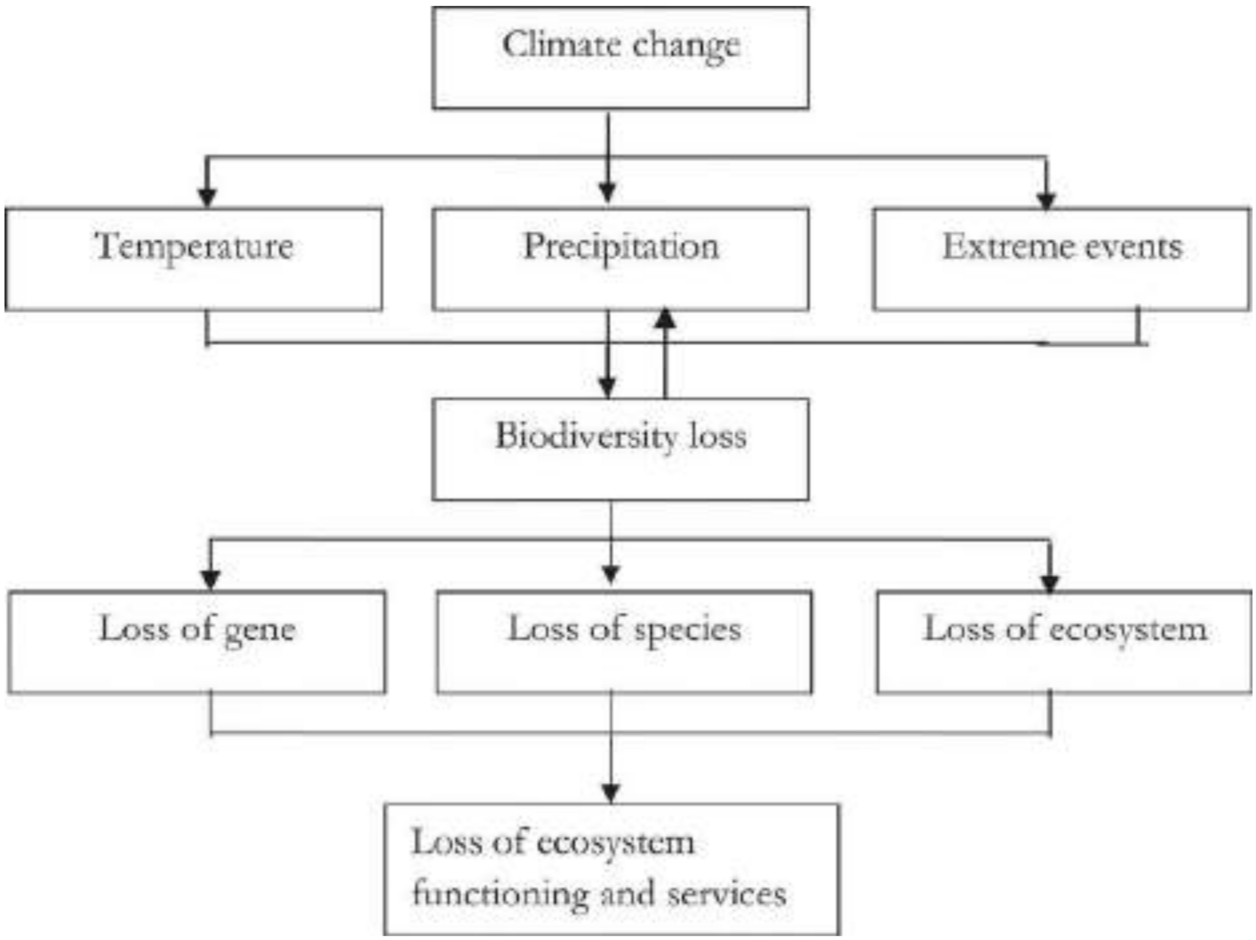
The rise in sea level in coastal regions possibly will threaten the livelihood and lives of millions of people. The occurrence of droughts and floods is likely to increase in many parts of the world. All these factors will contribute to high economic cost and decline in the yield ultimately leading to higher risk of hunger and poverty [132]. A study has been conducted to analyze the impact of climate change on stream flow in the Godavari basin simulated using a conceptual model including CMIP6 dataset. The findings highlighted the importance of taking into consideration the potential impacts of future scenarios on water resources so that effective and sustainable water management practices could be developed [133]. Another study investigated the impact of the climate and land-use changes on water balance in

2037, the end of the National Strategy, for the Mun River Basin, NE Thailand. The study recommended soil-water conservation measures to alleviate the adverse effects of bioenergy [134]. The changing climate will also impact the water quality of lakes. A study has been conducted to investigate the effects of climate change on the water quality of Baiyangdian Lake in the past 30 years using correlation analysis, regression analysis, and the generalized additive model. The major conclusions of the study were the increment in the oxygen demand of organic matter in the lake due to rising temperature, increased total phosphorus in the lake due to increased precipitation and altered nitrogen and dissolved oxygen concentration in lake [135]. It is very important for water resources managers to be aware of the impact the climate change will have on hydrological cycle and flow regime and be prepared to find the strategies to cope with it. The better understanding on the link between the change in climate, water resources and the anthropogenic activities will help the water resource managers to make more rational decisions on the allocation and management of the water resources [136]. Social and environmental aspects including agriculture, biodiversity conservation, and tourism are connected to quality and availability of water resources, and consequently adaptation measures will be strongly bound with policies in a wide spectrum of disciplines [137].

7. CONSERVATION OF SOIL HEALTH, FERTILITY, AND WATER RESOURCES IN CHANGING CLIMATE Soil and water are fundamental and basic necessities. The negative impact of changing climate on these basic resources is major global issue and developing strategies for their conservation is of utmost importance. The major research priorities of current studies are growing more food, conservation of the environment and reduction of global warming. Despite of changes in hydrology, climate, and increasing demand of agricultural commodities, there is a greater need to look further than the traditional approaches of the last century and embracing an expanded view of water and soil conservation to maintain an environmentally sound and sustainable landscape. Most importantly the new strategies must be based on far more effective policies and programs [138]. Agroforestry is one of the emerging technologies for water and soil conservation. It consists of a broad range of the practices including managing and establishing trees purposely around or within croplands, farm animal grounds, and pasture lands with the rationale of managing soil erosion, improving wildlife habitat, developing sustainable agricultural practices, ameliorating the effects of environmental pollution, and also adding to farm economy by harvesting tree based specialty products [139]. Conservation agriculture, another important approach for conservation of soil and water takes into account the conservation of biodiversity, labor and natural resources. It decreases drought stress, raises available soil water and maintains the soil health for a longer term. The strategy is practiced in Argentina, Australia, Brazil, Canada, New Zealand, Paraguay, and USA [140]. Further, it is also becoming popular in China, Kazakhstan, Russia and Ukraine and past decades it is spreading in Africa, Asia, and Europe [141]. Another important approach for maintaining soil health and fertility is the use of beneficial soil microbiomes. Microbes perform countless functions with key role in biogeochemical cycling and sustainability [142]. The utilization of the beneficial microbiomes is an important practice for agro-environmental sustainability. These microbiomes are treasure troves for innovative and potential developments in diverse sectors of agriculture, chemicals, environmental protection, food, and pharmaceuticals. The use of beneficial microbes is the vital practices for the sustainable energy and food production. The current research around the globe is majorly focused on exploring these beneficial microbes for maximizing their application under the limitation of the natural and anthropogenic activities, climate change, use of agro chemicals as these activities are continuously menacing stable agricultural production [143]. In order to fulfill water demand in the near future, it is necessary to rationalize the various means of collecting and storing water. In India, harvesting of rainwater is supposed to contribute in partially meeting the future water requirements. The climate change is expected to make monsoon less reliable as an assured source of water. Thus, efforts are required for more efficient groundwater recharge and rainwater harvesting through adoption and adaptation of technological options. Harnessing excessive monsoon runoff for additional groundwater storage will not only increase the water availability to meet growing demand, but also help to control the damage caused by flooding [144]. Other innovative approaches which may be adopted for water availability include desalination of seawater by evaporation using solar or wind energy which is cost effective and less expensive the cost of tapping groundwater, generation of rainfall using precipitation enhancement such as cloud seeding, and water in surface reservoirs or underground through artificial recharge. Furthermore, increasing irrigation efficiency using another new technology such as sprinkler design with low energy precision application might also be useful [145]. Many NGOs and government organizations are already working on the mitigation strategies for rising climate change. The Indian Council of Agricultural Research under ministry of agriculture and farmers welfare has launched a flagship network project which aims to study the impact of climate change on agricultural sector. The project also takes into account the development and promotion of climate resilient technologies in agriculture which will address vulnerable areas of the country and the output of the projects will help the districts and regions prone to climatic hazards. Rainfed area development scheme is being implemented for promotion of sustainable integrated farming systems. With the help of technological interventions, GOI is preparing efficiently to boost the crop produce and reduce the crop loss. Action against hunger is another important step to cope up with the hunger in scenario of climate crisis. Sankalp Taru Foundation is focusing on protection and conservation of the environment. Mukti is working for the social and economic development and environmental protection of the Sunderbans of West Bengal. Ashoka Trust for Research in Ecology and the Environment is working on issues including biodiversity and conservation, climate change mitigation and development, land and water resources, ecosystem services, and human well-being. Mobius Foundation is working for the environment in Delhi. The Gram Chetna Kendra aims to offer solutions to water problems keeping in mind the frequent damages droughts have induced in 8 Rajasthan. Greenpeace India is working on environment preservation. It has its presence in over 56 countries worldwide across various continents such as Asia, Europe, America, and few others. Greenpeace India promotes four different movements: preserving the oceans, preventing climate change, sustainable agriculture, and preventing another nuclear catastrophe [Figure 4].

8. EFFECTS OF CLIMATE CHANGE ON ECONOMICS It has long been understood that economic consequences are climaterelated. This relationship between climate and economics determines the extent and scale of the market impact of climate change in the next 100 years and beyond. Therefore, recent literature uses panel econometric methods to assess the response of economic results to weather, which is usually defined as implementation based on distribution of climate variables such as precipitation, temperature, and wind [146-148]. This estimation on economically and statistically important effects of weather on an assortment of economic outcomes, including crop yields, industrial output, and labor productivity [149]. The cumulative impact of global climate change is determined by how the world reacts to changes. According to the reports, climate change has already resulted in extreme weather events and a rise in sea level, posing new threats to agricultural production in several parts of the world. Current economic modeling may significantly understate the impact of potentially catastrophic climate change, emphasizing the need for a new generation of models capable of defining a more accurate picture of damages [150-152]. The main dynamic effect is through capital accumulation. Assuming a constant savings rate, if climate change negatively impacts production, the amount of economic investment will be reduced. In the long run, this will lead to lower capital stocks, lower GDP and, in most cases, lower consumption per capita. This effect of capital accumulation can be exacerbated in the context of endogenous growth if low investment slows technological advances while improving labor productivity or human capital accumulation. The second dynamic effect concerns savings. We can expect our forward-thinking agents to predict future climate change and change saving behavior in a perfect world. This, too, will have an impact on capital accumulation, and thus growth and future GDP [153]. Since then, practitioners and academics in development have grappled with the interplay of economic growth and environmental protection. Understanding and acting on these interactions has become critical to development in all countries, particularly in developing ones. The management of the environment has become an essential component of any viable path to poverty reduction and prosperity. Environmental degradation, poor health, and lost economic output result from poor environmental management practices. Poor people are the most vulnerable to these trends, though we must acknowledge that poverty also contributes to them [154,155]. Poor countries and poor people will suffer the most as they rely more on climate sensitive economic activities such as agriculture and possess weaker capability to adapt efficiently. In addition, poor people are also more likely to live in hazard zones and will be more vulnerable to the pests and diseases that follow drought, floods, and heat waves. Climate change can hinder development and growth, increase vulnerability, threaten health and return people to poverty [156]. Given the earth's finite resources, the application of economic principles and empirical findings should be a central component in the quest to meet humanity's aspirations for a good life. A study investigated that increment in temperature considerably reduces the economic performance in Sub-Saharan Africa. In addition, the relationship between real gross domestic product per capita on one hand, and the climate factors on the other, is intrinsically non-linear has been shown in the study [157]. An integrated assessment model (ENVISAGE), including a CGE-based economic module and a climate module has been used to assess the impact of climate change on economic aspects. Results revealed that the influence of climate change is substantial, particularly for developing countries and in the long run, amelioration and adaptation policies are required to bring about sustainability in economic growth [158]. Another study focused on the impact of the climate change shocks on economic growth. The non-linear autoregressive distributional lag technique has been used for estimation of the asymmetric effect of climate change on the economic growth of Pakistan. The report indicated that at national level, tree planting projects, and safeguard greenery at all costs while at international level, adoption of policies and mitigation strategies to control climate change are of major importance [159]. There is a strong case to be made for greater efforts to increase understanding of the environmental, social, and economic dimensions of sustainable development, which necessitates a greater integration of economics, social sciences, and natural sciences [160]. Figure 4: IPBES, global assessment report for policy makers. Kour, .: Journal of Applied Biology & Biotechnology 2024;12(2):1-1

Figure 1. Link between climate change and its impacts on biodiversity and ecosystem services, and the impact of biodiversity loss on climate change



Effects of climate change on oceans

There are many **effects of climate change on oceans**. One of the most important is an increase in ocean temperatures. More frequent marine heatwaves are linked to this. The rising temperature contributes to a rise in sea levels due to the expansion of water as it warms and the melting of ice sheets on land. Other effects on oceans include sea ice decline, reducing pH values and oxygen levels, as well as increased ocean stratification. All this can lead to changes of ocean currents, for example a weakening of the Atlantic meridional overturning circulation (AMOC).[2] The main cause of these changes are the emissions of greenhouse gases from human activities, mainly burning of fossil fuels and deforestation. Carbon dioxide and methane are examples of greenhouse gases. The additional greenhouse effect leads to ocean warming because the ocean takes up most of the additional heat in the climate system.[3] The ocean also absorbs some of the extra carbon dioxide that is in the atmosphere. This causes the pH value of the seawater to drop.[4] Scientists estimate that the ocean absorbs about 25% of all human-caused CO_2 emissions.[4]

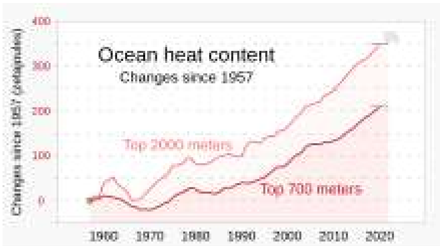
The various layers of the oceans have different temperatures. For example, the water is colder towards the bottom of the ocean. This temperature stratification will increase as the ocean surface warms due to rising air temperatures.[5]:471 Connected to this is a decline in mixing of the ocean layers, so that warm water stabilises near the surface. A reduction of cold, deep water circulation follows. The reduced vertical mixing makes it harder for the ocean to absorb heat. So a larger share of future warming goes into the atmosphere and land. One result is an increase in the amount of energy available for tropical cyclones and other storms. Another result is a decrease in nutrients for fish in the upper ocean layers. These changes also reduce the ocean's capacity to store carbon.[6] At the same time, contrasts in salinity are increasing. Salty areas are becoming saltier and fresher areas less salty.[7]

Warmer water cannot contain the same amount of oxygen as cold water. As a result, oxygen from the oceans moves to the atmosphere. Increased thermal stratification may reduce the supply of oxygen from surface waters to deeper waters. This lowers the water's oxygen content even more.[8] The ocean has already lost oxygen throughout its water column. Oxygen minimum zones are increasing in size worldwide.[5]:471

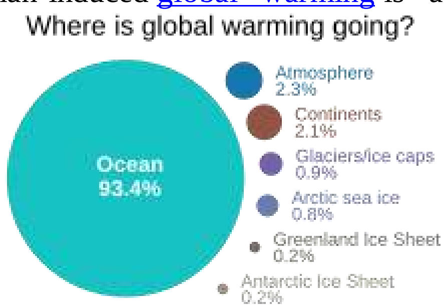
These changes harm marine ecosystems, and this can lead to biodiversity loss or changes in species distribution.[2] This in turn can affect fishing and coastal tourism. For example, rising water temperatures are harming tropical coral reefs. The direct effect is coral bleaching on these reefs, because they are sensitive to even minor temperature changes. So a small increase in water temperature could have a significant impact in these environments. Another example is loss of sea ice habitats due to warming. This will have severe impacts on polar bears and other animals that rely on it. The effects of climate change on oceans put additional pressures on ocean ecosystems which are already under pressure by other impacts from human activities.[2]

Changes due to rising greenhouse gas levels

[edit]



Most excess heat trapped by human-induced global warming is absorbed by the oceans, penetrating to its deeper layers.[9]



Energy (heat) added to various parts of the climate system due to global warming (data from 2007).

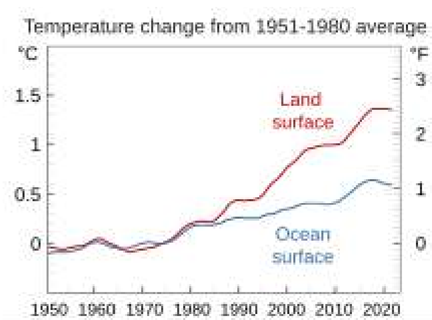
Further information: Climate change and Effects of climate change

Presently (2020), atmospheric carbon dioxide (CO_2) levels of more than 410 parts per million (ppm) are nearly 50% higher than preindustrial levels. These elevated levels and rapid growth rates are unprecedented in the geological record's 55 million years.[4] The source for this excess CO_2 is clearly established as human-driven, reflecting a mix of fossil fuel burning, industrial, and land-use/land-change emissions.[4] The idea that the ocean serves as a major sink for anthropogenic CO_2 has been discussed in scientific literature since at least the late 1950s.[4] Several pieces of evidence point to the ocean absorbing roughly a quarter of total anthropogenic CO_2 emissions.[4]

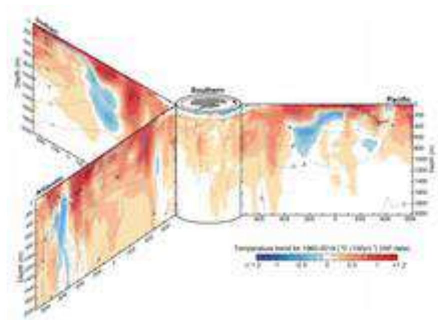
The latest key findings about the observed changes and impacts from 2019 include:

It is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system [...]. Since 1993, the rate of ocean warming has more than doubled [...]. Marine heatwaves have very likely doubled in frequency since 1982 and are increasing in intensity [...]. By absorbing more CO2, the ocean has undergone increasing surface acidification [...]. A loss of oxygen has occurred from the surface to 1000 m [...].— *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019),* [2]:9

Rising ocean temperature



Land surface temperatures have increased faster than ocean temperatures as the ocean absorbs about 92% of excess heat generated by climate change.[10] Chart with data from NASA[11] showing how land and sea surface air temperatures have changed vs a pre-industrial baseline.



The illustration of temperature changes from 1960 to 2019 across each ocean starting at the Southern Ocean around Antarctica.[12]

See also: [Ocean temperature](), [Sea surface temperature](), and [Marine heatwave]()

It is clear that the ocean is warming as a result of climate change, and this rate of warming is increasing.[2]:9 The global ocean was the warmest it had ever been recorded by humans in 2022.[13] This is determined by the ocean heat content, which exceeded the previous 2021 maximum in 2022.[13] The steady rise in ocean temperatures is an unavoidable result of the Earth's energy imbalance, which is primarily caused by rising levels of greenhouse gases.[13] Between pre-industrial times and the 2011–2020 decade, the ocean's surface has heated between 0.68 and 1.01 °C.[14]:1214

The majority of ocean heat gain occurs in the Southern Ocean. For example, between the 1950s and the 1980s, the temperature of the Antarctic Southern Ocean rose by 0.17 °C (0.31 °F), nearly twice the rate of the global ocean.[15]

The warming rate varies with depth. The upper ocean (above 700 m) is warming the fastest. At an ocean depth of a thousand metres the warming occurs at a rate of nearly 0.4 °C per century (data from 1981 to 2019).[5]:Figure 5.4 In deeper zones of the ocean (globally speaking), at 2000 metres depth, the warming has been around 0.1 °C per century.[5]:Figure 5.4 The warming pattern is different for the Antarctic Ocean (at 55°S), where the highest warming (0.3 °C per century) has been observed at a depth of 4500 m.[5]:Figure 5.4

Marine heatwaves

Marine heatwaves also take their toll on marine life: For example, due to fall-out from the 2019-2021 Pacific Northwest marine heatwave,[16] Bering Sea snow crab populations declined 84% between 2018 and 2022, a loss of 9.8 billion crabs.[17]

This section is an excerpt from Marine heatwave

Scientists predict that the frequency, duration, scale (or area) and intensity of marine heatwaves will continue to increase.[18]:1227 This is because sea surface temperatures will continue to increase with global warming. The IPCC Sixth Assessment Report in 2022 has summarized research findings to date and stated that "marine heatwaves are more frequent [...], more intense and longer [...] since the 1980s, and since at least 2006 very likely attributable to anthropogenic climate change".[19]:381 This confirms earlier findings in a report by the IPCC in 2019 which had found that "marine heatwaves [...] have doubled in frequency and have become longer lasting, more intense and more extensive (very likely).".[20]:67 The extent of ocean warming depends on greenhouse gas emission scenarios, and thus humans' climate change mitigation efforts. Scientists predict that marine heatwaves will become "four times more frequent in 2081–2100 compared to 1995–2014" under the lower greenhouse gas emissions scenario, or eight times more frequent under the higher emissions scenario.[18]:1214

Ocean heat content

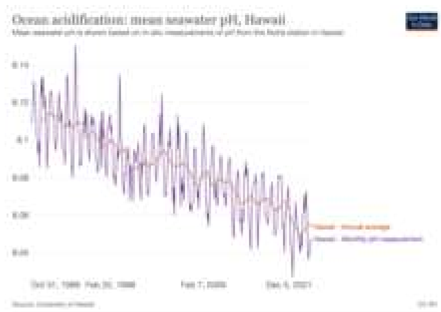
The ocean temperature varies from place to place. Temperatures are higher near the equator and lower at the poles. As a result, changes in total ocean heat content best illustrate ocean warming. When compared to 1969–1993, heat uptake has increased between 1993 and 2017.[5]:457

This section is an excerpt from Ocean heat content

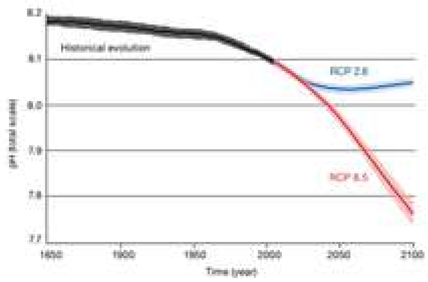
Ocean heat content (OHC) or ocean heat uptake (OHU) is the energy absorbed and stored by oceans. To calculate the ocean heat content, it is necessary to measure ocean temperature at many different locations and depths. Integrating the areal density of a change in enthalpic energy over an ocean basin or entire ocean gives the total ocean heat uptake.[21] Between 1971 and 2018, the rise in ocean heat content accounted for over 90% of Earth's excess energy from global heating.[22][23] The main driver of this increase was caused by humans via their rising greenhouse gas emissions.[24]:1228 By 2020, about one third of the added energy had propagated to depths below 700 meters.[25][26]

In 2023, the world's oceans were again the hottest in the historical record and exceeded the previous 2022 record maximum.[27] The five highest ocean heat observations to a depth of 2000 meters occurred in the period 2019–2023. The North Pacific, North Atlantic, the Mediterranean, and the Southern Ocean all recorded their highest heat observations for more than sixty years of global measurements.[28] Ocean heat content and sea level rise are important indicators of climate change.[29]

Ocean acidification



Ocean acidification: mean seawater pH. Mean seawater pH is shown based on in-situ measurements of pH from the Aloha station.[30]



Change in pH since the beginning of the industrial revolution. RCP2.6 scenario is "low CO_2 emissions". RCP8.5 scenario is "high CO_2 emissions".[31]

This section is an excerpt from Ocean acidification.[edit]

Ocean acidification is the ongoing decrease in the pH of the Earth's ocean. Between 1950 and 2020, the average pH of the ocean surface fell from approximately 8.15 to 8.05.[32] Carbon dioxide emissions from human activities are the primary cause of ocean acidification, with atmospheric carbon dioxide (CO_2) levels exceeding 422 ppm (as of 2024).[33] CO_2 from the atmosphere is absorbed by the oceans. This chemical reaction produces carbonic acid (H_2CO_3) which dissociates into a bicarbonate ion (HCO_3^-) and a hydrogen ion (H^+). The presence of free hydrogen ions (H^+) lowers the pH of the ocean, increasing acidity (this does not mean that seawater is acidic yet; it is still alkaline, with a pH higher than 8). Marine calcifying organisms, such as mollusks and corals, are especially vulnerable because they rely on calcium carbonate to build shells and skeletons.[34]

A change in pH by 0.1 represents a 26% increase in hydrogen ion concentration in the world's oceans (the pH scale is logarithmic, so a change of one in pH units is equivalent to a tenfold change in hydrogen ion concentration). Sea-surface pH and carbonate saturation states vary depending on ocean depth and location. Colder and higher latitude waters are capable of absorbing more CO_2. This can cause acidity to rise, lowering the pH and carbonate saturation levels in these areas. There are several other factors that influence the atmosphere-ocean CO_2 exchange, and thus local ocean acidification. These include ocean currents and upwelling zones, proximity to large continental rivers, sea ice coverage, and atmospheric exchange with nitrogen and sulfur from fossil fuel burning and agriculture.[35][36][37]

A lower ocean pH has a range of potentially harmful effects for marine organisms. Scientists have observed for example reduced calcification, lowered immune responses, and reduced energy for basic functions such as reproduction.[38] Ocean acidification can impact marine ecosystems that provide food and livelihoods for many people. About one billion people are wholly or partially dependent on the fishing, tourism, and coastal management services provided by coral reefs. Ongoing acidification of the oceans may therefore threaten food chains linked with the oceans.[39][40]

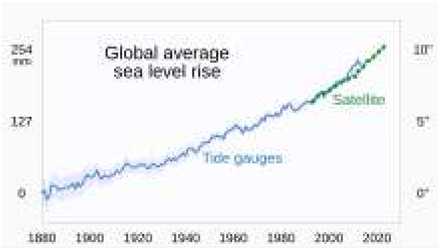
Time scales

Many ocean-related elements of the climate system respond slowly to warming. For instance, acidification of the deep ocean will continue for millennia, and the same is true for the increase in ocean heat content.[41]:43 Similarly, sea level rise will continue for centuries or even millennia even if greenhouse gas emissions are brought to zero, due to the slow response of ice sheets to warming and the continued uptake of heat by the oceans, which expand when warmed.[41]:77

Effects on the physical environment

Sea level rise

Main article: Sea level rise



The global average sea level has risen about 250 millimetres (9.8 in) since 1880,[42] increasing the elevation on top of which other types of flooding (high-tide flooding, storm surge) occur.

Many coastal cities will experience coastal flooding in the coming decades and beyond.[14]:1318 Local subsidence, which may be natural but can be increased by human activity, can exacerbate coastal flooding.[43] Coastal flooding will threaten hundreds of millions of people by 2050, particularly in Southeast Asia.[43]

This section is an excerpt from Sea level rise

Between 1901 and 2018, the average sea level rose by 15–25 cm (6–10 in), with an increase of 2.3 mm (0.091 in) per year since the 1970s.[44]:1216 This was faster than the sea level had ever risen over at least the past 3,000 years.[44]:1216 The rate accelerated to 4.62 mm (0.182 in)/yr for the decade 2013–2022.[45] Climate change due to human activities is the main cause.[46]:5,8 Between 1993 and 2018, melting ice sheets and glaciers accounted for 44% of sea level rise, with another 42% resulting from thermal expansion of water.[47]:1576

Changing ocean currents

Main articles: Ocean § Ocean currents and global climate, and Atlantic meridional overturning circulation


Waves on an ocean coast

Ocean currents are caused by temperature variations caused by sunlight and air temperatures at various latitudes, as well as prevailing winds and the different densities of salt and fresh water. Warm air rises near the equator. Later, as it moves toward the poles, it cools again. Cool air sinks near the poles, but warms and rises again as it moves toward the equator. This produces Hadley cells, which are large-scale wind patterns, with similar effects driving a mid-latitude cell in each hemisphere.[48][page needed] Wind patterns associated with these circulation cells drive surface currents which push the surface water to higher latitudes where the air is colder.[48][page needed] This cools the water, causing it to become very dense in comparison to lower latitude waters, causing it to sink to the ocean floor, forming North Atlantic Deep Water (NADW) in the north and Antarctic Bottom Water (AABW) in the south.[49]

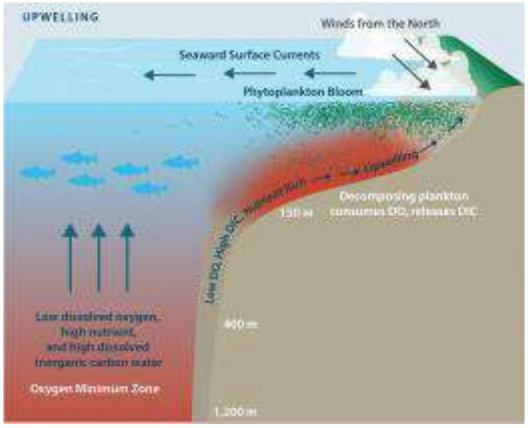
Driven by this sinking and the upwelling that occurs in lower latitudes, as well as the driving force of the winds on surface water, the ocean currents act to circulate water throughout the sea. When global warming is factored in, changes occur, particularly in areas where deep water is formed.[50] As the oceans warm and glaciers and polar ice caps melt, more and more fresh water is released into the high latitude regions where deep water forms, lowering the density of the surface water. As a result, the water sinks more slowly than it would normally.[50]

The Atlantic Meridional Overturning Circulation (AMOC) may have weakened since the preindustrial era, according to modern observations and paleoclimate reconstructions (the AMOC is part of a global thermohaline circulation), but there is too much uncertainty in the data to know for certain.[14]:1237 Climate change projections assessed in 2021 indicate that the AMOC is very likely to weaken over the course of the 21st century.[14]:1214 A weakening of this magnitude could have a significant impact on global climate, with the North Atlantic being particularly vulnerable.[2]:19

Any changes in ocean currents affect the ocean's ability to absorb carbon dioxide (which is affected by water temperature) as well as ocean productivity because the currents transport nutrients (see Impacts on phytoplankton and net primary production). Because the AMOC deep ocean circulation is slow (it takes hundreds to thousands of years to circulate the entire ocean), it is slow to respond to climate change.[51]:137

Increasing stratification

Main articles: Ocean stratification and Ocean § Physical properties



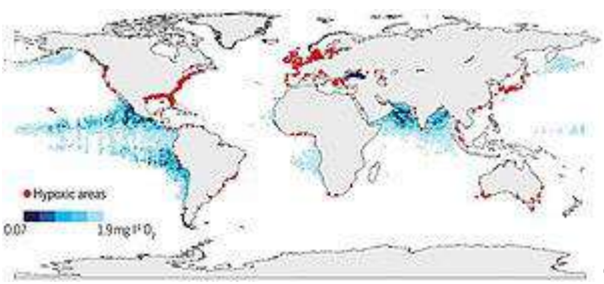
Drivers of hypoxia and ocean acidification intensification in upwelling shelf systems. Equatorward winds drive the upwelling of low dissolved oxygen (DO), high nutrient, and high dissolved inorganic carbon (DIC) water from above the oxygen minimum zone. Cross-shelf gradients in productivity and bottom water residence times drive the strength of DO (DIC) decrease (increase) as water transits across a productive continental shelf.[52][53]

Changes in ocean stratification are significant because they can influence productivity and oxygen levels. The separation of water into layers based on density is known as stratification. Stratification by layers occurs in all ocean basins. The stratified layers limit how much vertical water mixing takes place, reducing the exchange of heat, carbon, oxygen and particles between the upper ocean and the interior.[54] Since 1970, there has been an increase in stratification in the upper ocean due to global warming and, in some areas, salinity changes.[14] The salinity changes are caused by evaporation in tropical waters, which results in higher salinity and density levels. Meanwhile, melting ice can cause a decrease in salinity at higher latitudes.[14]

Temperature, salinity and pressure all influence water density. As surface waters are often warmer than deep waters, they are less dense, resulting in stratification.[54] This stratification is crucial not just in the production of the Atlantic Meridional Overturning Circulation, which has worldwide weather and climate ramifications, but it is also significant because stratification controls the movement of nutrients from deep water to the surface. This increases ocean productivity and is associated with the compensatory downward flow of water that carries oxygen from the atmosphere and surface waters into the deep sea.[51]

Reduced oxygen levels

Main article: Ocean deoxygenation



Global map of low and declining oxygen levels in the open ocean and coastal waters. The map indicates coastal sites where anthropogenic nutrients have resulted in oxygen declines to less than 2 mg L^{-1} (red dots), as well as ocean oxygen minimum zones at 300 metres (blue shaded regions).[55]

Climate change has an impact on ocean oxygen, both in coastal areas and in the open ocean.[55]

The open ocean naturally has some areas of low oxygen, known as oxygen minimum zones. These areas are isolated from the atmospheric oxygen by sluggish ocean circulation. At the same time, oxygen is consumed when sinking organic matter from surface waters is broken down. These low oxygen ocean areas are expanding as a result of ocean warming which both reduces water circulation and also reduces the oxygen content of that water, while the solubility of oxygen declines as the temperature rises.[56]

Overall ocean oxygen concentrations are estimated to have declined 2% over 50 years from the 1960s.[56] The nature of the ocean circulation means that in general these low oxygen regions are more pronounced in the Pacific Ocean. Low oxygen represents a stress for almost all marine animals. Very low oxygen levels create regions with much reduced fauna. It is predicted that these low oxygen zones will expand in future due to climate change, and this represents a serious threat to marine life in these oxygen minimum zones.[2]

The second area of concern relates to coastal waters where increasing nutrient supply from rivers to coastal areas leads to increasing production and sinking organic matter which in some coastal regions leads to extreme oxygen depletion, sometimes referred to as *dead zones*.[57] These dead zones are expanding driven particularly by increasing nutrient inputs, but also compounded by increasing ocean stratification driven by climate change.[2]

Oceans turning green

Satellite image analysis reveals that the oceans have been gradually turning green from blue as climate breakdown continues. The color change has been detected for a majority of the word's ocean surfaces and may be due to changing plankton populations caused by climate change.[58][59]

Changes to Earth's weather system and wind patterns

Further information: Effects of climate change on the water cycle

Climate change and the associated warming of the ocean will lead to widespread changes to the Earth's climate and weather system including increased tropical cyclone and monsoon intensities and weather extremes with some areas becoming wetter and others drier.[14] Changing wind patterns are predicted to increase wave heights in some areas.[60][14]:1310

Intensifying tropical cyclones

Human-induced climate change "continues to warm the oceans which provide the memory of past accumulated effects".[61] The result is a higher ocean heat content and higher sea surface temperatures. In turn, this "invigorates tropical cyclones to make them more intense, bigger, longer lasting and greatly increases their flooding rains".[61] One example is Hurricane Harvey in 2017.[61]

This section is an excerpt from Tropical cyclones and climate change.

Climate change affects tropical cyclones in a variety of ways: an intensification of rainfall and wind speed, an increase in the frequency of very intense storms and a poleward extension of where the cyclones reach maximum intensity are among the consequences of human-induced climate change.[62][63] Tropical cyclones use warm, moist air as their source of energy or *fuel*. As climate change is warming ocean temperatures, there is potentially more of this fuel available.[64]

Between 1979 and 2017, there was a global increase in the proportion of tropical cyclones of Category 3 and higher on the Saffir–Simpson scale. The trend was most clear in the north Indian Ocean,[65][66] North Atlantic and in the Southern Indian Ocean. In the north Indian Ocean, particularly the Arabian Sea, the frequency, duration, and intensity of cyclones have increased significantly. There has been a 52% increase in the number of cyclones in the Arabian Sea, while the number of very severe cyclones have increased by 150%, during 1982–2019. Meanwhile, the total duration of cyclones in the Arabian Sea has increased by 80% while that of very severe cyclones has increased by 260%.[65] In the North Pacific, tropical cyclones have been moving poleward into colder waters and there was no increase in intensity over this period.[67] With 2 °C (3.6 °F) warming, a greater percentage (+13%) of tropical cyclones are expected to reach Category 4 and 5 strength.[62] A 2019 study indicates that climate change has been driving the observed trend of rapid intensification of tropical cyclones in the Atlantic basin. Rapidly intensifying cyclones are hard to forecast and therefore pose additional risk to coastal communities.[68]

Salinity changes

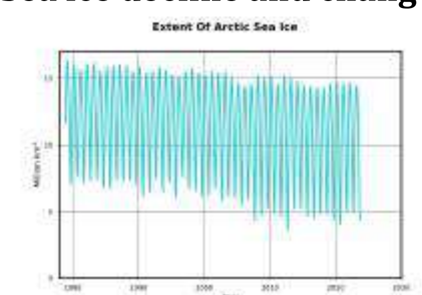
Further information: Ocean § Salinity, and Effects of climate change on the water cycle

Due to global warming and increased glacier melt, thermohaline circulation patterns may be altered by increasing amounts of freshwater released into oceans and, therefore, changing ocean salinity. Thermohaline circulation is responsible for bringing up cold, nutrient-rich water from the depths of the ocean, a process known as upwelling.[69]

Seawater consists of fresh water and salt, and the concentration of salt in seawater is called salinity. Salt does not evaporate, thus the precipitation and evaporation of freshwater influences salinity strongly. Changes in the water cycle are therefore strongly visible in surface salinity measurements, which has been known since the 1930s.[7][70]

The long term observation records show a clear trend: the global salinity patterns are amplifying in this period.[71][72] This means that the high saline regions have become more saline, and regions of low salinity have become less saline. The regions of high salinity are dominated by evaporation, and the increase in salinity shows that evaporation is increasing even more. The same goes for regions of low salinity that are becoming less saline, which indicates that precipitation is becoming more intensified.[73][5]

Sea ice decline and changes



Decline in arctic sea ice extent (area) from 1979 to 2022

Sea ice decline occurs more in the Arctic than in Antarctica, where it is more a matter of *changing* sea ice conditions.

This section is an excerpt from Arctic sea ice decline. [edit]

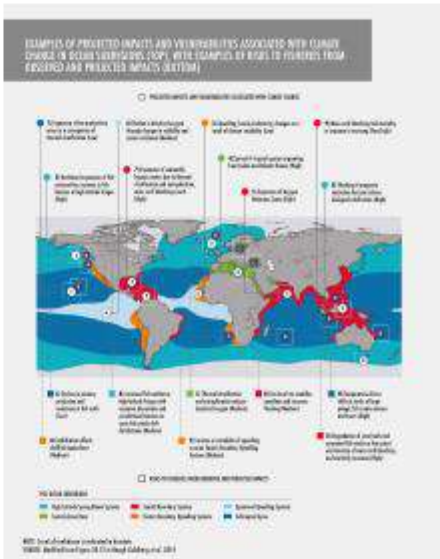
Sea ice in the Arctic region has declined in recent decades in area and volume due to climate change. It has been melting more in summer than it refreezes in winter. Global warming, caused by greenhouse gas forcing is responsible for the decline in Arctic sea ice. The decline of sea ice in the Arctic has been accelerating during the early twenty-first century, with a decline rate of 4.7% per decade (it has declined over 50% since the first satellite records).[74][75][76] Summertime sea ice will likely cease to exist sometime during the 21st century.[77]

This section is an excerpt from Antarctic sea ice § Recent trends and climate change. [edit]

Sea ice extent in Antarctica varies a lot year by year. This makes it difficult determine a trend, and record highs and record lows have been observed between 2013 and 2023. The general trend since 1979, the start of the satellite measurements, has been roughly flat. Between 2015 and 2023, there has been a decline in sea ice, but due to the high variability, this does not correspond to a significant trend.[78] The flat trend is in contrast with Arctic sea ice, which has seen a declining trend.[78][79]

Impacts on biological processes

[edit]



Examples of projected impacts and vulnerabilities for fisheries associated with climate change

Ocean productivity

[edit]

Further information: Ocean § Oxygen, photosynthesis and carbon cycle

The process of photosynthesis in the surface ocean releases oxygen and consumes carbon dioxide. This photosynthesis in the ocean is dominated by phytoplankton – microscopic free-floating algae. After the plants grow, bacterial decomposition of the organic matter formed by photosynthesis in the ocean consumes oxygen and releases carbon dioxide. The sinking and bacterial decomposition of some organic matter in deep ocean water, at depths where the waters are out of contact with the atmosphere, leads to a reduction in oxygen concentrations and increase in carbon dioxide, carbonate and bicarbonate.[51] This cycling of carbon dioxide in oceans is an important part of the global carbon cycle.

The photosynthesis in surface waters consumes nutrients (e.g. nitrogen and phosphorus) and transfers these nutrients to deep water as the organic matter produced by photosynthesis sinks upon the death of the organisms. Productivity in surface waters therefore depends in part on the transfer of nutrients from deep water back to the surface by ocean mixing and currents. The increasing stratification of the oceans due to climate change therefore acts generally to reduce ocean productivity. However, in some areas, such as previously ice covered regions, productivity may increase. This trend is already observable and is projected to continue under current projected climate change.[14][failed verification] In the Indian Ocean for example, productivity is estimated to have declined over the past sixty years due to climate warming and is projected to continue.[80]

Ocean productivity under a very high emission scenario (RCP8.5) is very likely to drop by 4-11% by 2100.[5]:452 The decline will show regional variations. For example, the tropical ocean NPP will decline more: by 7–16% for the same emissions scenario.[5]:452 Less organic matter will likely sink from the upper oceans into deeper ocean layers due to increased ocean stratification and a reduction in nutrient supply.[5]:452 The reduction in ocean productivity is due to the "combined effects of warming, stratification, light, nutrients and predation".[5]:452

Calcifying organisms and ocean acidification

This section is an excerpt from Ocean acidification § Complexity of research findings.

The full ecological consequences of the changes in calcification due to ocean acidification are complex but it appears likely that many calcifying species will be adversely affected by ocean acidification.[81][82]:413 Increasing ocean acidification makes it more difficult for shell-accreting organisms to access carbonate ions, essential for the production of their hard exoskeletal shell.[83] Oceanic calcifying organism span the food chain from autotrophs to heterotrophs and include organisms such as coccolithophores, corals, foraminifera, echinoderms, crustaceans and molluscs.[84][85]

Overall, all marine ecosystems on Earth will be exposed to changes in acidification and several other ocean biogeochemical changes.[86] Ocean acidification may force some organisms to reallocate resources away from productive endpoints in order to maintain calcification.[87] For example, the oyster *Magallana gigas* is recognized to experience metabolic changes alongside altered calcification rates due to energetic tradeoffs resulting from pH imbalances.[88]

Harmful algal blooms

Further information: Harmful algal bloom

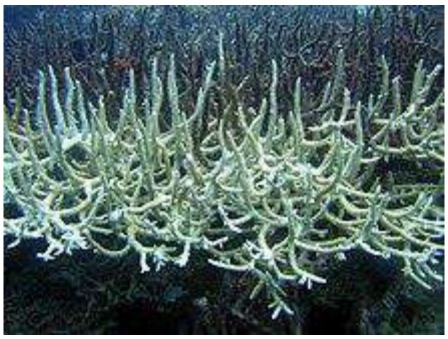
Although the drivers of harmful algal blooms (HABs) are poorly understood, they appear to have increased in range and frequency in coastal areas since the 1980s.[2]:16 This is the result of human induced factors such as increased nutrient inputs (nutrient pollution) and climate change (in particular the warming of water temperatures).[2]:16 The parameters that affect the formation of HABs are ocean warming, marine heatwaves, oxygen loss, eutrophication and water pollution.[89]:582 These increases in HABs are of concern because of the impact of their occurrence on local food security, tourism and the economy.[2]:16

It is however also possible that the perceived increase in HABs globally is simply due to more severe bloom impacts and better monitoring and not due to climate change.[90]:463

Impacts on coral reefs and fisheries

Coral reefs

Further information: Coral bleaching, Coral reef, and Coral



Bleached Staghorn coral in the Great Barrier Reef.

While some mobile marine species can migrate in response to climate change, others such as corals find this much more difficult. A coral reef is an underwater ecosystem characterised by reef-building corals. Reefs are formed by colonies of coral polyps held together by calcium carbonate.[91] Coral reefs are important centres of biodiversity and vital to millions of people who rely on them for coastal protection, food and for sustaining tourism in many regions.[92]

Warm water corals are clearly in decline, with losses of 50% over the last 30–50 years due to multiple threats from ocean warming, ocean acidification, pollution and physical damage from activities such as fishing. These pressures are expected to intensify.[92]

The warming ocean surface waters can lead to bleaching of the corals which can cause serious damage and/or coral death. The IPCC Sixth Assessment Report in 2022 found that: "Since the early 1980s, the frequency and severity of mass coral bleaching events have increased sharply worldwide".[90]:416 Marine heatwaves have caused coral reef mass mortality.[90]:381 It is expected that many coral reefs will suffer irreversible changes and loss due to marine heatwaves with global temperatures increasing by more than 1.5 °C.[90]:382

Coral bleaching occurs when thermal stress from a warming ocean results in the expulsion of the symbiotic algae that resides within coral tissues. These symbiotic algae are the reason for the bright, vibrant colors of coral reefs.[93] A 1-2°C sustained increase in seawater temperatures is sufficient for bleaching to occur, which turns corals white.[94] If a coral is bleached for a prolonged period of time, death may result. In the Great Barrier Reef, before 1998 there were no such events. The first event happened in 1998 and after that, they began to occur more frequently. Between 2016 and 2020 there were three of them.[95]

Apart from coral bleaching, the reducing pH value in oceans is also a problem for coral reefs because ocean acidification reduces coralline algal biodiversity.[96] The physiology of coralline algal calcification determines how the algae will respond to ocean acidification.[96]

This section is an excerpt from Ocean acidification § Corals.

Warm water corals are clearly in decline, with losses of 50% over the last 30–50 years due to multiple threats from ocean warming, ocean acidification, pollution and physical damage from activities such as fishing, and these pressures are expected to intensify.[97][82]:416

The fluid in the internal compartments (the coelenteron) where corals grow their exoskeleton is also extremely important for calcification growth. When the saturation state of aragonite in the external seawater is at ambient levels, the corals will grow their aragonite crystals rapidly in their internal compartments, hence their exoskeleton grows rapidly. If the saturation state of aragonite in the external seawater is lower than the ambient level, the corals have to work harder to maintain the right balance in the internal compartment. When that happens, the process of growing the crystals slows down, and this slows down the rate of how much their exoskeleton is growing. Depending on the aragonite saturation state in the surrounding water, the corals may halt growth because pumping aragonite into the internal compartment will not be energetically favorable.[98] Under the current progression of carbon emissions, around 70% of North Atlantic cold-water corals will be living in corrosive waters by 2050–60.[99]

Effects on fisheries

This section is an excerpt from Climate change and fisheries

Fisheries are affected by climate change in many ways: marine aquatic ecosystems are being affected by rising ocean temperatures,[100] ocean acidification[101] and ocean deoxygenation, while freshwater ecosystems are being impacted by changes in water temperature, water flow, and fish habitat loss.[102] These effects vary in the context of each fishery.[103] Climate change is modifying fish distributions[104] and the productivity of marine and freshwater species. Climate change is expected to lead to significant changes in the availability and trade of fish products.[105] The geopolitical and economic consequences will be significant, especially for the countries most dependent on the sector. The biggest decreases in maximum catch potential can be expected in the tropics, mostly in the South Pacific regions.[105]:iv

The impacts of climate change on ocean systems has impacts on the sustainability of fisheries and aquaculture, on the livelihoods of the communities that depend on fisheries, and on the ability of the oceans to capture and store carbon (biological pump). The effect of sea level rise means that coastal fishing communities are significantly impacted by climate change, while changing rainfall patterns and water use impact on inland freshwater fisheries and aquaculture.[106] Increased risks of floods, diseases, parasites and harmful algal blooms are climate change impacts on aquaculture which can lead to losses of production and infrastructure.[105]

It is projected that "climate change decreases the modelled global fish community biomass by as much as 30% by 2100".[107]

Impacts on marine mammals

Regions and habitats particularly affected

Some effects on marine mammals, especially those in the Arctic, are very direct such as loss of habitat, temperature stress, and exposure to severe weather. Other effects are more indirect, such as changes in host pathogen associations, changes in body condition because of predator–prey interaction, changes in exposure to toxins and CO_2 emissions, and increased human interactions.[108] Despite the large potential impacts of ocean warming on marine mammals, the global vulnerability of marine mammals to global warming is still poorly understood.[109]

Marine mammals have evolved to live in oceans, but climate change is affecting their natural habitat.[110][111][112][113] Some species may not adapt fast enough, which might lead to their extinction.[114]

It has been generally assumed that the Arctic marine mammals were the most vulnerable in the face of climate change given the substantial observed and projected decline in Arctic sea ice. However, research has shown that the North Pacific Ocean, the Greenland Sea and the Barents Sea host the species that are most vulnerable to global warming.[109] The North Pacific has already been identified as a hotspot for human threats for marine mammals[115] and is now also a hotspot for vulnerability to global warming. Marine mammals in this region will face double jeopardy from both human activities (e.g., marine traffic, pollution and offshore oil and gas development) and global warming, with potential additive or synergetic effects. As a result, these ecosystems face irreversible consequences for marine ecosystem functioning.[109]

Marine organisms usually tend to encounter relatively stable temperatures compared to terrestrial species and thus are likely to be more sensitive to temperature change than terrestrial organisms.[116] Therefore, the ocean warming will lead to the migration of increased species, as endangered species look for a more suitable habitat. If sea temperatures continue to rise, then some fauna may move to cooler water and some range-edge species may disappear from regional waters or experience a reduced global range.[116] Change in the abundance of some species will alter the food resources available to marine mammals, which then results in marine mammals' biogeographic shifts. Furthermore, if a species is unable to successfully migrate to a suitable environment, it will be at risk of extinction if it cannot adapt to rising temperatures of the ocean.

Arctic sea ice decline leads to loss of the sea ice habitat, elevations of water and air temperature, and increased occurrence of severe weather. The loss of sea ice habitat will reduce the abundance of seal prey for marine mammals, particularly polar bears.[117] Sea ice changes may also have indirect effects on animal health due to changes in the transmission of pathogens, impacts on animals' body condition due to shifts in the prey-based food web, and increased exposure to toxicants as a result of increased human habitation in the Arctic habitat.[118]

Sea level rise is also important when assessing the impacts of global warming on marine mammals, since it affects coastal environments that marine mammal species rely on.[119]

Polar bears

A polar bear waiting in the Fall for the sea ice to form.

This section is an excerpt from Polar bear conservation § Climate change.[edit]

The key danger for polar bears posed by the effects of climate change is malnutrition or starvation due to habitat loss. Polar bears hunt seals from a platform of sea ice. Rising temperatures cause the sea ice to melt earlier in the year, driving the bears to shore before they have built sufficient fat reserves to survive the period of scarce food in the late summer and early fall.[120] Reduction in sea-ice cover also forces bears to swim longer distances, which further depletes their energy stores and occasionally leads to drowning.[121] Thinner sea ice tends to deform more easily, which appears to make it more difficult for polar bears to access seals.[122] Insufficient nourishment leads to lower reproductive rates in adult females and lower survival rates in cubs and juvenile bears, in addition to poorer body condition in bears of all ages.[123]

Seals

Further information: Ringed seal § Climate change

Harp seal mother nursing pup on sea ice

Seals are another marine mammal that are susceptible to climate change.[114] Much like polar bears, some seal species have evolved to rely on sea ice. They use the ice platforms for breeding and raising young seal pups. In 2010 and 2011, sea ice in the Northwest Atlantic was at or near an all-time low and harp seals as well as ringed seals that bred on thin ice saw increased death rates.[124][125] Antarctic fur seals in South Georgia in the South Atlantic Ocean saw extreme reductions over a 20-year study, during which scientists measured increased sea surface temperature anomalies.[126]

Dolphins

Climate change has had a significant impact on various dolphin species. For example: In the Mediterranean, increased sea surface temperatures, salinity, upwelling intensity, and sea levels have led to a reduction in prey resources, causing a steep decline in the short-beaked common dolphin subpopulation in the Mediterranean, which was classified as endangered in 2003.[127] At the Shark Bay World Heritage Area in Western Australia, the local population of the Indo-Pacific bottlenose dolphin had a significant decline following a marine heatwave in 2011.[128] River dolphins are highly affected by climate change as high evaporation rates, increased water temperatures, decreased precipitation, and increased acidification occur.[129][130]

This section is an excerpt from Dolphin § Impacts of climate change

Dolphins are marine mammals with broad geographic extent, making them susceptible to climate change in various ways. The most common effect of climate change on dolphins is the increasing water temperatures across the globe.[131] This has caused a large variety of dolphin species to experience range shifts, in which the species move from their typical geographic region to cooler waters.[132][133] Another side effect of increasing water temperatures is the increase in harmful algae blooms, which has caused a mass die-off of bottlenose dolphins.[131]

North Atlantic right whales

This section is an excerpt from North Atlantic right whale § Climate change

Anthropogenic climate change poses a clear and growing threat to right whales.[134][135] Documented effects in the scientific literature include impacts on reproduction, range, prey access, interactions with human activities, and individual health condition.[135]

Climate-driven changes to ocean circulation and water temperatures have affected the species' foraging and habitat use patterns, with numerous harmful consequences.[136] Warming waters lead to decreased abundance of an important prey species, the zooplankton *Calanus finmarchicus*.[137] This reduction in prey availability affects the health of the right whale population in numerous ways. The most direct impacts are on the survival and reproductive success of individual whales, as lower *C. finmarchicus* densities have been associated with malnutrition-related health issues[138] and difficulties successfully giving birth to and rearing calves.[136][139]

Potential feedback effects

Methane release from methane clathrate

Rising ocean temperatures also have the potential to impact methane clathrate reservoirs located under the ocean floor sediments. These trap large amounts of the greenhouse gas methane, which ocean warming has the potential to release. However, it is currently considered unlikely that gas clathrates (mostly methane) in subsea clathrates will lead to a "detectable departure from the emissions trajectory during this century".[41]:107

In 2004 the global inventory of ocean methane clathrates was estimated to occupy between one and five million cubic kilometres.[140]

CLIMATE ACTION

CLIMATE change-adoption,

What is climate change adaptation?

Climate change adaptation refers to actions that help reduce vulnerability to the current or expected impacts of climate change like weather extremes and hazards, sea-level rise, biodiversity loss, or food and water insecurity.

Many adaptation measures need to happen at the local level, so rural communities and cities have a big role to play. Such measures include planting crop varieties that are more resistant to drought and practicing regenerative agriculture, improving water storage and use, managing land to reduce wildfire risks, and building stronger defences against extreme weather like floods and heat waves.

However, adaptation also needs to be driven at the national and international levels. In addition to developing the policies needed to guide adaptation, governments need to look at large-scale measures such as strengthening or relocating infrastructure from coastal areas affected by sea-level rise, building infrastructure able to withstand more extreme weather conditions, enhancing early warning systems and access to disaster information, developing insurance mechanisms specific to climate-related threats, and creating new protections for wildlife and natural ecosystems.

Why do we need to adapt? And why is it so urgent?

Scientific studies show that the Earth is now about 1.1°C warmer than it was in the 1800s. This warming is causing widespread and rapid changes in our planet's atmosphere, ocean and ecosystems. As a result, weather and climate extremes are becoming more frequent in every region of the world.

According to climate models, without significant climate action, the world is headed for 2.5 to 2.9°C temperature rise above pre-industrial levels this century, which is well above the safety limits established by scientists.

With every fraction of a degree of warming, the impacts of climate change will become more frequent and more intense – and adaptation will become that much harder and more expensive for people and ecosystems.

The urgency is especially great for developing countries, which are already feeling the impacts of climate change and are particularly vulnerable due to a combination of factors, including their geographical and climatic conditions, their high dependence on natural resources, and their limited capacity to adapt to a changing climate. Adaptation is also particularly important for women and young children, older populations, ethnic minorities, Indigenous Peoples, refugees and displaced persons, who are shown to be disproportionately affected by climate change.

Even in very positive scenarios in which we manage to significantly and swiftly cut greenhouse gas emissions, climate change will continue to impact our world for decades to come because of the energy already trapped in the system. This means cutting down emissions is only one part of our response to the climate crisis: adaptation is needed to limit the impacts and safeguard people and nature.

What are the challenges related to climate change adaptation?

Efforts to adapt to the impacts of climate change face a number of significant challenges.

The first major bottleneck for adaptation action is the availability of and access to finance. In fact, the adaptation finance needs of developing countries are estimated to be 10 to 18 times larger than what is currently available from public sources.

Finance is needed to drive investment in a range of adaptation solutions, so countries can learn what works and scale up what is most effective. But it is also needed to empower communities – those on the frontlines of climate change – in locally-led, locally-appropriate action.

Another major challenge is information and knowledge gaps. Accurate climate data is not easily available in many developing countries – localized risk assessments often do not exist – and systems for monitoring, learning and evaluation of adaptation are still fragmented. Without these pieces of the puzzle, it is difficult for governments, communities and the private sector to plan effectively and make sound decisions on where to invest.

Finally, institutional and governance constraints are a major issue. Challenges of coordination among sectors and levels of government, and lack of specialized knowledge and experience – for example in realizing climate-risk informed planning and investments – are hindering effective adaptation in many countries.

What is the Global Goal on Adaptation?

The Global Goal on Adaptation, often referred to as "GGA", is a key component of the Paris Agreement. It commits all 196 Parties of the Paris Agreement to enhancing resilience, reducing vulnerability, and supporting adaptation actions.

Its inclusion in the Paris Agreement was significant because it underscores the equal importance of adapting to climate change alongside efforts to reduce emissions. It also recognizes the vulnerability of developing countries to climate impacts and encourages support for their adaptation efforts.

At COP28 in Dubai, as part of the Global Stocktake, world leaders took decisions on the GGA, now named the "UAE Framework for Global Climate Resilience." Countries agreed to global time-bound targets around specific themes and sectors – for example in areas such as water and sanitation, food and agriculture, and poverty eradication and livelihoods – as well as under what's called the "adaptation cycle," a global framework guiding countries on the steps necessary to plan for and implement adaptation.

These were important steps forward, however there is still a lot of work to be done to accelerate adaptation globally. The targets set need to be more detailed and a clear roadmap for increasing finance towards adaptation needs to be drawn. This includes realizing the goal of doubling adaptation finance by 2025. Developed countries must deliver pledged contributions to the Green Climate Fund, Adaptation Fund, the Least Developed Countries Fund and Special Climate Change Fund to support the world's most vulnerable countries. At the same time, all governments must find new innovative sources of finance, including mobilizing the private sector, which has historically favoured mitigation initiatives.

What are National Adaptation Plans and why do they matter?

National Adaptation Plans (NAPs) are comprehensive medium and long-term strategies that outline how a nation will adapt to the changing climate and reduce its vulnerability to climate-related risks. Often, countries will focus their NAPs on key sectors that contribute to their economy, food security and natural resources.

NAPs are a way for countries to prioritize their adaptation efforts, integrating climate considerations into their national policies and development plans, and mobilizing the required finance by supporting the development of effective financing strategies and directing investments.

NAPs are also crucial because they enable countries to systematically assess their vulnerability to climate change, identify adaptation needs and design effective strategies to build resilience.

Notably, these plans link closely to Nationally Determined Contributions (NDCs) and other national and sectoral policies and programmes.

What are some examples of climate adaptation around the world?

There are a great number of countries leading the way in climate change adaptation, many of them showing outsized ambition and innovation, despite limited resources.

In the Pacific, the small island state of Tuvalu has drawn on the best available science – and around 270,000 cubic meters of sand – to reclaim a 780m-long, 100m-wide strip of land to protect against sea level rise and storm waves beyond 2100. This is an important initiative for a low-lying atoll country comprised of only around 26 square kilometres of land.

Other countries such as Malawi and Pakistan are modernizing the capture and use of climate data and early warning systems, equipping communities, farmers and policy makers with the information they need to protect lives and livelihoods.

Cuba and Colombia are leading the way on nature-based approaches, restoring crucial ecosystems – mangroves, wetlands and more – to protect against floods and drought. In this process, Colombia is capitalising on the knowledge of its Indigenous Peoples, who have invaluable expertise in adapting to extreme environmental changes.

Bhutan, the world's first carbon-negative country, and Chad are among the world's Least Developed Countries (LDCs) to finalize National Adaptation Plans. The result of years of meticulous planning and rigorous consultation, the plans are crucial roadmaps for adaptation in the years ahead. In Bhutan's case, the plan is deeply rooted in the country's unique ethos of Gross National Happiness.

How does UNDP support countries on climate change adaptation?

For UNDP, adapting to climate change is inseparable from sustainable development and each one of the 17 Sustainable Development Goals. Adaptation is therefore a key pillar of UNDP's support to developing countries worldwide.

Today, UNDP is the largest service provider in the UN system on climate change adaptation with active projects targeting more than 164 million people across more than 90 countries, including 13 Small Island Developing States and 44 Least Developed Countries.

Since 2002, with finance via global funds such as the Green Climate Fund, Global Environment Facility and Adaptation Fund, and hand-in-hand with governments, UNDP has completed more than 173 adaptation projects across 79 countries. This work has contributed to building the resilience of millions of people worldwide. For example, more than 3 million people are now covered by enhanced climate information and early warning systems, more than 645,000 people are benefitting from climate-smart agricultural practices, and 473,000 people have improved access to water.

Vulnerability assessment –IPCC Framework (AR5 &AR6)

IPCC fifth assessment report: climate change 2014 - impacts, adaptation, and vulnerability (IPCC WGII AR5)

Source

Intergovernmental Panel on Climate Change (IPCC)

This document presents the Working Group II (WGII) contribution to the IPCC Fifth Assessment Report (AR5). It details the impacts of climate change to date, the future risks from a changing climate, and the opportunities for effective action to reduce risks. A total of 309 coordinating lead authors, lead authors, and review editors, drawn from 70 countries, were selected to produce the report. They enlisted the help of 436 contributing authors, and a total of 1,729 expert and government reviewers.

The report concludes that responding to climate change involves making choices about risks in a changing world. The nature of the risks of climate change is increasingly clear, though climate change will also continue to produce surprises. The report identifies vulnerable people, industries, and ecosystems around the world. It finds that risk from a changing climate comes from vulnerability (lack of preparedness) and exposure (people or assets in harm's way) overlapping with hazards (triggering climate events or trends). Each of these three components can be a target for smart actions to decrease risk.

Download

- View full summary for policymakers English
- View report by chapters English

Document links last validated on: 18 December 2019

Editors' recommendations

- IPCC Report: A changing climate creates pervasive risks but opportunities exist for effective responses
- Special report on managing the risks of extreme events and disasters to advance climate change adaptation (SREX)
- More about words into action implementation guide for local disaster risk reduction and resilience strategies

The **Sixth Assessment Report** (**AR6**) of the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) is the sixth in a series of reports which assess the available scientific information on climate change. Three Working Groups (WGI, II, and III) covered the following topics: The Physical Science Basis (WGI); Impacts, Adaptation and Vulnerability (WGII); Mitigation of Climate Change (WGIII). Of these, the first study was published in 2021, the second report February 2022, and the third in April 2022. The final synthesis report was finished in March 2023. It includes a summary for policymakers and was the basis for the 2023 United Nations Climate Change Conference (COP28) in Dubai.[1]

The first of the three working groups published its report on 9 August 2021, *Climate Change 2021: The Physical Science Basis*.[2][3] A total of 234 scientists from 66 countries contributed to this first working group (WGI) report.[4][5] The authors[6] built on more than 14,000 scientific papers to produce a 3,949-page report, which was then approved by 195 governments.[7] The Summary for Policymakers (SPM) document was drafted by scientists and agreed to line-by-line by the 195 governments in the IPCC during the five days leading up to 6 August 2021.[6]

In the report, there are guidelines for both responses in the near term and in the long-term. According to the report, the main source of the increase in global warming is due to the increase in CO_2 emissions, stating that it is likely or very likely to exceed 1.5 °C under higher emission scenarios.[8]

According to the WGI report, it is only possible to avoid warming of 1.5 °C (2.7 °F) or 2.0 °C (3.6 °F) if massive and immediate cuts in greenhouse gas emissions are made.[2] *The Guardian* described the report as "its starkest warning yet" of "major inevitable and irreversible climate changes",[9] a theme echoed by many newspapers[10] as well as political leaders and activists around the world.

Production

See also: Intergovernmental Panel on Climate Change § Assessment reports

In April 2016, at the 43rd session which took place in Nairobi, Kenya, the topics for three Special Reports (SR) and one methodology report on Greenhouse Gases (GHG) inventories in the AR6 assessment cycle were decided.[11][12] These reports were completed in the interim phase since the finalisation of the Fifth Assessment Report and the publication of results from the Sixth Assessment Report.

Structure

The sixth assessment report is made up of the reports of three working groups (WG I, II, and III) and a synthesis report which concluded the assessment in early 2023.[13]

- *The Physical Science Basis of Climate Change* in August 2021[14][15] (WGI contribution)
- *Impacts, Adaptation and Vulnerability* in February 2022 (WGII contribution)
- *Mitigation of Climate Change* in April 2022 (WGIII contribution)
- *Synthesis Report* in March 2023[16]

Geopolitics

Geopolitics has been included in climate models for the first time, in the form of five Shared Socioeconomic Pathways: SSP1 "Taking the Green Road", SSP2 "Middle of the Road", SSP3 "A Rocky Road", SSP4 "A Road Divided", and SSP5 "Taking the Highway", which have been published in 2016.

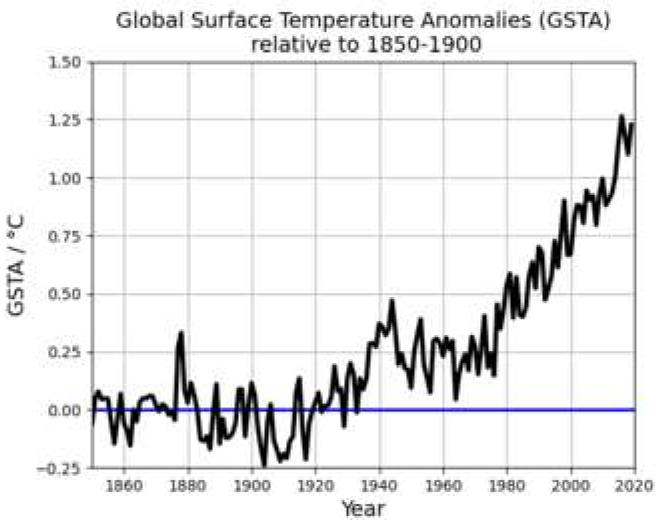
Those pathways assume that international cooperation and worldwide increase in GDP will facilitate adaptation to climate change. The geopolitical pathways served as one of the sources for the formation of the Shared Socioeconomic Pathways in the report among with other sources.[17]: 1–98ff One of the assumptions is that enough GDP and technology derived from fossil fuels development will permit to adapt even to 5.0 °C (9.0 °F) temperature rise. Some experts assume, that while the odds for a worst-case scenario (5 °C) and the best base-case (1.5 °C) today seem lower, the most plausible outcome is around 3.0 °C (5.4 °F).[18]

Special reports during same assessment cycle

Sequence of release dates of special IPCC reports during the same assessment cycle:

- *Special Report on Global Warming of 1.5 °C* (SR15) in October 2018
    - *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* in May 2019
- *Special Report on Climate Change and Land* (SRCCL) in August 2019
- *Special Report on the Ocean and Cryosphere in a Changing Climate* (SROCC) in September 2019

Working Group 1 report (physical science basis)



Variation of annual observed global average temperature (1850–2019) relative to the 1850–1900 average (blue line), as reported in the Summary for Policymakers (SPM)[19]

A total of 234 scientists from 66 countries contributed to the first of three working group reports.[4][5] Working group 1 (WGI) published *Climate Change 2021: The Physical Science Basis*.[2][3] The report's authors[6] built on more than 14,000 scientific papers to produce a 3,949-page report, which was then approved by 195 governments.[7] The Summary for Policymakers (SPM) document was drafted by scientists and agreed to line-by-line by the 195 governments in the IPCC during the five days leading up to 6 August 2021.[6] It was published on Monday, 9 August 2021.

According to the report, it is only possible to avoid warming of 1.5 °C or 2 °C if massive and immediate cuts in greenhouse gas emissions are made.[2] In a front-page story, *The Guardian* described the report as "its starkest warning yet" of "major inevitable and irreversible climate changes",[9] a theme echoed by many newspapers around the world.[10]

The Technical Summary (TS) provides a level of detail between the Summary for Policymakers (SPM) and the full report. In addition, an interactive atlas was made "for a flexible spatial and temporal analysis of both data-driven climate change information and assessment findings in the report".[20]

Important findings of WG 1 report

The Working Group 1 (WGI) report, *Climate Change 2021: The Physical Science Basis* comprises thirteen chapters and is focused on the foundational consensus of the climate science behind the causes and effects of human greenhouse gas emissions. Compared with previous assessments, the report included much more detail on the regional effects of climate change,[7] although more research is needed on climate change in eastern and central North America.[21] Sea-level rise by 2100 is likely to be from half to one metre, but two to five metres is not ruled out, as ice sheet instability processes are still poorly understood.[21]

The report quantifies climate sensitivity as between 2.5 °C (4.5 °F) and 4.0 °C (7.2 °F) for each doubling of carbon dioxide in the atmosphere,[7] while the best estimate is 3 °C.[22]:SPM-11 In all the represented Shared Socioeconomic Pathways the temperature reaches the 1.5 °C warming limit, at least for some period of time in the middle of the 21st century. However, Joeri Rogelj, director of the Grantham Institute and a lead IPCC author, said that it is possible to completely avoid warming of 1.5 °C, but to achieve that the world would need to cut emissions by 50% by the year 2030 and by 100% by the year 2050. If the world does not begin to drastically cut emissions by the time of the next report of the IPCC, then it will no longer be possible to prevent 1.5 °C of warming.[23] SSP1-1.9 is a new pathway with a rather low radiative forcing of 1.9 W/m[2] in 2100 to model how people could keep warming below the 1.5 °C threshold. But, even in this scenario, the global temperature peaks at 1.6 °C in the years 2041–2060 and declines after.[21]

Shared Socioeconomic Pathways in the IPCC Sixth Assessment Report [24]:14

- v
- t
- e

SSP	Scenario	Estimated warming (2041–2060)	Estimated warming (2081–2100)	Very likely range in °C (2081–2100)
SSP1-1.9	very low GHG emissions: CO_2 emissions cut to net zero around 2050	1.6 °C	1.4 °C	1.0 – 1.8
SSP1-2.6	low GHG emissions: CO_2 emissions cut to net zero around 2075	1.7 °C	1.8 °C	1.3 – 2.4
SSP2-4.5	intermediate GHG emissions: CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2.0 °C	2.7 °C	2.1 – 3.5
SSP3-7.0	high GHG emissions: CO_2 emissions double by 2100	2.1 °C	3.6 °C	2.8 – 4.6
SSP5-8.5	very high GHG emissions: CO_2 emissions triple by 2075	2.4 °C	4.4 °C	3.3 – 5.7

The IPCC Sixth report did not estimate the likelihoods of the scenarios[24]:12 but a 2020 commentary described SSP5–8.5 as highly unlikely, SSP3–7.0 as unlikely, and SSP2–4.5 as likely.[25]

However, a report citing the above commentary shows that RCP8.5 is the best match to the cumulative emissions from 2005 to 2020. [26]

According to AR6 coauthors, the probable temperature rise is in the middle of the scenario spectrum that ranges from 1.5 °C to 5 °C, at about 3 °C at the end of the century.[18] It is likely that 1.5 °C will be reached before 2040.[21] The threats from compound impacts are rated higher than in previous IPCC reports.[21] The famous hockey stick graph has been extended.[21]

Extreme weather is expected to increase in line with temperature, and compound effects (such as heat and drought together) may impact more on society.[21] The report includes a major change from previous IPCC in the ability of scientists to attribute specific extreme weather events.[27]

The global carbon budget to keep below 1.5 °C is estimated at 500 billion more tonnes of greenhouse gas, which would need the whole world to be net zero before 2050.[6] Staying within this budget, if counting from the beginning of the year 2020, gives a 50% chance to stay below 1.5 °C. For having a 67% chance, the budget is 400 billion tonnes and for an 83% chance it is 300 billion tonnes.[22]:SPM-29f The report says that rapidly reducing methane emissions is very important, to make short-term gains to buy time for carbon dioxide emission cuts to take effect.[6]

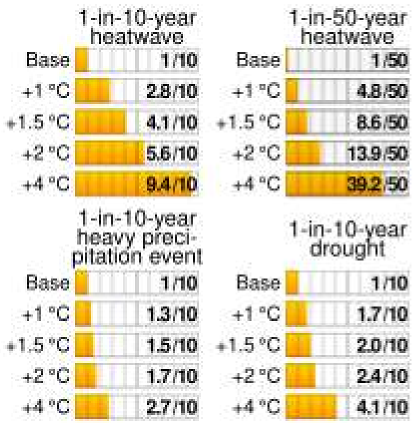
Any future warming will increase the occurrence of extreme weather events. Even in a 1.5 °C temperature rise there will be "an increasing occurrence of some extreme events unprecedented in the observational record". The likelihood of more rare events increases more.[22]:SPM-15

The frequency, and the intensity of such events will considerably increase with warming, as described in the following table:[22]:SPM-18

Increase in frequency and intensity of extreme events with global warming

Name of event	Climate in 1850–1900	1 °C warming	1.5 °C warming	2 °C warming	4 °C warming
1 in 10 years heatwave	Normal	2.8 times more often, 1.2 °C hotter	4.1 times more often, 1.9 °C hotter	5.6 times more often, 2.6 °C hotter	9.4 times more often, 5.1 °C hotter
1 in 50 years heatwave	Normal	4.8 times more often, 1.2 °C hotter	8.6 times more often, 2.0 °C hotter	13.9 times more often, 2.7 °C hotter	39.2 times more often, 5.3 °C hotter

1 in 10 years heavy precipitation event	Normal	1.3 times more often, 6.7% wetter	1.5 times more often, 10.5% wetter	1.7 times more often, 14.0% wetter	2.7 times more often, 30.2% wetter
1 in 10 years drought	Normal	1.7 times more often, 0.3 sd drier	2.0 times more often, 0.5 sd drier	2.4 times more often, 0.6 sd drier	4.1 times more often, 1.0 sd drier



Increase in frequency of extreme events with global warming in the Sixth Assessment Report's Summary for Policymakers[28]

Working Group 2 report (impacts, adaptation and vulnerability)

The second part of the report, a contribution of working group II (WGII), was published on 28 February 2022. Entitled *Climate Change 2022: Impacts, Adaptation & Vulnerability*, the full report is 3675 pages, plus a 37-page summary for policymakers.[29] It contains information on the impacts of climate change on nature and human activity.[30] Topics examined included biodiversity loss, migration, risks to urban and rural activities, human health, food security, water scarcity, and energy. It also assesses ways to address these risks and highlights how climate resilient development can be part of a larger shift towards sustainability.[31]

The report was published during the first week of the 2022 Russian invasion of Ukraine.[32] In the context of the conflict, the Ukrainian delegation connected the Russian aggression to the global dependency on oil, and a Russian official, Oleg Anisimov, apologized for the conflict despite the possible repercussions.[32][33] The Ukrainian delegation also called for news reporting on the war not to overshadow the WGII report.[34]

Important findings of WG 2 report

The report found that climate impacts are at the high end of previous estimates, with all parts of the world being affected.[30] At least 3.3 billion people,[34] about 40% of the world population, now fall into the most serious category of "highly vulnerable", with the worst effects in the developing world.[35] If emissions continue on their current path, Africa will lose 30% of its maize cultivation territory and 50% of its land cultivated for beans.[35] One billion people face flooding due to sea level rise.[34] Climate change, together with other factors, also increases the risk of infectious diseases outbreaks like the COVID-19 pandemic.[36] The report also cites evidence that China will pay the highest financial cost if the temperature continue to rise. The impacts will include food insecurity, water scarcity, flooding, especially in coastal areas where most of the population lives due to higher than average sea level rise, and more powerful cyclones. At some point part of the country may face wet-bulb temperatures higher than humans and other mammals can tolerate more than six hours.[37] Overall, the report identified 127 different negative impacts of climate change, some of them irreversible.[34]

People can protect themselves to some degree from the effects of climate change, which is known as adaptation. Overall, progress on adaptation has been made in all sectors and regions, although this progress is unevenly distributed and many initiatives prioritise immediate risks over longer-term transformational changes.[31] Still, there are feasible and effective adaptation options available and many adaption actions have benefits beyond reducing climate risks, including positive effects on the Sustainable Development Goals.[38]:Figure SPM.4 For example, the majority of current adaptations address water-related risks; adaptations like improved water management, water storage and irrigation reduce vulnerability and can also provide economic and ecological benefits.[38]:SPM.C.2.1 Similarly, adaptation actions like agroforestry, farm- and landscape diversification and urban agriculture can increase food availability, while at the same time improving sustainability.[38]:SPM.C.2.2

The report further highlighted the need for conservation in order to maintain biodiversity, and mitigate the effects of climate change. The report reads, "Recent analyses, drawing on a range of lines of evidence, suggest that maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems."[31] The report was critical of technological approaches to carbon dioxide removal, instead indicating that urbanisation could help drive adoption of mitigation strategies such as public transport and renewable energy.[35] The report also warns there are high risks associated with strategies such as solar radiation management; planting forests in unnatural locations; or "poorly implemented bioenergy, with or without carbon capture and storage".[38]:SPM-19, 20

In line with the emphasis on adaptation limits, the report also highlights loss and damage, meaning negative consequences of climate change that cannot be avoided through adaptation. The report states that such losses and damages are already widespread: droughts, floods and heatwaves are becoming more frequent, and a mass extinction is already underway.[30] Taking near-term actions to limit warming to below 1.5 °C would substantially reduce future losses and damages, but cannot eliminate them all.[31] Previously, rich countries have resisted taking responsibility for these losses.[35]

The report states that even a temporary overshoot of the 1.5 degree limit will lead to negative effects on humans and ecosystems. According to the report: "Depending on the magnitude and duration of overshoot, some impacts will cause release of additional greenhouse gases (medium confidence) and some will be irreversible, even if global warming is reduced (high confidence)".[38]:SPM-20 Climate resilient development will be more difficult if the global temperature will rise by 1.5 degrees above pre-industrial levels, while if it will rise by more than 2 degrees it will become impossible "in some regions and sub-regions".[38]:SPM-32,33,35

Although the report's outlook is bleak, its conclusion argues that there is still time to limit warming to 1.5 °C (2.7 °F) by drastic cuts to greenhouse gas emission, but such action must be taken immediately.[35] Moreover, climate resilient development can have both adaptation and mitigation benefits, but it requires international cooperation and collaborations with local communities and organisations.[38]:SPM-32,33,35

Working Group 3 report (mitigation of climate change)

The report was presented on 4 April 2022.[39] Some observers are worried that the conclusions might be watered down, considering the way the reports are adopted.[40] According to The Observer, some countries "have sought to make changes that would weaken the final warnings".[40]

Important findings of WG 3 report

The report uses some new approaches like to include different social aspects, the participation of youth, indigenous people, cities, businesses in the solution.[41]:SPM-2,3 It states that "International cooperation is a critical enabler for achieving ambitious climate change mitigation goals."[41]:SPM-62 For preventing global temperature from rising more than 2 degrees above the preindustrial level, international cooperation needs to be much stronger than now as many developing countries need support from other countries higher than present for strong climate action.[42]

According to the report demand side mitigation measures can reduce GHG emissions by 40–70% by the year 2050 compared to scenarios in which countries will fulfill its national pledges given before 2020. For being implemented successfully those measures should be linked "with improving basic wellbeing for all".[41]:SPM-44

The report concluded that in order to achieve net zero emissions, it is necessary to employ carbon dioxide removal technologies, stating "All global pathways that limit warming to 1.5 °C ... with no or limited overshoot, and those that limit warming to 2 °C... involve rapid and deep and in most cases immediate GHG emission reductions in all sectors. Modelled mitigation strategies to achieve these reductions include transitioning from fossil fuels without CCS to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demand side measures and improving efficiency, reducing non-CO_2 emissions, and deploying carbon dioxide removal (CDR) methods to counterbalance residual GHG emissions".[43][44] The report compares different methods of carbon dioxide removal (CDR) including agroforestry, reforestation, blue carbon management, restoration of peatland and others.[41]:SPM-47

Cities have great potential for reducing greenhouse gas emissions. With full scale mitigation action the emissions of cities could be brought down to near zero, with the worst-case scenario assuming a non-mitigatable remainder of 3 $GtCO_2$-eq. City planning, supporting mixed use of space, transit, walking, cycling and sharing vehicles can reduce urban emissions by 23–26%. Urban forests, lakes and other blue and green infrastructure can reduce emissions directly and indirectly (e.g. by reducing the energy demand for cooling).[45]

Buildings emitted 21% of global GHG emissions in the year 2019. 80–90% of their emissions can be cut while helping to achieve other Sustainable Development Goals. The report introduces a new scheme for reducing GHG emissions in buildings: SER = Sufficiency, Efficiency, Renewable. Sufficiency measures do not need very complex technology, energy supply, maintenance or replacement during the life of the building. Those include, natural ventilation, green roofs, white walls, mixed use of spaces, collective use of devices etc.[46] Reducing GHG emissions from buildings is linked to sharing economy and circular economy.[47]

The IPCC found that decent living standards could be achieved using less energy than prior consensus assumed. According to the report for reaching well being for all, the required energy consumption is "between 20 and 50 GJ cap-1 yr-1 depending on context." More equitable income distribution can lower emissions. Mitigation pathways based on low demand and high efficiency can achieve decent living standards and well being for all. Pathways based on reducing consumption, involving sustainable development have less negative outcomes than pathways based on high consumption and narrow mitigation. According to table TS30, narrow mitigation can increase habitat loss by 600%, while avoiding habitat degradation by around 95%. Mitigation with sustainable development did not harm forest cover and biodiversity.[48]

The report mentions some improvement in global climate action. For example, the rate of deforestation slowed after 2010 and the total forest cover increased in the latest years due to reforestation in Europe, Asia and North America.[49]

Reactions to all three working group reports

In science

The publication of the Working Group 1 report in 2021 was during the Northern Hemisphere summer, where there was much extreme weather, such as a Western North America heat wave, flooding in Europe, extreme rainfall in India and China, and wildfires in several countries.[4][50] Some scientists are describing these extreme weather events as clear gaps in the models used for writing the report, with the lived experience proving more severe than the consensus science.[50][51]

In politics

After publication of the Working Group 1 report, EU Vice President Frans Timmermans said that it is not too late to prevent runaway climate change.[52] UK Prime Minister Boris Johnson said that the next decade will be pivotal to the future of the planet.[53]

Rick Spinrad, administrator of the US's National Oceanic and Atmospheric Administration, stated that his agency "will use the new insights from this IPCC report to inform the work it does with communities to prepare for, respond to, and adapt to climate change".[54]

The United States special presidential envoy for climate, John Kerry, said about the Working Group 2 report: "We have seen the increase in climate-fuelled extreme events, and the damage that is left behind – lives lost and livelihoods ruined. The question at this point is not whether we can altogether avoid the crisis – it is whether we can avoid the worst consequences."[30]

NGOs and activists

Swedish climate activist Greta Thunberg said that the Working Group 1 report "confirms what we already know from thousands [of] previous studies and reports – that we are in an emergency".[55]

Environmentalist Inger Andersen commented: "Nature can be our saviour ... but only if we save it first."[35]

In media

In a front-page story, dedicated to the report *The Guardian* described the Working Group 1 report as the "starkest warning yet" of "major inevitable and irreversible climate changes".[9][56] This message was echoed by many media channels after the release of the report.[10]

The Working Group 3 report found that there is no evidence that sustainable development requires fossil fuels.[57] Climate journalist Amy Westervelt reacting to the report, described this finding as one of the most radical, debunking a common refrain by energy poverty advocates, that development requires use of fossil fuels.[57]

From the United Nations

The Secretary-General of the UN, António Guterres, called the report of Working Group 1 a "code red for humanity".[58] Responding to the Working Group 2 report, he called it "an atlas of human suffering and a damning indictment of failed climate leadership"[30] and "the facts are undeniable ... the world's biggest polluters are guilty of arson of our only home."[59] He also said that the report of Working Group 3 described "litany of broken climate promises [by policy makers]" and in his remarks called for more action, saying "Climate activists are sometimes depicted as dangerous radicals. But, the truly dangerous radicals are the countries that are increasing the production of fossil fuels."[60]

Synthesis report for all three working group reports

The synthesis report which summarises the entire document was finalised at the 58th plenary meeting of the panel at Interlaken in March 2023 and was published on 20 March 2023. It includes a summary for policymakers and was the basis for the 2023 United Nations Climate Change Conference (COP28) in Dubai.[1]

In the report, there are guidelines for both responses in the near term and in the long-term. According to the report, the main source of the increase in global warming is due to the increase in CO_2 emissions, stating that it is likely or very likely to exceed 1.5 °C under higher emission scenarios.[8]

The panel published a longer report,[61] a summary for policymakers[62] a presentation[63] and a short "Headline Statements" document.[64] Some key example *headline statements* include:

- "Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals."
- "Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5°C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards (*high confidence*). Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years (*high confidence*)."
- "Climate change is a threat to human well-being and planetary health (*very high confidence*). There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (*very high confidence*)."

Society and culture

Leaks

During the preparation of the three main AR6 reports, a small group of scientists leaked some information on the results of Working Group III (Mitigation of Climate Change) through the organization Scientist Rebellion. As governments can change the summaries for policymakers (SPM) for IPCC reports, the scientists were afraid that politicians might dilute this information in the summary. According to the leaked information, humanity should cut GHG emissions by 50% by 2030 and completely by 2050 in order to limit warming to 1.5 °C (2.7 °F). These efforts require strong changes in lifestyle and economy.[65][56]

Lack of participation from Global South scholars

Like other major international scientific processes, the IPCC has been accused of not sufficiently including scholars from the Global South. For example, some aspects of the production can prevent African scholars from participating, such as publication requirements and being an expert reviewer before joining the panel of contributors.[66]

Choices for climate action: A review of the multiple roles individuals play

Author links open overlay panelSam Hampton [1] [2], Lorraine Whitmarsh [1]
Show more

https://doi.org/10.1016/j.oneear.2023.08.006Get rights and content

Summary

Tackling climate change requires significant behavior change to reduce emissions, yet the scale required is far from being achieved. Behaviors are influenced by psychological characteristics, social and cultural norms, material and spatial environments, and political conventions. Much social scientific debate continues to be characterized by calls for *either* individual *or* system change, but a more cross-cutting perspective to understand various factors that can enable and accelerate pro-environmental choices is needed. This review provides an interdisciplinary synthesis of evidence on the potential and limitations of individual choice to mitigate climate change. We identify six domains of individual choice for climate action (food, energy, transport, shopping, influence, and citizenship). We find that individual, social, physical, and political factors combine to shape low-carbon choices but in ways specific to each domain, demanding different responses from policy-makers. Effective climate action requires a mix of interventions which address the multiple roles played by individuals: structural change by governments ("upstream" interventions), businesses and local authorities making sustainable options more available and attractive ("midstream"), and informational measures to shape individuals' decision-making ("downstream").

Introduction

Aiming to limit global temperature rise to less than 2°C, the European Union, United Kingdom, and United States have committed to achieving net-zero emissions by 2050, while China is aiming for 2060. Meeting these ambitious targets will require changes to everyday practices and lifestyles, including reducing flying and driving, decreasing red meat and dairy products in diets, and adopting low-carbon technologies. While there is an increase in some pro-environmental behaviors (e.g., recycling) in many countries, most of the behavior changes required are not yet happening.[1] Those with the largest carbon footprints will need to make the most substantial behavioral changes, and the distribution of individual impacts is highly uneven.[2] Besides changes to *consumption* behaviors, individuals can take climate action to indirectly cut emissions through activities such as influencing others, making professional choices, voting, or protesting.[3]

The choices made by individuals will have a critical bearing on global efforts to address climate change. However, individual choices are influenced by a wide range of factors, and many everyday behaviors are subject to habit, rather than deliberative choice.[4] Our behaviors are influenced by psychological characteristics, social and cultural norms, material and spatial environments, and political conventions. The ways in which these factors combine create conditions that either *constrain* or *enable* the translation of individual choices into sustained low-carbon lifestyles and routines.

There is a substantial and growing body of work on the behaviors and choices needed to deliver radical carbon emissions.[5] Some of this work has been subject to critique, however, for its apparent tendency to over-emphasize the need for individual behavior change without adequately acknowledging or addressing those structures and systems that embed the consumption of fossil fuels into everyday life, constrain individual agency, and create barriers to low-carbon lifestyles.[6] Such debates reflect the philosophical tussle between structure and agency, which is as old as social science itself.[7,8] But there is a danger that academic exchanges create theoretical and methodological schisms that can serve to confuse and even deter those outside social scientific niches, such as policy-makers.[9] In the absence of a comprehensive understanding of what can influence pro-environmental choices, and in light of the escalating climate emergency, there is a need for more philosophically agnostic approaches that synthesize evidence across the social sciences on the potential for, and limits to, behavior change to mitigate climate change.

In this review, we address this need by gathering and presenting a wide range of evidence in a coherent and accessible way for audiences within and outside of the academic social sciences. It draws on evidence spanning psychology, sociology, geography, and interdisciplinary climate research, but does not follow a systematic review methodology. Instead, our aim was to construct an account of the full breadth of climate choices using illustrative examples that help the reader to navigate a complex and expanding body of research. Reflecting the evidence base, these are somewhat skewed toward Europe and North America, but where possible we include examples from elsewhere. We first identify six major "domains" of choice. Four of these represent the key sources of individual and household greenhouse gas (GHG) emissions: energy, transportation, diet, and the consumption of other goods and services (termed "shopping" as shorthand). The other two domains concern those sets of choices that have important, but indirect, impacts on climate mitigation: the ability to influence others as a family member, social agent, and organizational participant; and civic activities, such as voting. We further map out combinations of psychological, socio-cultural, material, and political factors that can help to foster low-carbon choices, and also those in which incumbent structures create barriers to individuals seeking sustainable lifestyles. In order to enable and accelerate more sustainable choices, a mix of upstream (e.g., structural), midstream (e.g., choice environment), and downstream (e.g., informational) interventions are required. This review contributes new heuristic frameworks to explain the scope, potential, and limitations of individual choice for climate action.

Choosing climate: Understanding the potential of choice

In recent years there has been much debate over who should bear responsibility for climate change. Since the advent of ecological footprint, there has been substantial effort to quantify the climate impacts of different entities, including corporations,[10] territories,[11] households,[12] and individuals.[13] Around two-thirds of GHG emissions can be linked to household consumption, amounting to a global average of around 6 tonnes of carbon dioxide equivalent per person.[14] In advanced liberal economies, climate policy has hitherto been focused on maximizing opportunities for emissions reductions that have minimal impact on individuals. The UK government for instance, boasts of a 47.3% reduction in emissions since 1990,[15] thanks to the widespread deployment of renewable electricity generation and the improved efficiency of appliances and vehicles. However, its statutory advisors on climate policy, the Climate Change Committee, have highlighted the need for substantially greater social engagement on emissions reduction if climate targets are to be met.[16]

For individuals, the major activities that generate emissions involve transport and mobility; the use of energy in the home for space heating, hot water, and running appliances; food and diets; and the consumption of goods and services. Reviewing studies that quantify the mitigation potential of pro-environmental behaviors, Ivanova and colleagues compiled evidence across each of these activity domains.[14] Their findings show that there is considerable heterogeneity in the reduction potential of behaviors across contexts. For transport choices, they find that the greatest potential for emissions reductions is from living car-free, shifting to battery electric vehicles, taking one less long-haul flight, and shifting to public transport. The most impactful energy-related decisions include installing renewable electricity generation, renovating homes to be more energy efficient, and switching to a heat pump or other renewable heating system. Food-related choices include reducing meat consumption (especially adopting a vegan diet) and improving the efficiency of cooking equipment. Other pro-climate consumption choices include not having pets and buying services from the sharing economy.

A plethora of tools have been created to help individuals estimate their own carbon footprints, sponsored by governments,[17,18] global charities,[19] and corporations.[20] These are intended to enable individuals to learn about the impacts of their own behaviors, the unequal distribution of footprints within and between countries,[2] and help make more informed, sustainable choices. Certainly, there is evidence that individuals' knowledge and awareness of their contribution to climate change is limited,[21] that they tend to overestimate the contribution of waste behaviors (e.g., recycling), and underestimate the contribution of diet and air travel.[22] Although research has consistently found weak causal links between the provision of information about climate impacts and more sustainable consumption choices,[5,23] the *way* in which information is delivered (content, timing, context, type of messenger) is crucial.[24] Moreover, there are multiple forms of knowledge (e.g., action-related, effectiveness knowledge[25]) that play a part in shaping environmental behaviors, besides scientific knowledge about the impacts of certain activities.

The rationale for creating tools to raise awareness among individuals has been subject to further criticism on the basis that by placing the onus on individuals, attention is deflected from the principal culprits of climate change. The Carbon Disclosure Project attributes responsibility for 70% of global GHG emissions to just 100 companies,[26] while a widely read blog article from 2020 criticizes the concept of the carbon footprint, declaring it a "sham … intended to manipulate your thinking about one of the greatest environmental threats of our time."[27] Clearly, the role of individual action on climate is subject to disagreement, and as global GHG emissions continue to rise, the degree to which individuals should take responsibility for climate action has become a mainstream debate.

A further criticism of emissions calculators is that individuals are reduced to their role as *consumers*. Carbon footprints typically quantify the emissions associated with the consumption of energy, transport fuel, food, and other goods, providing users with an estimate of their personal impact alongside tips for making lower-carbon choices and appeals such as "it's time to go on a low-carbon diet."[27] But individuals are much more than consumers. They are also family and community members, workers and professionals, and citizens and voters.[3] Several academic researchers have sought to build the case for greater public discourse on the topic of climate change, not just in politics and the media, but in everyday conversations at home and among social networks.[28,29] Climate scientist Katherine Hayhoe's TED talk titled "The most important thing you can due to fight climate change: talk about it," has been viewed over 4 million times, while the popular movie *Don't Look Up* was released alongside guidance for individual action spanning multiple roles.[30]

Individuals can also help to address climate change as citizens: voting, protesting, and lobbying for change. Some climate scientists are leading by example by taking direct action.[31] Whereas the link between knowledge of climate change and sustainable consumption choices is weak, evidence from Germany indicates that increased environmental awareness *has* translated into strong pressure on political actors, as a result of changed voter behavior.[32] Considering the activities of individuals in roles other than as consumers helps to shift the focus beyond the comparatively narrow framing of choice and agency that is encouraged by a focus on individual carbon footprints.[33] Whereas an emphasis on personal impacts can engender feelings of guilt and powerlessness,[34] focusing on *influence* and *climate citizenship* can foster more constructive, empowering associations with climate change. Figure 1 represents the six major domains of individual choice for climate action and identifies some of the most impactful behaviors.

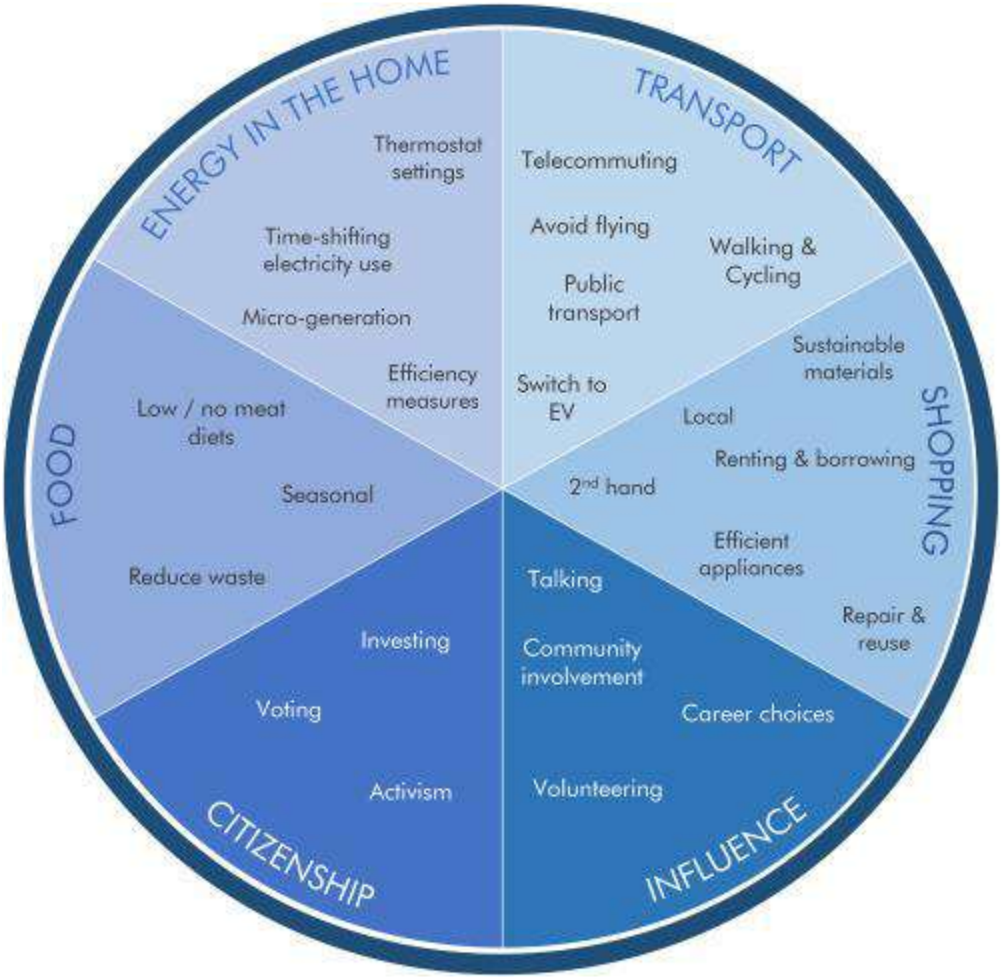


Figure 1. The six domains of choice for climate action

Food, energy, transport, and shopping represent direct emissions-related choices and constitute the majority of individual carbon footprints. Influence and citizenship are important, indirect domains of choice that have a bearing on climate change. Examples of key choices within each are represented.

Influences on individual choice capabilities

Human behavior is subject to a variety of influences, and a plethora of theoretical frameworks have been developed to understand how behaviors and habits become established, entrenched, changed, and discontinued.[35,36,37,38] These models tend to distinguish between intrinsic (values, personality traits, and abilities) and extrinsic (norms, meanings, and material and political structures) influences, and conventionally, psychologists have focused their efforts on understanding the former category.[5] Understanding the distribution and strength of these influences is crucial for those seeking to encourage pro-environmental behavior change. However, empirical and theoretical research has shown that the distinction between intrinsic and extrinsic influences is often blurred. For instance, we know that family dynamics[39,40] and wealth[41] are important predictors of an individual's environmental behaviors, but neither can easily be categorized as either internal or external factors. Alongside the emergence of environmental psychology as a discipline in its own right, there have been calls to move beyond the simple distinction between individual (intrinsic) and structural (extrinsic) factors, to distinguish different types of influence.[5,42]

Several more integrative, interdisciplinary frameworks have been created, but none have been widely adopted in either climate research or policy-making. Notable examples include the concept of carbon capability,[33] the individual-social-material (ISM) framework,[43] and the capability, opportunity, motivation-behavior model (COM-B).[44] Each approach balances individual and structural influences and combines these with an appreciation of their context and inter-connectedness. Inspired by these models, Figure 2 identifies four main sources of influence and provides examples of factors that typically enable, or place constraints on, individual choice.

Influences on climate choice capabilities		Examples of choice enablers	Common constraints on individual agency	Indicative references
Individual	Psychological	Pro-environmental values; personality traits; digital skills	Resistance to change, perceived lack of agency	Brick & Lewis, 2016[45] Marshall et al. 2019[46]
	Demographic	Education; member of socially advantaged groups (younger, ethnic majority, male, heterosexual)	Disability; member of disadvantaged groups (ethnic minority, female, sexuality)	Wisner, 2010[47] Latter, 2022[48] Lovelock 2010[49]
Social	Cultural	Low-carbon norms; social pressure to decarbonise; positive role models; aspirational environmentalism	High-consumption norms; consumption-linked identity; negative images of environmentalism	Whitmarsh et al. 2017[50] Nielsen et al. 2021[1]
	Social capital	Prevalence of community organisations; strength of social networks	Community deprivation; loneliness	Jones & Clark 2014[51] Sharp et al. 2011[52]
Physical	Material	Income and wealth; asset ownership; availability of green products	Renting housing; poor infrastructure; poverty; limited consumer choices	Huebner et al. 2015[53] McKenna et al. 2022[54]
	Spatial	Access to infrastructure (active transport, electrical grid); renewable potential (sunny/windy)	Isolation; limited infrastructure; planning constraints (heritage buildings); extreme weather	Gill & Moeller 2018[55] Goldthau et al. 2020[56]
Political	Governance & Democracy	Locally devolved powers; multiple channels for engagement; citizens assemblies; right to protest; freedom of press, transparency; subsidies available	Excessively bureaucratic, technocratic, or autocratic systems; lack of transparency and accountability	Niemeyer, 2013[57] Fiorino, 2018[58] Climate Assembly UK, 2020[59]

1. Download: Download high-res image (1MB)
2. Download: Download full-size image

Figure 2. Influences to enable and constrain climate choices can be divided into individual, social, physical, and political categories

Examples of choice enablers and common constraints are provided alongside indicative references.[45,46,47,48,49,50,51,52,53,54,55,56,57,58,59]

These diverse sources of influence do not work in isolation, and when combined they have uneven effects on individuals and their behavior. For instance, the uptake of urban cycling is predicted by age and gender,[60] but is also strongly influenced by the availability of (physical) low-carbon transport infrastructure, which is in turn moderated by economic and political factors. How these influences combine also has different effects with respect to the six domains of climate choice. The remainder of this section highlights the complex interplay of influences on individual choice, drawing on systematic reviews and meta-analyses where available, and providing illustrative examples from different geographical and behavioral contexts.

Food and diet choices

Compared with other domains, food and diet choices are relatively frequent and situational and are highly mediated by social, cultural, and health-related norms.[61] Individual choices are said to bear relatively low behavioral costs and few long-term consequences for the decision-maker (although their cumulative effects are significant).[62] Economic, spatial, and political factors influence the options available for dietary choices, such as the availability, range, and price of plant-based foods.[63,64,65] However, several systematic reviews and other assessments of food choice determinants conclude that individual and social factors are the strongest predictors of behavior.[66,67,68,69] Despite the relative degree of agency in this domain, individuals are known to be resistant to changing their diets, and various psychological barriers have been identified that help to explain this. These include lack of knowledge (or outright denial) of evidence linking foodstuffs to GHG emissions, as well as conflicting priorities or limited resources (financial, time).[70]

Diets are strongly influenced by social and cultural norms and traditions.[67,69] Meat consumption is significantly influenced by gender,[71] and at least in some cultures is associated with masculinity, while vegetarianism connotes femininity and weakness.[72] Internationally, the number of people following a vegetarian diet varies widely. India has the highest proportion (22%) and absolute population of vegetarians, while Serbia, Hungary, and Russia are the top three meat-eating countries.[73] Practical barriers can compound socio-cultural norms: where vegetarianism is rare, it can be difficult to find sufficient meat-free options in cafés and restaurants. Skill and know-how are also important prerequisites for more climate-friendly food practices. Cooking varied, tasty vegetarian meals can demand new skillsets among people living in cultures where meat dishes are more traditional, while flexibility and creativity are needed to minimize household food waste.[74]

Influences on transport and mobility choices

A meta-analysis of psychological and behavioral determinants of transport choices found the strongest predictors to be intentions, habits, and past experiences.[75] However, material and spatial factors such as the cost and availability of public transport and electric vehicles (EVs), active travel infrastructure, and urban density and design set the context and boundaries for individual choice. The decision to adopt an EV is simply not available to many low-income households with little access to charging infrastructure.[76,77] Flying is strongly correlated with income.[78] A systematic review-of-reviews found that individual, social, and infrastructural factors unambiguously influence mode-choice, but that urban form explains the most variation in transport behaviors.[79] Supporting this observation, international evidence has consistently shown that the biggest barrier to individuals choosing to walk or cycle more is the perception of safety.[80,81,82] The provision of safe, segregated infrastructure is the most significant predictor of active travel in urban areas across the United States.[83]

Although physical factors dominate, social and cultural influences also impact low-carbon travel behaviors. The uptake of cycling is lower among women and ethnic minorities,[84] while in some countries such as the United States, the use of public transport such as urban buses can be stigmatized.[85] Urban planning and design for active travel is often politically contentious. For instance, in response to climate change, many urban municipalities in the United Kingdom have introduced low-traffic neighborhoods and other controls on car access, with unforeseen controversy and even reports of violence among residents.[86] The reallocation of road space became a key political issue for local elections in the United Kingdom in 2022, and polling in London found that support and opposition was split according to political opinion.[86]

Energy consumption in the home

Domestic energy use is most strongly predicted by building characteristics such as fabric efficiency, dwelling area, and heating system type.[53,87] Socio-demographic factors including number of occupants, age, and income have also been found to predict annual consumption,[87,88] although the strength of these variables is inconsistent across studies.[89] Nonetheless, individual choices *can* have a significant impact on domestic energy usage, and a large-scale study from the United Kingdom demonstrated that everyday conservation behaviors such as setting lower set-point temperatures, using warm clothes in cold weather, and switching off lights significantly predicted gas and electricity consumption.[54] Psychological factors are influential, particularly with respect to action-related and effectiveness knowledge.[25] Householders struggle to estimate their overall energy use[90] and to identify the greatest opportunities for conservation,[91] while many (particularly older people) find heating controls confusing and difficult to use.[92]

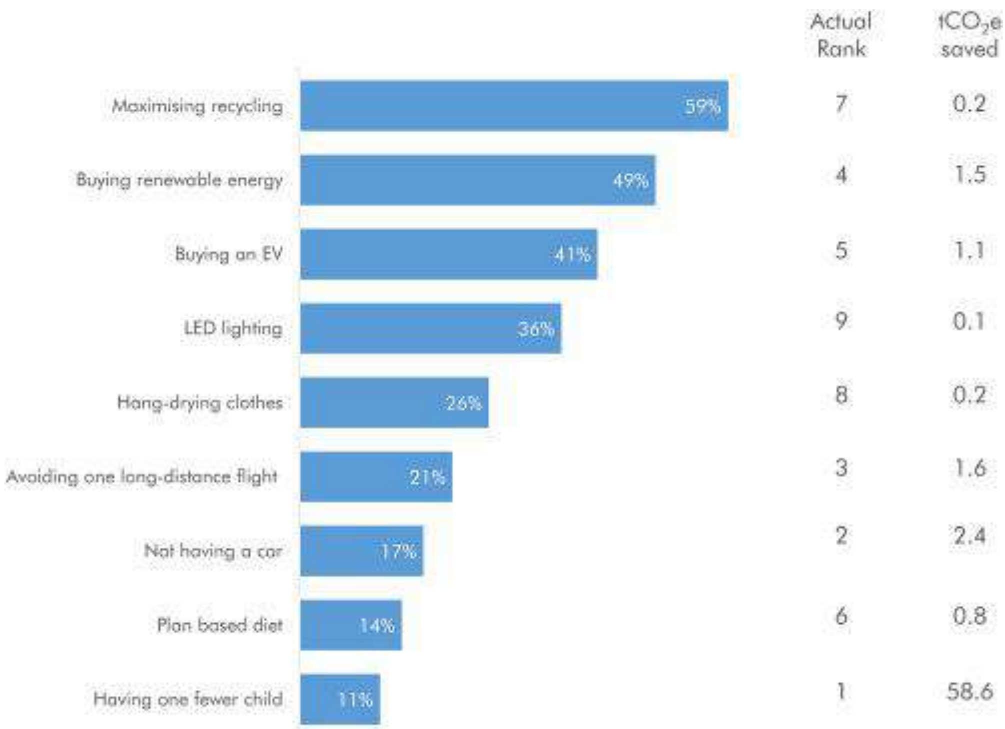
Given the significance of building characteristics, non-habitual choices have an important influence on emissions. These include the installation of efficiency measures such as insulation and glazing, as well as investments in rooftop solar arrays and low-carbon heating systems (e.g., heat pumps). Here, household income and tenure are key variables. Income and home ownership correspond with higher energy use; however, access to capital also boosts a household's capability to invest in one-off, impactful measures.[89] In rented properties, landlords lack the incentive to invest in efficiency or renewable technologies, as it is tenants who typically pay energy bills. Tenants are reluctant to invest in property upgrades or may be contractually prevented from doing so. This "split-incentive" problem limits energy-related choice capabilities for millions of householders,[93] especially in countries where home ownership is relatively low, such as Germany[94] and Japan.[95]

Consumption of goods and services

Non-food consumption involves myriad behaviors that range from buying clothes, pets, and household goods, to services such as education. As such, there are no systematic evidence reviews spanning all consumption or shopping behaviors. While income is the strongest predictor of overall consumption, reviews of sustainable consumption find that social and individual factors are significant influences. Predictors of shopping behaviors depend on the products and services in question.[14] For instance, a systematic review of sustainable fashion consumption found social norms, knowledge, and values to be key drivers,[96] while adoption of "sharing economy" activities are predicted by perceptions of control, injunctive norms (perceptions of peer-approval), platform trustworthiness, and risk.[97,98]

Social and economic context is important too. A representative survey of individuals in the United Kingdom and Brazil in 2019 asked respondents a series of questions about buying habits.[50] Environmental concern was found to be higher in Brazil than in the United Kingdom, and individuals there were more likely to avoid buying new things and buy items with less packaging. However, these social norms are influenced in turn by material and economic factors: in Brazil, items with less packaging are often cheaper, whereas this is not the case in the United Kingdom.

The carbon impacts of shopping behaviors can hinder climate-conscious choices. Emissions "embodied" in goods and services are less visible to consumers than those associated with driving fossil fueled vehicles, for example, and carbon labeling on products is not widespread. This is one reason why awareness of the carbon emissions associated with consumption behaviors is relatively low. In fact, the most popular and best supported pro-environmental behaviors tend to have limited potential for emissions reductions.[1,33] Figure 3 shows results from a global survey demonstrating a mismatch between what individuals perceive to be the most effective choices for reducing emissions and actual impacts.



1. Download: Download high-res image (180KB)
2. Download: Download full-size image

Figure 3. Choices for climate: Perception vs. reality

Survey participants were asked "From this list of options, which three do you think would most reduce the greenhouse gas emissions of an individual living in one of the world's richer countries?" Respondents tend to overestimate the significance of recycling. Source: Ipsos, 2021, n = 21,011.[1]

Influencing others

In one conceptual model of "carbon capability," the ability to influence others is posited as the pinnacle activity for individuals seeking to take climate action.[99] The ability of individuals to influence others on climate change varies according to the different roles and capacities they play in different contexts, although evidence on what predicts their capacity to influence others is limited. In personal relationships (e.g., friends, family), personality traits are likely to be important, and we know that openness, conscientiousness, and extraversion predict pro-environmental attitudes and behaviors.[45,100] In a professional context, some individuals (e.g., in customer-facing, communications, human-resources, or leadership roles) can leverage greater influence over others than those in other roles.[3,101,102] In this context, personality traits can again be important: conscientiousness and agreeableness are significant predictors of ethical leadership behaviors, for instance.[103] However, the presence of human and social capital,[104,105] organizational norms and values,[106] and the strength of network ties[107] all influence the ability of leaders to effect change.

Katherine Hayhoe[29] and others[28] have argued, when it comes to influencing others on climate, talking to people within and beyond one's immediate social circles is important. In the United States, those with higher risk perceptions and knowledge of global warming are more likely to talk with family and friends about climate change.[108] Holding climate conversations appears to be one of the more straightforward choices an individual might make. But social discourse is mediated by politics, norms, and complex, context-specific interpersonal dynamics. For instance, climate change is becoming increasingly polarized in many countries[109,110] and on social media,[111] and many commentators have expressed concern that climate change is being dragged into so called "culture wars" that are characterized by divergent views along social, political, and demographic lines.[112,113]

Climate citizenship

Like the ability to influence others, the willingness to take part in civic activity such as voting, direct action, and investing money in environmentally sustainable funds and pensions is influenced to a great extent by individual factors. Individuals who attach personal meaning to social and political events or who exhibit high openness traits are more likely to engage in political activism,[114,115,116] while participation in *Fridays for Future* climate strikes among Swiss students was predicted by low trust in governments, high trust in climate scientists, and faith in the success of protest for achieving change.[117,118] General voting behavior is linked with personality characteristics and socio-demographic variables, although studies from the United Kingdom,[119] Nigeria,[120] and across the EU[121] highlight how the weight of these vary in different contexts. More specific to climate citizenship, support for climate policies in the United States is unsurprisingly predicted by beliefs and attitudes toward global warming, but Republican voters who support climate action are more influenced by injunctive norms and risk perceptions than Democrats.[122] In the United Kingdom, women are slightly more supportive of net-zero policies than men; older age groups have higher support for transport and consumption policies such as low-traffic neighborhoods, frequent flyer levies, and carbon taxes, while younger age groups favor policies that encourage EV uptake and dietary change.[123] It is often asserted that motivated reasoning (biased information processing in accordance with prevailing beliefs) lies behind attitudes to climate change and policy support, even among individuals with high levels of scientific knowledge.[124,125] However, other studies have argued that the evidence for motivated reasoning is relatively weak,[126,127] and there is a need for further empirical research to inform interventions to address polarization.[128]

There is a tendency in research that models socio-technical pathways to a more sustainable future, to emphasize the need for community-led activity at the local level, highlighting the multiple benefits associated with climate-oriented transitions.[129,130,131] Examples include community ownership of renewable energy assets, car sharing, local farming cooperatives, and peer-to-peer energy trading.[132] Each of these relies on abundant social capital, which is a product of multifaceted economic, social, and political variables.[133]

Last, political regimes and governance arrangements have a direct bearing on an individual's potential to be a good climate citizen. Autocratic regimes often prevent voting and place severe restrictions on protest, while the ability of individuals to contribute to political and policy-making processes varies significantly across democracies. In many liberal democracies, there has been an increase in climate activism in recent years. High-profile examples of direct action such as transport disruption[134] and protests in art galleries[135] have helped to keep climate change prominent in news media and public discourse. However, freedom to protest in many countries remains highly limited and in the United Kingdom, the 2022 Police, Crime, Sentencing, and Courts Act increased police powers to break-up and prevent protests, largely in response to climate activism. Nonetheless, even in authoritarian regimes, activism can influence politics and policy,[136] as demonstrated by the easing of COVID-19 restrictions in China following protests in late 2022.[137]

Closing the gap: Enabling choices for climate action

To achieve net-zero emissions, there is a need for transformation in each of the six domains of climate-related activity. This section outlines the type and scale of change needed to enable individuals to make choices for climate action. We identify areas of everyday life where attitudes, motivations, and social norms are becoming more environmentally oriented, and physical factors are increasingly enabling climate action. Domains of choice where high-emissions behaviors remain entrenched and resistant to change are also highlighted.

Food and diet choices

As they are, Western diets are not compatible with a stable climate. It has been estimated that the food-related emissions of those consuming Western diets could be reduced by up to 40% through individual choices such as reducing meat consumption and reducing food waste.[138] Neither are they healthy: in the United Kingdom, individuals eat more than twice the amount of meat considered safe.[139] However, recent polling there found strong support for substituting red for white meat, and reducing overall meat consumption and food waste.[140] Given the influence of individual and social factors on dietary behaviors, a key challenge is to shift the social and psychological norms that embed food choices into everyday life.

There is a growing body of research focused on how to encourage more climate-friendly food choices.[141] Two independent meta-analyses have found choice architecture interventions (or "nudges") have significant effects in the food domain,[62,142] although approaches are context specific. For instance in restaurant settings, effective social norm interventions include encouraging the use of "doggy bags"[143] for reducing food waste, and "dynamic norm" messages that indicate that other people are reducing meat in their diets can also help to promote more sustainable food choices.[144] On the other hand, a systematic review found mixed results for different interventions designed to reduce meat consumption,[145] and a trial of 59 interventions found that while information provision was effective at changing choices in *virtual* environments, this did not translate into *actual* diet behaviors.[146] Effect sizes are more robust when it comes to changing defaults such as reducing portion sizes[147] and serving vegetarian meals at catered events.[148] However, as a behavioral intervention, changing defaults risks consumer backlash, especially where there is insufficient trust, or where the choice-architect's motivations are unclear or unsupported.[149,150] Nonetheless, public acceptance of low-meat alternatives appears to be growing in many countries[151,152] and in different contexts: even Burger King is experimenting with changing its default menu options to plant-based burgers.[153]

One barrier to individuals making climate-conscious food choices is the lack of awareness relating to the carbon impacts of foodstuffs.[154,155] Carbon labeling for food items attracted significant interest from grocery retailers in the 2000s,[156] but progress has been limited by the difficulty of calculating supply chain emissions.[157] The idea is once again gaining traction,[158] helped by the digitalization of agriculture, which is enabling greater product traceability and emissions estimates.[159]

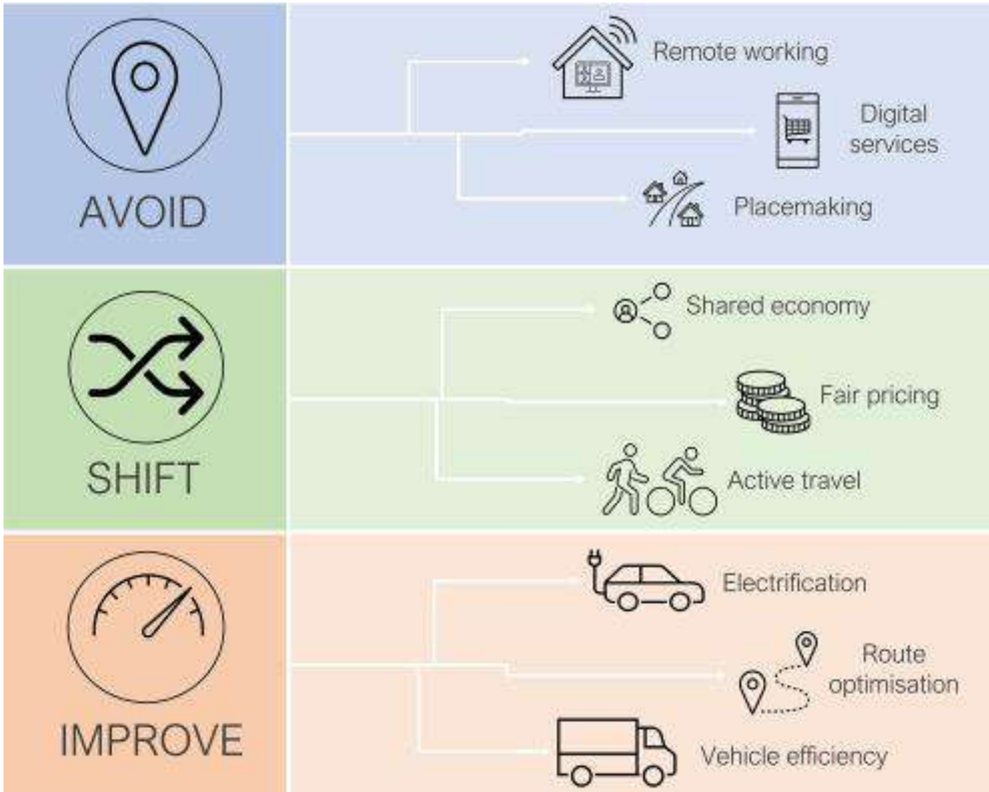
In emerging economies, there is a concerning trend toward increasing meat in diets,[160] with consequences for increasing methane emissions (from ruminant livestock) and deforestation.[161] Technological innovations such as lab-grown meat may help to mitigate this trend, but are likely to be insufficient alone.[162] There is a need for upstream changes to enable pro-environmental food choices. In many countries, subsidy regimens and international trade deals actively encourage emissions-intensive livestock farming, and a carbon tax on the highest impact foods is politically divisive.[140] Recalibrating complex food systems toward more sustainable outcomes is a major challenge, requiring collaboration among governments, the food industry, and civil society.[163]

Enabling low-carbon transport choices

In Europe, the transport sector is responsible for nearly 25% of greenhouse gas emissions, and emissions have remained stubbornly high compared with other sectors such as power and industry that have seen reductions.[164] Consistent with analysis of behavioral determinants,[79] most research points to the need for investment in low-carbon transport infrastructure, which is currently insufficient for driving emissions reductions.[165,166]

In the 2000s, the potential of soft measures to change behavior attracted interest from some European governments, and the United Kingdom's Department of Transport commissioned a major study into the potential of "soft measures" to effect traffic reduction. It found that interventions such as the promotion of workplace or individualized travel plans, car sharing schemes, and awareness campaigns have potential to reduce national road traffic levels by around 11%, and up to 21% of peak urban traffic.[167] Since then, several innovations driven by digital technologies, such as app-enabled shared mobility, telework, and online shopping have reduced barriers to implementing "soft" measures; and yet evidence from systematic reviews indicates limited impact to date,[79] while road traffic has steadily risen across Organisation for Economic Co-operation and Development (OECD) countries.[168,169]

There is growing agreement among transport researchers that overall demand reduction will be required to meet climate goals.[170] Figure 4 depicts the influential "avoid, shift, improve" framework that emphases the need to *first* reduce mobility demand, then encourage the greater use of public transport and active modes, before focusing on fuel switching for private vehicles. In Europe, however, most policies in this domain focus on promoting the adoption of EVs and a modal shift to public transport.[164] Crucially, the avoidance of travel often falls outside the scope of transport policy. Digitalization is a key driver, but the benefits of digital services are uneven and they risk compounding social exclusion and rural deprivation.[171] Other interventions to drive down travel demand include creating "15-min neighborhoods" by prioritizing *access* to local amenities in planning and development policy.[172]



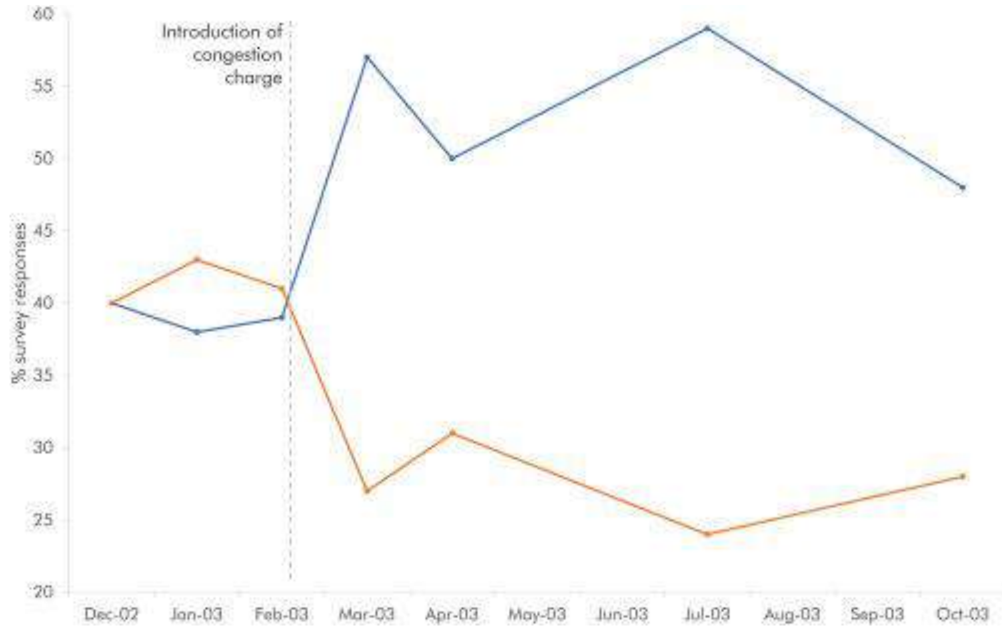
1. Download: Download high-res image (369KB)
2. Download: Download full-size image

Figure 4. The Avoid, Shift, Improve framework helps policy-makers to prioritize investments for transport emissions reduction

The COVID-19 pandemic disrupted travel behaviors, but there is mixed evidence about its effect on long-term habits. The adoption of teleworking practices has increased dramatically in many countries[173] and emerging evidence suggests it may have lasting effects.[174] In the United Kingdom, car usage remains below 2019 levels and there has been a substantial increase in walking for shorter trips.[175] However, the use of passenger vehicles in the United States had recovered to pre-pandemic levels by the end of 2021.[176] Some cities have capitalized on the disruption caused by the pandemic, leveraging this "moment of change" to reallocate road space for active travel. Many deployed "pop-up" bike lanes during the pandemic,[177] and Sydney, Australia, and Mexico City, Mexico, are among those that have since made these permanent.[178]

Besides investing in active travel infrastructure and public transport provision, urban municipalities have a role to play in addressing social and cultural barriers. The Netherlands boasts world-leading cycling infrastructure, but participation remains lower among women and ethnic minorities than other groups. From 2015 to 2021, the City of Leiden, Netherlands, launched a campaign called Flink Fietsen (translation: "cool cycling") aiming to normalize cycling among women and older people and in poor weather. In the United States, Seattle, Portland, and San Francisco have sought to overcome the stigma of bus travel by equivalizing fares with light rail, introducing bus lanes, and giving routes equal prominence on public transit maps.[179,180]

After decades of emissions stasis, there is an urgent need to accelerate transport decarbonization, and policy-makers cannot afford to rely on the shift to EVs. Direct policy interventions, such as the reallocation of road space, restrictions on private car access in cities, or the introduction of congestion charging, are needed in urban environments, but they often generate controversy that can halt progress and temper the ambitions of political leaders. However, evidence suggests that individuals tend to resist change, until it has happened. For instance, Figure 5 shows that support for London's congestion charge grew following its introduction. Climate-conscious policy-makers should be reassured, and hold their nerve.



1. Download: Download high-res image (166KB)
2. Download: Download full-size image

Figure 5. Support for London congestion charge over time
Source: TFL,[181] recreated from BIT[148]; support is in blue, opposition in orange.

Energy consumption in the home

Evidence has found that habitual domestic energy behaviors can be influenced by social norms, feedback, and smart technologies. Studies led by US utility Opower found that informing customers about the average consumption by neighbors and similar households led to reductions of 2%,[182] while visual and accessible feedback via in-home displays has been shown to reduce electricity and gas consumption by 1%–3% in large control studies.[183,184] Given that heating controls are a barrier to energy conservation,[92] there are opportunities to enhance user capabilities. A proliferation of smart thermostats and zonal control systems in recent years has led to design improvements,[185] although evidence of their effectiveness for energy savings is mixed.[92,186] How installers (e.g., plumbers, heating engineers) select and explain controls to users also has a significant effect on how effectively they are used.[187,188,189]

Progress toward enabling non-habitual, one-off choices for improving the energy performance of housing varies internationally. In Europe for instance, the differing uptake of energy efficiency and renewable technologies can be largely explained by the ambition and effectiveness of national policy, rather than economic cost-benefit.[190,191,192] However, the energy price crisis that began in 2021 is rapidly changing the economics of energy efficiency and renewable generation, and demand for domestic photovoltaic installations is increasing, representing 28% of all new solar capacity globally in 2021.[193] China is driving this trend, with installations expected to reach 108 GW in 2022. In Europe, the market for domestic heat pumps is growing. Having already achieved high penetration in Scandinavia,[194] deployment is accelerating in France and Italy.[195] However in the United Kingdom, Netherlands, and the United States, where natural gas dominates domestic heating supply, there remain a series of barriers to householders choosing heat pumps, including high installation costs, skill shortages, and low public awareness.[196] Alongside the challenge of decarbonizing heating, demand for cooling is projected to triple by 2050, driven by population growth in (increasingly) warm climates and changing comfort preferences.[197] While co-deployment of solar photovoltaics will help to offset the substantial increase in peak electricity demand, the International Energy Agency stresses the need for appliance efficiency to limit emissions.[198]

The split-incentive problem remains an intransigent barrier in the rented sector, but the introduction of Minimum Energy Efficiency Standards in the United Kingdom, Netherlands, and parts of the United States is a promising development.[171,199] Germany—an outlier for home ownership compared with comparable countries—is using its recently introduced carbon pricing mechanism to incentivize landlords to invest in building energy upgrades.[200,201]

Sustainable consumption of goods and services

The avoid, shift, improve framework applies to the consumption of non-food products. The most impactful choices are those involving consuming fewer products overall, followed by buying second-hand items or paying for services (such as car clubs over car ownership), and finally improving the quality, longevity, and sourcing of goods we do buy.

While in some advanced economies a trend toward minimalism and dematerialization has emerged in recent years, these practices remain exceptional,[202] and outweighed by economic forces in which consumption is seen as a key driver for growth and is encouraged by a raft of government policies and commercial activities. Similarly, while public concern for the impact of plastics on marine life in recent years raised pressure on retailers to reduce packaging and single-use items, progress remains limited to certain products such as straws and cutlery,[203] and behaviors such as buying products with less packaging[50] or using recycled materials[204] remain uncommon. Nonetheless, with strong public support for bans on single-use plastics,[205] there is potential for regulation to drive down unsustainable consumption.

Other key enablers of climate-friendly consumption choices are the development of the sharing and the circular economy. Polling from the European Union[206] and the United Kingdom[140] has found broad public support for these, but there is a need for innovation in business models and practices, aided by digitalization and the development of new materials and recycling methods. However, it is also essential that innovations such as paying for services or peer-to-peer trading are made accessible to wider publics, including those without digital capabilities.[207] Moreover, evidence from a UK study indicates that knowledge and awareness of sustainable consumption practices remain low,[140] and consumers find it difficult to distinguish between the environmental claims of one company's products over another.[208] A recent global study found that 40% of environmental claims made online could be potentially misleading.[209] Examples include vague use of language such as "eco" and "green" without accompanying evidence, use of unaccredited environmental labels, and the omission of information relating to emissions or pollution. Advertising standards agencies, consumer protection bodies, and anti-monopoly authorities have a key role to play in monitoring and regulating "greenwash."

Given the mismatch between public perception and reality associated with environmental behaviors (Figure 3), there is a need to enhance awareness and "carbon literacy," especially with respect to less visible, embodied emissions. Achieving this will require a range of interventions, from product carbon labeling and increased media coverage (see next section), to school-aged education and training.[210]

Leveraging the power of influence

Building the capacity of individuals to influence others toward pro-climate choices begins with awareness raising. The news media plays a crucial role. People who consume climate change news are more concerned about climate change, consider themselves to be more knowledgeable about the issue, and—importantly—tend to feel more empowered.[211] However, as a driver of public concern, news media is secondary to elite cues, protest, and extreme weather events, which are among those sources that drive climate coverage in the news.[212] A repeated finding is that the provision of factual information about climate change fails to influence opinion,[212] but when given information about the *views* of the scientific community, individuals are more likely to support climate policies. In other words, people relate to people, not facts.[213] In the context of increasingly polarized attitudes toward climate change, there is a need for interventions to enable more open and constructive discourse among diverse individuals. For influential institutions such as the news media, combating mis- and dis-information is essential to counteract polarization.[112] Greenpeace, The Nature Conservancy, and even the World Economic Forum have produced guides to help individuals talk about climate change with others in a variety of contexts.[214,215,216]

The workplace is a crucial site of (two-way) influence. This can be exerted by individuals in management and leadership roles through human-resource management practices such as rewards, education, and training[102]; green initiatives[217]; or values-based activities.[106,218] With respect to environmental behaviors, there is relatively little research on home-to-work and work-to-home spillover, and empirical work to date has shown mixed results.[219] For instance, a social-marketing experiment examining the effects of sustainable food interventions in the workplace found that positive spillover effects *can* be produced, but depend on various individual and material factors.[220] However, it is clear that pressure from employees and jobseekers is driving many organizations to adopt more sustainable practices,[221,222,223] and with unemployment at historically low levels in many OECD countries,[224] evidence that green businesses find it easier to recruit and retain staff is helping to drive action on climate change by corporations.[225]

Becoming climate citizens

Different trends enable and constrain climate citizenship. Climate change has (finally) entered mainstream political debate, meaning that it is easier than ever for voters to choose political candidates based on their climate stance. In many countries, climate action is no longer a partisan issue, although concern remains higher among left-wing voters[211]; and in the United States and Brazil, where climate policies have global ramifications, it continues to be politically divisive.[226] Addressing public polarization on climate change is essential in order to build consensus support for action. Different moral framings,[227] values-based engagement,[228,229] use of imagery,[230] and targeted provision of information[231] can help to counteract polarization. While political parties, corporate branding and communications agencies, and news media outlets may hold the greatest sway in countering polarization through public engagement and eradicating mis-information, these pivotal actors respond to the choices that individuals make as consumers (e.g., of media) and as organizational and political activists.[3,223,232,233,234]

Recent trends are making it easier for individuals to participate in climate action at multiple levels of governance. Both national and local governments are increasingly employing methods of deliberative and participative democracy, diversifying the ways in which citizens' voices are heard.[235,236,237] However, while citizens panels or assemblies can represent a cross-section of views on climate, they do not enable mass participation. Examples of "e-democracy" include online petitions and deliberative opinion polling that can enable individuals to engage more actively in the political process.

Digital technologies help connect communities at multiple scales, enabling pro-environmental solutions such as peer-to-peer energy trading.[238] It is easier than ever (for those with digital capabilities) to engage in grassroots climate action. This is also being supported by the global trend toward greater autarky that has emerged in response to supply chain disruption, trade wars, and a focus on energy and resource security by national governments. Whether this trend has negative ramifications for global cooperation on climate is yet to be seen, but in the meantime "slowbalization" is bringing a renewed focus on local and community solutions, boosting opportunities for participation in sustainability initiatives.[239] Building the social capital that is needed for such projects to be successful can be difficult, but trends such as telecommuting and increased part-time working are helping, as residents invest more of their time and money in the local community.[240] Directing these investments toward climate action can generate positive feedback loops: individuals getting involved in renewable energy projects, farming cooperatives, or circular economy activities can help to enhance social capital, boost the local economy, and build the local capabilities that enable further climate action.

Toward an ecology of choice for climate action

Individual choices are at the sharp end of climate action, with the potential to drive down emissions and keep global temperature rise within safe limits. Identifying six domains of choice for climate action, this review has shown that the capabilities to make choices for climate are unevenly distributed among populations, and depend on individual, social, material, physical, and political factors, which combine in complex ways, depending on context. Choices are thus best conceived as part of an ecology of decision-making with myriad influences. To achieve climate goals, all elements of the ecology must be addressed through a range of interventions, including information provision, social marketing, choice architecture, economic measures, infrastructure change, and regulation (see Figure 6). There is a tendency in behavior change scholarship and policy discourse to focus on so called "downstream" interventions: those focused on educating, persuading and encouraging individuals to make more sustainable everyday consumption choices[5,241] However, as this review has demonstrated, individual consumption behaviors are influenced by a range of social, physical, and political factors that can constrain or enable pro-environmental choice capabilities. Extending the metaphor of a river-based ecosystem, there is a need to design and implement more *midstream* and *upstream* interventions. Midstream interventions relate to the "choice environment," where actors such as businesses, service providers, and local governments can act to make sustainable options easier, more available, and socially acceptable.[241] Midstream initiatives might also identify "moments of change," such as when individuals move home, start new jobs, or when energy-intensive appliances breakdown, designing timely interventions to take advantage of habit discontinuity and enable individuals to establish more sustainable routines.[5] Upstream activities involve substantive change to the structures and systems that set the conditions and context for individual choice, and are typically considered the domain of government departments and market regulators. However, individuals have significant agency for shaping the success of interventions at all levels, acting in different capacities.

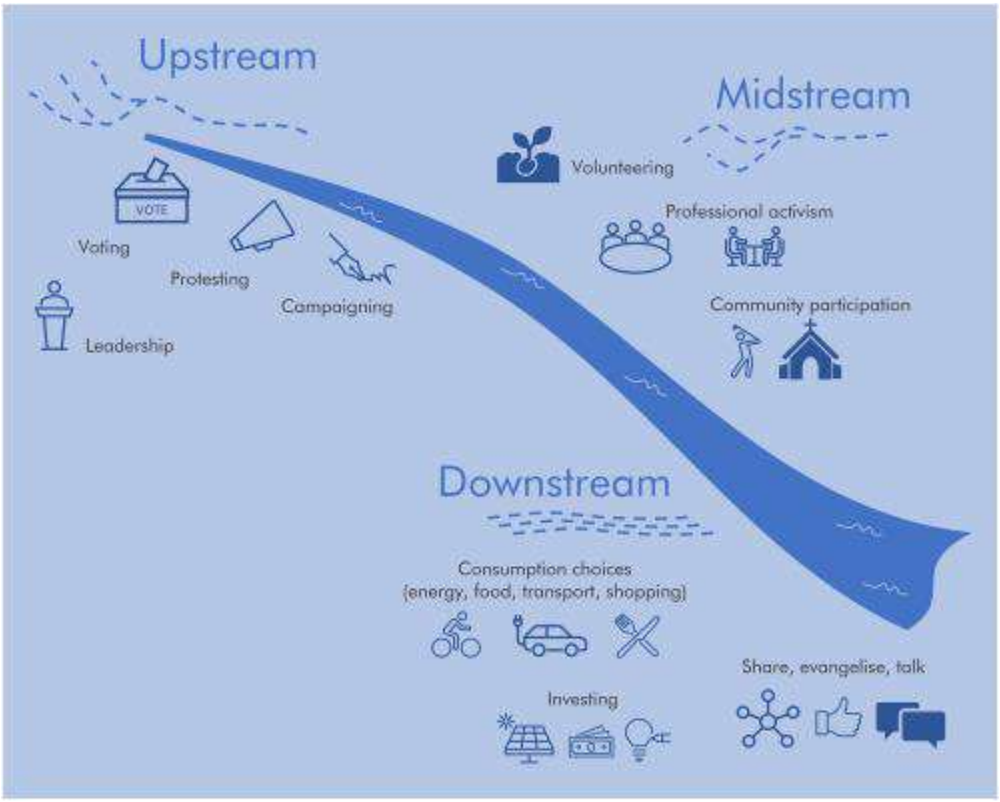


Figure 6. The *riverine ecology* of choice for climate action
A combination of upstream, midstream, and downstream interventions is needed to enable and scale choices for climate action.

For upstream interventions, individuals in positions of leadership can influence systemic change, while as this review has shown, activism (within organizational settings and the public realm), and political participation can help to reshape the terms of debate on climate change, and accelerate policy and action. The choices individuals make as organizational members are key for shaping the midstream choice environment. These include effecting change within business or public sector organizations; helping to set environmental policies and targets in line with national and global climate targets[10,242]; volunteering in local initiatives to enhance nature recovery or facilitate the sharing economy; or spreading the word about the need for climate action among sports, religious, or cultural groups. Last, while individual consumption choices have the most immediate potential to reduce carbon emissions in the four domains of food, transport, domestic energy, and shopping, individuals can also help to accelerate downstream change when acting as economic and social agents. One-off, high-impact choices such as choosing to invest in rooftop solar, renewable heating systems, or even switching pension and savings to sustainable providers can deliver significant emissions savings for individuals, but when coupled with choices to share experiences of making low-carbon choices and evangelize about their benefits, these can have catalyzing effects.[3]

To meet the scale of the challenge posed by climate change, there is a need for transformation in the lifestyles led by individuals across much of the world. Choice is a central component of this transformation, and this review has highlighted the power of decision-making that extends beyond individual consumption behavior. There is a need for change among systems of provision and governance, businesses and communities, and in social and cultural norms that each set the context for individual decision-making. Individuals acting as citizens, influencers, investors, professionals, and consumers hold the key to delivering this change.

Acknowledgments

This research has been enabled by funding from the Economic and Social Research Council (ESRC) grant ref: ES/V015133/1. Funding has also been received from ES/S012257/1. We thank the peer reviewers for their detailed and constructive comments in preparing this manuscript for publication.

Author contributions

Conceptualization, methodology, investigation, S.H. and L.W. Writing – Original Draft, S.H. Writing – Review & Editing, L.W.

Declaration of interests

The authors declare no competing interests.

References

1. 1

Ipsos

Perils of Perception

Environmental Perils (2021)

Google Scholar

2. 2

L. Chancel

Global carbon inequality over 1990–2019

Nat. Sustain., 5 (2022), pp. 931-938, 10.1038/s41893-022-00955-z
View in ScopusGoogle Scholar

3. 3

K.S. Nielsen, K.A. Nicholas, F. Creutzig, T. Dietz, P.C. Stern

The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions

Nat. Energy, 6 (2021), pp. 1011-1016

CrossrefView in ScopusGoogle Scholar

4. 4

T. Kurz, B. Gardner, B. Verplanken, C. Abraham

Habitual behaviors or patterns of practice? Explaining and changing repetitive climate-relevant actions

WIREs Clim. Change, 6 (2015), pp. 113-128, 10.1002/wcc.327
View in ScopusGoogle Scholar

5. 5

L. Whitmarsh, W. Poortinga, S. Capstick

Behaviour change to address climate change

Curr. Opin. Psychol., 42 (2021), pp. 76-81, 10.1016/j.copsyc.2021.04.002
View PDFView articleView in ScopusGoogle Scholar

6. 6

E. Shove

Beyond the ABC: Climate Change Policy and Theories of Social Change

Environ. Plan. A., 42 (2010), pp. 1273-1285, 10.1068/a42282
View in ScopusGoogle Scholar

7. 7

A. Giddens

The Constitution of Society [electronic Resource] : Outline of the Theory of Structuration

Wiley (1984)

Google Scholar

8. 8

A. Reckwitz

Toward a theory of social practices: a development in culturalist theorizing

Eur. J. Soc. Theor, 5 (2002), pp. 243-263

View in ScopusGoogle Scholar

9. 9

S. Hampton, R. Adams

Behavioural economics vs social practice theory: Perspectives from inside the United Kingdom government

Energy Res. Social Sci., 46 (2018), pp. 214-224, 10.1016/j.erss.2018.07.023
View PDFView articleView in ScopusGoogle Scholar

10. 10

J. Walenta

The making of the corporate carbon footprint: the politics behind emission scoping

Journal of Cultural Economy, 14 (2021), pp. 533-548, 10.1080/17530350.2021.1935297
View in ScopusGoogle Scholar

11. 11

M. Bhattacharya, J.N. Inekwe, P. Sadorsky

Consumption-based and territory-based carbon emissions intensity: Determinants and forecasting using club convergence across countries

Energy Econ., 86 (2020), Article 104632, 10.1016/j.eneco.2019.104632
View PDFView articleView in ScopusGoogle Scholar

12. 12

B. Goldstein, D. Gounaridis, J.P. Newell

The carbon footprint of household energy use in the United States

Proc. Natl. Acad. Sci. USA, 117 (2020), pp. 19122-19130, 10.1073/pnas.1922205117
View in ScopusGoogle Scholar

13. 13

S. Wynes, K.A. Nicholas

The climate mitigation gap: education and government recommendations miss the most effective individual actions

Environ. Res. Lett., 12 (2017), Article 074024, 10.1088/1748-9326/aa7541
View in ScopusGoogle Scholar

14. 14

D. Ivanova, J. Barrett, D. Wiedenhofer, B. Macura, M. Callaghan, F. Creutzig

Quantifying the potential for climate change mitigation of consumption options

Environ. Res. Lett., 15 (2020), Article 093001, 10.1088/1748-9326/ab8589
View in ScopusGoogle Scholar

15. 15

BEIS (2022)

UK Greenhouse Gas Emissions, Provisional Figures

Department for Business, Energy and Industrial Strategy (2021)

Google Scholar

16. 16

Climate Change Committee

The Sixth Carbon Budget: The UK's Path to Net Zero (Climate Change Committee)

(2020)

Google Scholar

17. 17

US EPA Carbon Footprint Calculator. https://www3.epa.gov/carbon-footprint-calculator.
Google Scholar

18. 18

DEFRA

Act on CO2 Calculator: Public Trial Version. Data, Methodology and Assumptions Paper

Department for Environment, Food and Rural Affairs (2007)

Google Scholar

19. 19

WWF Footprint Calculator https://footprint.wwf.org.uk/.
Google Scholar

20. 20

BP Know Your Carbon Footprint. https://www.knowyourcarbonfootprint.com/.
Google Scholar

21. 21

HM Government

Climate Change and Net Zero: Public Awareness and Perceptions

(2021)

Google Scholar

22. 22

S. Wynes, J. Zhao, S.D. Donner

How well do people understand the climate impact of individual actions?

Climatic Change, 162 (2020), pp. 1521-1534, 10.1007/s10584-020-02811-5
View in ScopusGoogle Scholar

23. 23

F. Brocklehurst, C. Whittle, C. McAlister, L. Whitmarsh

Can the provision of energy and resource efficiency information influence what consumers buy? A review of the evidence

Proceedings of the eceee Summer Study Conference (2019)

Google Scholar

24. 24

A.M. van Valkengoed, W. Abrahamse, L. Steg

To select effective interventions for pro-environmental behaviour change, we need to consider determinants of behaviour

Nat. Human Behav., 6 (2022), pp. 1482-1492, 10.1038/s41562-022-01473-w
View in ScopusGoogle Scholar

25. 25

J. Frick, F.G. Kaiser, M. Wilson

Environmental knowledge and conservation behavior: exploring prevalence and structure in a representative sample

Pers. Indiv. Differ., 37 (2004), pp. 1597-1613, 10.1016/j.paid.2004.02.015
View PDFView articleView in ScopusGoogle Scholar

26. 26

P. Griffin

The Carbon Majors Database. CDP Carbon Majors Report

CDP Worldwide (2017)

Google Scholar

27. 27

M. Kaufman

The Carbon Footprint Sham: A “Successful, Deceptive” PR Campaign

Mashable (2020)

https://mashable.com/feature/carbon-footprint-pr-campaign-sham
Google Scholar

28. 28

A. Corner, J. Clarke

Talking Climate: From Research to Practice in Public Engagement

Palgrave) (2016)

Google Scholar

29. 29

K. Hayhoe

Saving Us: A Climate Scientist’s Case for Hope and Healing in a Divided World First One

Signal Publishers/Atria Books (2021)

hardcover edition. (One Signal Publishers/Atria Books)

Google Scholar

30. 30

Count Us in, and Netflix Take a Step with Don’t Look up & Count Us In. https://dontlookup.count-us-in.com/steps.
Google Scholar

31. 31

S. Capstick, A. Thierry, E. Cox, O. Berglund, S. Westlake, J.K. Steinberger

Civil disobedience by scientists helps press for urgent climate action

Nat. Clim. Change, 12 (2022), pp. 773-774, 10.1038/s41558-022-01461-y
View in ScopusGoogle Scholar

32. 32

S. Venghaus, M. Henseleit, M. Belka

The impact of climate change awareness on behavioral changes in Germany: changing minds or changing behavior?

Energy Sustain. Soc., 12 (2022), p. 8, 10.1186/s13705-022-00334-8
View in ScopusGoogle Scholar

33. 33

L. Whitmarsh, G. Seyfang, S. O’Neill

Public engagement with carbon and climate change: To what extent is the public ‘carbon capable

Global Environ. Change, 21 (2011), pp. 56-65, 10.1016/j.gloenvcha.2010.07.011
View PDFView articleView in ScopusGoogle Scholar

34. 34

C. Hickman, E. Marks, P. Pihkala, S. Clayton, R.E. Lewandowski, E.E. Mayall, B. Wray, C. Mellor, L. van Susteren

Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey

Lancet Planet. Health, 5 (2021), pp. e863-e873, 10.1016/S2542-5196(21)00278-3
View PDFView articleView in ScopusGoogle Scholar

35. 35

I. Ajzen

The theory of planned behavior

Organ. Behav. Hum. Decis. Process., 50 (1991), pp. 179-211, 10.1016/0749-5978(91)90020-T
View PDFView articleView in ScopusGoogle Scholar

36. 36

A. Darnton

An Overview of Behaviour Change Models and Their Uses

Centre for Sustainable Development, University of Westminster (2008)

Google Scholar

37. 37

T. Jackson

Motivating Sustainable Consumption: A Review of Evidence on Consumer Behaviour and Behavioural Change

A report to the Sustainable Development Research Network (2005)

Google Scholar

38. 38

P.C. Stern

New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior

J. Soc. Issues, 56 (2000), pp. 407-424, 10.1111/0022-4537.00175
View in ScopusGoogle Scholar

39. 39

A. Grønhøj, J. Thøgersen

Like father, like son? Intergenerational transmission of values, attitudes, and behaviours in the environmental domain

J. Environ. Psychol., 29 (2009), pp. 414-421, 10.1016/j.jenvp.2009.05.002
View PDFView articleView in ScopusGoogle Scholar

40. 40

H. Pearce, L. Hudders, D. Van de Sompel

Young energy savers: Exploring the role of parents, peers, media and schools in saving energy among children in Belgium

Energy Res. Social Sci., 63 (2020), Article 101392, 10.1016/j.erss.2019.101392
View PDFView articleView in ScopusGoogle Scholar

41. 41

S. Moser, S. Kleinhückelkotten

Good Intents, but Low Impacts: Diverging Importance of Motivational and Socioeconomic Determinants Explaining Pro-Environmental Behavior, Energy Use, and Carbon Footprint

Environ. Behav., 50 (2018), pp. 626-656, 10.1177/0013916517710685
View in ScopusGoogle Scholar

42. 42

K.S. Nielsen, S. Clayton, P.C. Stern, T. Dietz, S. Capstick, L. Whitmarsh

How psychology can help limit climate change

Am. Psychol., 76 (2021), pp. 130-144, 10.1037/amp0000624
View in ScopusGoogle Scholar

43. 43

A. Darnton, D. Evans, Scottish Government

Influencing Behaviours: A Technical Guide to the ISM Tool

Scottish Government (2013)

Google Scholar

44. 44

S. Michie, M.M. van Stralen, R. West

The behaviour change wheel: A new method for characterising and designing behaviour change interventions

Implement. Sci., 6 (2011), p. 42, 10.1186/1748-5908-6-42
View in ScopusGoogle Scholar

45. 45

C. Brick, G.J. Lewis

Unearthing the “Green” Personality: Core Traits Predict Environmentally Friendly Behavior

Environ. Behav., 48 (2016), pp. 635-658, 10.1177/0013916514554695
View in ScopusGoogle Scholar

46. 46

N.A. Marshall, L. Thiault, A. Beeden, R. Beeden, C. Benham, M.I. Curnock, A. Diedrich, G.G. Gurney, L. Jones, P.A. Marshall, *et al.*
Our Environmental Value Orientations Influence How We Respond to Climate Change

Front. Psychol., 10 (2019), p. 938

View in ScopusGoogle Scholar

47. 47

B. Wisner

Climate change and cultural diversity

Int. Soc. Sci. J., 61 (2010), pp. 131-140, 10.1111/j.1468-2451.2010.01752.x
View in ScopusGoogle Scholar

48. 48

B. Latter

Climate Change Communication and Engagement With Older People in England

Front. Commun. (Lausanne)., 7 (2022)

Google Scholar

49. 49

B. Lovelock

Disability and going green: a comparison of the environmental values and behaviours of persons with and without disability

Disabil. Soc., 25 (2010), pp. 467-484, 10.1080/09687591003755856
View in ScopusGoogle Scholar

50. 50

L. Whitmarsh, S. Capstick, N. Nash

Who is reducing their material consumption and why? A cross-cultural analysis of dematerialization behaviours

Philos. Trans. A Math. Phys. Eng. Sci., 375 (2017), Article 20160376, 10.1098/rsta.2016.0376
View in ScopusGoogle Scholar

51. 51

N. Jones, J.R.A. Clark

Social capital and the public acceptability of climate change adaptation policies: a case study in Romney Marsh, UK

Climatic Change, 123 (2014), pp. 133-145, 10.1007/s10584-013-1049-0
View in ScopusGoogle Scholar

52. 52

E.B. Sharp, D.M. Daley, M.S. Lynch

Understanding Local Adoption and Implementation of Climate Change Mitigation Policy

Urban Aff. Rev., 47 (2011), pp. 433-457, 10.1177/1078087410392348
View in ScopusGoogle Scholar

53. 53

G.M. Huebner, I. Hamilton, Z. Chalabi, D. Shipworth, T. Oreszczyn

Explaining domestic energy consumption – The comparative contribution of building factors, socio-demographics, behaviours and attitudes

Appl. Energy, 159 (2015), pp. 589-600, 10.1016/j.apenergy.2015.09.028
View PDFView articleView in ScopusGoogle Scholar

54. 54

E. McKenna, J. Few, E. Webborn, B. Anderson, S. Elam, D. Shipworth, A. Cooper, M. Pullinger, T. Oreszczyn

Explaining daily energy demand in British housing using linked smart meter and socio-technical data in a bottom-up statistical model

Energy Build., 258 (2022), Article 111845, 10.1016/j.enbuild.2022.111845
View PDFView articleView in ScopusGoogle Scholar

55. 55

B. Gill, S. Moeller

GHG Emissions and the Rural-Urban Divide. A Carbon Footprint Analysis Based on the German Official Income and Expenditure Survey

Ecol. Econ., 145 (2018), pp. 160-169, 10.1016/j.ecolecon.2017.09.004
View PDFView articleView in ScopusGoogle Scholar

56. 56

A. Goldthau, L. Eicke, S. Weko

The Global Energy Transition and the Global South

M. Hafner, S. Tagliapietra (Eds.), The Geopolitics of the Global Energy Transition Lecture Notes in Energy, Springer International Publishing) (2020), pp. 319-339, 10.1007/978-3-030-39066-2_14
View in ScopusGoogle Scholar

57. 57

S. Niemeyer

Democracy and Climate Change: What Can Deliberative Democracy Contribute?

Aust. J. Polit. Hist., 59 (2013), pp. 429-448, 10.1111/ajph.12025
View in ScopusGoogle Scholar

58. 58

D.J. Fiorino

Can Democracy Handle Climate Change?

John Wiley & Sons (2018)

Google Scholar

59. 59

CAUK

The Path to Net Zero: Climate Assembly UK Full Report (Climate Assembly UK)

(2020)

Google Scholar

60. 60

R. Aldred, J. Woodcock, A. Goodman

Does More Cycling Mean More Diversity in Cycling?

Transport Rev., 36 (2016), pp. 28-44, 10.1080/01441647.2015.1014451
View articleView in ScopusGoogle Scholar

61. 61

J. Sobal, C.A. Bisogni

Constructing Food Choice Decisions

Ann. Behav. Med., 38 (2009), pp. s37-s46, 10.1007/s12160-009-9124-5
Google Scholar

62. 62

S. Mertens, M. Herberz, U.J.J. Hahnel, T. Brosch

The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains

Proc. Natl. Acad. Sci. USA, 119 (2022), Article e2107346118, 10.1073/pnas.2107346118
View in ScopusGoogle Scholar

63. 63

N. Larson, M. Story

A Review of Environmental Influences on Food Choices

Ann. Behav. Med., 38 (2009), pp. s56-s73, 10.1007/s12160-009-9120-9
Google Scholar

64. 64

S. Bridle-Fitzpatrick

Tortillas, Pizza, and Broccoli

Food Cult. Soc., 19 (2016), pp. 93-128, 10.1080/15528014.2016.1147871
View in ScopusGoogle Scholar

65. 65

T.M. Marteau, N. Chater, E.E. Garnett

Changing behaviour for net zero 2050

BMJ, 375 (2021), p. n2293, 10.1136/bmj.n2293
View in ScopusGoogle Scholar

66. 66

E. Köster

Diversity in the determinants of food choice: A psychological perspective

Food Qual. Prefer., 20 (2009), pp. 70-82, 10.1016/j.foodqual.2007.11.002
View PDFView articleView in ScopusGoogle Scholar

67. 67

T. Cruwys, K.E. Bevelander, R.C.J. Hermans

Social modeling of eating: A review of when and why social influence affects food intake and choice

Appetite, 86 (2015), pp. 3-18, 10.1016/j.appet.2014.08.035
View PDFView articleView in ScopusGoogle Scholar

68. 68

G. Leng, R.A.H. Adan, M. Belot, J.M. Brunstrom, K. de Graaf, S.L. Dickson, T. Hare, S. Maier, J. Menzies, H. Preissl, *et al.*
The determinants of food choice

Proc. Nutr. Soc., 76 (2017), pp. 316-327, 10.1017/S002966511600286X

View in ScopusGoogle Scholar

69. 69

J.P. Enriquez, J.C. Archila-Godinez

Social and cultural influences on food choices: A review

Crit. Rev. Food Sci. Nutr., 62 (2022), pp. 3698-3704, 10.1080/10408398.2020.1870434
View in ScopusGoogle Scholar

70. 70

R.D. Gifford, A.K.S. Chen

Why aren't we taking action? Psychological barriers to climate-positive food choices

Climatic Change, 140 (2017), pp. 165-178, 10.1007/s10584-016-1830-y
View in ScopusGoogle Scholar

71. 71

C. Tobler, V.H.M. Visschers, M. Siegrist

Eating green. Consumers' willingness to adopt ecological food consumption behaviors

Appetite, 57 (2011), pp. 674-682, 10.1016/j.appet.2011.08.010
View PDFView articleView in ScopusGoogle Scholar

72. 72

M.B. Ruby, S.J. Heine

Meat, morals, and masculinity

Appetite, 56 (2011), pp. 447-450, 10.1016/j.appet.2011.01.018
View PDFView articleView in ScopusGoogle Scholar

73. 73

I. Mori

Diets Around the World: An Exploration

(2018)

Google Scholar

74. 74

A. Warde

The Practice of Eating

John Wiley & Sons (2016)

Google Scholar

75. 75

P. Lanzini, S.A. Khan

Shedding light on the psychological and behavioral determinants of travel mode choice: A meta-analysis

Transport. Res. F Traffic Psychol. Behav., 48 (2017), pp. 13-27, 10.1016/j.trf.2017.04.020
View PDFView articleView in ScopusGoogle Scholar

76. 76

K. Canepa, S. Hardman, G. Tal

An early look at plug-in electric vehicle adoption in disadvantaged communities in California

Transport Pol., 78 (2019), pp. 19-30, 10.1016/j.tranpol.2019.03.009
View PDFView articleView in ScopusGoogle Scholar

77. 77

H.A.U. Khan, S. Price, C. Avraam, Y. Dvorkin

Inequitable access to EV charging infrastructure

Electr. J., 35 (2022), Article 107096, 10.1016/j.tej.2022.107096
View PDFView articleView in ScopusGoogle Scholar

78. 78

R. Fouquet, T. O'Garra

In pursuit of progressive and effective climate policies: Comparing an air travel carbon tax and a frequent flyer levy

Energy Pol., 171 (2022), Article 113278, 10.1016/j.enpol.2022.113278
View PDFView articleView in ScopusGoogle Scholar

79. 79

A. Javaid, F. Creutzig, S. Bamberg

Determinants of low-carbon transport mode adoption: systematic review of reviews

Environ. Res. Lett., 15 (2020), Article 103002, 10.1088/1748-9326/aba032
View in ScopusGoogle Scholar

80. 80

L. Tatah, Y. Wasnyo, M. Pearce, T. Oni, L. Foley, E. Mogo, C. Obonyo, J.C. Mbanya, J. Woodcock, F. Assah

Travel Behaviour and Barriers to Active Travel among Adults in Yaoundé, Cameroon

Sustainability, 14 (2022), p. 9092, 10.3390/su14159092
View in ScopusGoogle Scholar

81. 81

P. Chillón, D. Hales, A. Vaughn, Z. Gizlice, A. Ni, D.S. Ward

A cross-sectional study of demographic, environmental and parental barriers to active school travel among children in the United States

Int. J. Behav. Nutr. Phys. Activ., 11 (2014), p. 61, 10.1186/1479-5868-11-61
View in ScopusGoogle Scholar

82. 82

T. Lorenc, G. Brunton, S. Oliver, K. Oliver, A. Oakley

Attitudes to walking and cycling among children, young people and parents: a systematic review

J. Epidemiol. Community Health, 62 (2008), pp. 852-857, 10.1136/jech.2007.070250
View in ScopusGoogle Scholar

83. 83

H.T.K. Le, R. Buehler, S. Hankey

Correlates of the Built Environment and Active Travel: Evidence from 20 US Metropolitan Areas

Environ. Health Perspect., 126 (2018), Article 077011, 10.1289/EHP3389
View in ScopusGoogle Scholar

84. 84

E.K. Nehme, A. Pérez, N. Ranjit, B.C. Amick, H.W. Kohl

Sociodemographic Factors, Population Density, and Bicycling for Transportation in the United States

J. Phys. Activ. Health, 13 (2016), pp. 36-43, 10.1123/jpah.2014-0469
View in ScopusGoogle Scholar

85. 85

A. Hess

Race, Class, and the Stigma of Riding the Bus in America

The Atlantic (2012)

Google Scholar

86. 86

N. Bosetti, K. Connelly, C. Harding, D. Rowe

Street Shift: The Future of Low-Traffic Neighbourhoods

Centre for London) (2022)

Google Scholar

87. 87

A. Satre-Meloy

Investigating structural and occupant drivers of annual residential electricity consumption using regularization in regression models

Energy, 174 (2019), pp. 148-168, 10.1016/j.energy.2019.01.157
View PDFView articleView in ScopusGoogle Scholar

88. 88

C.f. Chen, X. Xu, Z. Cao, A. Mockus, Q. Shi

Analysis of social–Psychological factors and financial incentives in demand response and residential energy behavior

Front. Energy Res., 11 (2023)

Google Scholar

89. 89

E. Frederiks, K. Stenner, E. Hobman

The Socio-Demographic and Psychological Predictors of Residential Energy Consumption: A Comprehensive Review

Energies, 8 (2015), pp. 573-609, 10.3390/en8010573
View in ScopusGoogle Scholar

90. 90

T. Marghetis, S.Z. Attari, D. Landy

Simple interventions can correct misperceptions of home energy use

Nat. Energy, 4 (2019), pp. 874-881, 10.1038/s41560-019-0467-2
View in ScopusGoogle Scholar

91. 91

S.Z. Attari, M.L. DeKay, C.I. Davidson, W. Bruine de Bruin

Public perceptions of energy consumption and savings

Proc. Natl. Acad. Sci. USA, 107 (2010), pp. 16054-16059, 10.1073/pnas.1001509107
View in ScopusGoogle Scholar

92. 92

K.J. Lomas, S. Oliveira, P. Warren, V.J. Haines, T. Chatterton, A. Beizaee, E. Prestwood, B. Gething

Do domestic heating controls save energy? A review of the evidence

Renew. Sustain. Energy Rev., 93 (2018), pp. 52-75, 10.1016/j.rser.2018.05.002
View PDFView articleView in ScopusGoogle Scholar

93. 93

H. Nie, R. Kemp, J.-H. Xu, V. Vasseur, Y. Fan

Split incentive effects on the adoption of technical and behavioral energy-saving measures in the household sector in Western Europe

Energy Pol., 140 (2020), Article 111424, 10.1016/j.enpol.2020.111424
View PDFView articleView in ScopusGoogle Scholar

94. 94

Eurostat

Distribution of Population by Tenure Status, Type of Household and Income Group

EU-SILC survey (2023)

Google Scholar

95. 95

Statistics Japan

Homeownership. Homeownership｜Statistics Japan : Prefecture Comparisons

(2022)

https://stats-japan.com/t/kiji/23131
Google Scholar

96. 96

C.S. Dabas, C. Whang

A systematic review of drivers of sustainable fashion consumption: 25 years of research evolution

Journal of Global Fashion Marketing, 13 (2022), pp. 151-167, 10.1080/20932685.2021.2016063
View in ScopusGoogle Scholar

97. 97

A. Akande, P. Cabral, S. Casteleyn

Understanding the sharing economy and its implication on sustainability in smart cities

J. Clean. Prod., 277 (2020), Article 124077, 10.1016/j.jclepro.2020.124077
View PDFView articleView in ScopusGoogle Scholar

98. 98

M. ter Huurne, A. Ronteltap, R. Corten, V. Buskens

Antecedents of trust in the sharing economy: A systematic review

J. Consum. Behav., 16 (2017), pp. 485-498, 10.1002/cb.1667
View in ScopusGoogle Scholar

99. 99

J. Wei, H. Chen, X. Cui, R. Long

Carbon capability of urban residents and its structure: Evidence from a survey of Jiangsu Province in China

Appl. Energy, 173 (2016), pp. 635-649, 10.1016/j.apenergy.2016.04.068
View PDFView articleView in ScopusGoogle Scholar

100. 100

A.R.B. Soutter, T.C. Bates, R. Mõttus

Big Five and HEXACO Personality Traits, Proenvironmental Attitudes, and Behaviors: A Meta-Analysis

Perspect. Psychol. Sci., 15 (2020), pp. 913-941, 10.1177/1745691620903019
View in ScopusGoogle Scholar

101. 101

K.S. Nielsen, T.M. Marteau, J.M. Bauer, R.B. Bradbury, S. Broad, G. Burgess, M. Burgman, H. Byerly, S. Clayton, D. Espelosin, *et al.*
Biodiversity conservation as a promising frontier for behavioural science

Nat. Human Behav., 5 (2021), pp. 550-556, 10.1038/s41562-021-01109-5

View in ScopusGoogle Scholar

102. 102

L.D. Zibarras, P. Coan

HRM practices used to promote pro-environmental behavior: a UK survey

Int. J. Hum. Resour. Manag., 26 (2015), pp. 2121-2142, 10.1080/09585192.2014.972429
View in ScopusGoogle Scholar

103. 103

K. Kalshoven, D.N. Den Hartog, A.H.B. De Hoogh

Ethical Leader Behavior and Big Five Factors of Personality

J. Bus. Ethics, 100 (2011), pp. 349-366, 10.1007/s10551-010-0685-9
View in ScopusGoogle Scholar

104. 104

C.W. Choo

Sensemaking, knowledge creation, and decision making: Organizational knowing as emergent strategy

Strategic management of intellectual capital and organizational knowledge (2006)

Google Scholar

105. 105

W.B. Stevenson, R.F. Radin

Social Capital and Social Influence on the Board of Directors

J. Manag. Stud., 46 (2009), pp. 16-44, 10.1111/j.1467-6486.2008.00800.x
View in ScopusGoogle Scholar

106. 106

S. Hampton, R. Blundel, A. Wahga, T. Fawcett, C. Shaw

Transforming small and medium-sized enterprises to address the climate emergency: The case for values-based engagement

Corp. Soc. Responsib. Environ. Manag., 29 (2022), pp. 1424-1439, 10.1002/csr.2279
View in ScopusGoogle Scholar

107. 107

D. Centola

Change: How to Make Big Things Happen

John Murray Publishers Ltd) (2021)

Google Scholar

108. 108

M.T. Ballew, A. Leiserowitz, C. Roser-Renouf, S.A. Rosenthal, J.E. Kotcher, J.R. Marlon, E. Lyon, M.H. Goldberg, E.W. Maibach

Climate Change in the American Mind: Data, Tools, and Trends

Environment, 61 (2019), pp. 4-18, 10.1080/00139157.2019.1589300
View in ScopusGoogle Scholar

109. 109

C. Funk

The Politics of Climate

Pew Research Center Science & Society (2016)

https://www.pewresearch.org/science/2016/10/04/the-politics-of-climate/
Google Scholar

110. 110

S. Chinn, P.S. Hart, S. Soroka

Politicization and Polarization in Climate Change News Content

Science Communication (2020), pp. 1985-2017, 10.1177/1075547019900290
Google Scholar

111. 111

M. Falkenberg, A. Galeazzi, M. Torricelli, N. Di Marco, F. Larosa, M. Sas, A. Mekacher, W. Pearce, F. Zollo, W. Quattrociocchi, A. Baronchelli

Growing polarization around climate change on social media

Nat. Clim. Change, 12 (2022), pp. 1114-1121, 10.1038/s41558-022-01527-x

View in ScopusGoogle Scholar

112. 112

J. King, L. Janulewicz, F. Arcostanzo

Deny, Deceive, Delay: Documenting and Responding to Climate Disinformation at COP26 and beyond

(2022)

Google Scholar

113. 113

L.D. Bevan, T. Colley, M. Workman

Climate change strategic narratives in the United Kingdom: Emergency, Extinction, Effectiveness

Energy Res. Social Sci., 69 (2020), Article 101580, 10.1016/j.erss.2020.101580
View PDFView articleView in ScopusGoogle Scholar

114. 114

L.E. Duncan, A.J. Stewart

Personal Political Salience: The Role of Personality in Collective Identity and Action

Polit. Psychol., 28 (2007), pp. 143-164, 10.1111/j.1467-9221.2007.00560.x
View in ScopusGoogle Scholar

115. 115

N. Curtin, A.J. Stewart, L.E. Duncan

What Makes the Political Personal? Openness, Personal Political Salience, and Activism

J. Pers., 78 (2010), pp. 943-968, 10.1111/j.1467-6494.2010.00638.x
View in ScopusGoogle Scholar

116. 116

C. Roser-Renouf, E.W. Maibach, A. Leiserowitz, X. Zhao

The genesis of climate change activism: from key beliefs to political action

Climatic Change, 125 (2014), pp. 163-178, 10.1007/s10584-014-1173-5
View in ScopusGoogle Scholar

117. 117

V. Cologna, G. Hoogendoorn, C. Brick

To strike or not to strike? an investigation of the determinants of strike participation at the Fridays for Future climate strikes in Switzerland

PLoS One, 16 (2021), Article e0257296, 10.1371/journal.pone.0257296
View in ScopusGoogle Scholar

118. 118

A. Brügger, M. Gubler, K. Steentjes, S.B. Capstick

Social Identity and Risk Perception Explain Participation in the Swiss Youth Climate Strikes

Sustainability, 12 (2020), Article 10605, 10.3390/su122410605
Google Scholar

119. 119

A. Furnham, H. Cheng

Personality traits and socio-demographic variables as predictors of political interest and voting behavior in a British cohort

J. Indiv. Differ., 40 (2019), pp. 118-125, 10.1027/1614-0001/a000283
View in ScopusGoogle Scholar

120. 120

E.E. Dim, J.Y. Asomah

Socio-demographic Predictors of Political participation among women in Nigeria: Insights from Afrobarometer 2015 Data

J. Int. Wom. Stud., 20 (2019), pp. 91-105

View in ScopusGoogle Scholar

121. 121

M. Kitanova

Youth political participation in the EU: evidence from a cross-national analysis

J. Youth Stud., 23 (2020), pp. 819-836, 10.1080/13676261.2019.1636951
View in ScopusGoogle Scholar

122. 122

M.H. Goldberg, A. Gustafson, M.T. Ballew, S.A. Rosenthal, A. Leiserowitz

Identifying the most important predictors of support for climate policy in the United States

Behav. Public Policy, 5 (2021), pp. 480-502, 10.1017/bpp.2020.39
View in ScopusGoogle Scholar

123. 123

Ipsos Mori, and CAST

Net Zero Living

Ipsos Mori and the Centre for Climate Change and Social Transformation (2022)

Google Scholar

124. 124

D.M. Kahan, E. Peters, M. Wittlin, P. Slovic, L.L. Ouellette, D. Braman, G. Mandel

The polarizing impact of science literacy and numeracy on perceived climate change risks

Nat. Clim. Change, 2 (2012), pp. 732-735, 10.1038/nclimate1547
View in ScopusGoogle Scholar

125. 125

C. Drummond, B. Fischhoff

Individuals with greater science literacy and education have more polarized beliefs on controversial science topics

Proc. Natl. Acad. Sci. USA, 114 (2017), pp. 9587-9592, 10.1073/pnas.1704882114
View in ScopusGoogle Scholar

126. 126

J.N. Druckman, M.C. McGrath

The evidence for motivated reasoning in climate change preference formation

Nat. Clim. Change, 9 (2019), pp. 111-119, 10.1038/s41558-018-0360-1
View in ScopusGoogle Scholar

127. 127

R. Bayes, J.N. Druckman

Motivated reasoning and climate change

Current Opinion in Behavioral Sciences, 42 (2021), pp. 27-35, 10.1016/j.cobeha.2021.02.009
View PDFView articleView in ScopusGoogle Scholar

128. 128

E.P. Hennes, T. Kim, L.J. Remache

A goldilocks critique of the hot cognition perspective on climate change skepticism

Current Opinion in Behavioral Sciences, 34 (2020), pp. 142-147, 10.1016/j.cobeha.2020.03.009

View PDFView articleView in ScopusGoogle Scholar

129. 129

C. Bataille, H. Waisman, Y. Briand, J. Svensson, A. Vogt-Schilb, M. Jaramillo, R. Delgado, R. Arguello, L. Clarke, T. Wild, *et al.*
Net-zero deep decarbonization pathways in Latin America: Challenges and opportunities

Energy Strategy Rev., 30 (2020), Article 100510, 10.1016/j.esr.2020.100510

View PDFView articleView in ScopusGoogle Scholar

130. 130

K. Riahi, D.P. van Vuuren, E. Kriegler, J. Edmonds, B.C. O'Neill, S. Fujimori, N. Bauer, K. Calvin, R. Dellink, O. Fricko, *et al.*
The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview

Global Environ. Change, 42 (2017), pp. 153-168, 10.1016/j.gloenvcha.2016.05.009

View PDFView articleView in ScopusGoogle Scholar

131. 131

National Grid

Future Energy Scenarios 2022

(2022)

Google Scholar

132. 132

R. Ford, C. Maidment, C. Vigurs, M.J. Fell, M. Morris

Smart local energy systems (SLES): A framework for exploring transition, context, and impacts

Technol. Forecast. Soc. Change, 166 (2021), Article 120612, 10.1016/j.techfore.2021.120612
View PDFView articleView in ScopusGoogle Scholar

133. 133

P. Selman

Social Capital, Sustainability and Environmental Planning

Plann. Theor. Pract., 2 (2001), pp. 13-30, 10.1080/14649350122850
View in ScopusGoogle Scholar

134. 134

Radio New Zealand

Extinction Rebellion Protesters Arrested at Coal Protest in Dunedin

RNZ (2021)

Google Scholar

135. 135

D. Gayle

Just Stop Oil Activists Throw Soup at Van Gogh's Sunflowers

The Guardian (2022)

Google Scholar

136. 136

F. Wu, E. Martus

Contested environmentalism: the politics of waste in China and Russia

Environ. Polit., 30 (2021), pp. 493-512, 10.1080/09644016.2020.1816367
View in ScopusGoogle Scholar

137. 137

K. Huang, M. Han

Did China's Street Protests End Harsh COVID Policies? Council on Foreign Relations

(2022)

https://www.cfr.org/blog/did-chinas-street-protests-end-harsh-covid-policies
Google Scholar

138. 138

R. Green, J. Milner, A.D. Dangour, A. Haines, Z. Chalabi, A. Markandya, J. Spadaro, P. Wilkinson

The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change

Climatic Change, 129 (2015), pp. 253-265, 10.1007/s10584-015-1329-y
View in ScopusGoogle Scholar

139. 139

L. Aleksandrowicz, R. Green, E.J.M. Joy, P. Smith, A. Haines

The Impacts of Dietary Change on Greenhouse Gas Emissions, Land Use, Water Use, and Health: A Systematic Review

PLoS One, 11 (2016), Article e0165797, 10.1371/journal.pone.0165797
View in ScopusGoogle Scholar

140. 140

CAST

The Road to Net Zero: UK Public Preferences for Low-Carbon Lifestyles

Centre for Climate Change and Social Transformations (2022)

Google Scholar

141. 141

W. Abrahamse

How to Effectively Encourage Sustainable Food Choices: A Mini-Review of Available Evidence

Front. Psychol., 11 (2020), p. 589674

View in ScopusGoogle Scholar

142. 142

A. Arno, S. Thomas

The efficacy of nudge theory strategies in influencing adult dietary behaviour: a systematic review and meta-analysis

BMC Publ. Health, 16 (2016), p. 676, 10.1186/s12889-016-3272-x
View in ScopusGoogle Scholar

143. 143

M. Giaccherini, M. Gilli, S. Mancinelli, M. Zoli

Nudging food waste decisions at restaurants

Eur. Econ. Rev., 135 (2021), Article 103722, 10.1016/j.euroecorev.2021.103722
View PDFView articleView in ScopusGoogle Scholar

144. 144

G. Sparkman, G.M. Walton

Dynamic Norms Promote Sustainable Behavior, Even if It Is Counternormative

Psychol. Sci., 28 (2017), pp. 1663-1674, 10.1177/0956797617719950
View in ScopusGoogle Scholar

145. 145

F. Bianchi, E. Garnett, C. Dorsel, P. Aveyard, S.A. Jebb

Restructuring physical micro-environments to reduce the demand for meat: a systematic review and qualitative comparative analysis

Lancet Planet. Health, 2 (2018), pp. e384-e397, 10.1016/S2542-5196(18)30188-8
View PDFView articleView in ScopusGoogle Scholar

146. 146

F. Bianchi, C. Dorsel, E. Garnett, P. Aveyard, S.A. Jebb

Interventions targeting conscious determinants of human behaviour to reduce the demand for meat: a systematic review with qualitative comparative analysis

Int. J. Behav. Nutr. Phys. Activ., 15 (2018), p. 102, 10.1186/s12966-018-0729-6
View in ScopusGoogle Scholar

147. 147

WRAP

Portion Size Is the Main Reason for Plate Waste when We Eat Out

WRAP (2023)

https://wrap.org.uk/media-centre/press-releases/portion-size-main-reason-plate-waste-when-we-eat-out
Google Scholar

148. 148

Behavioural Insights Team

A Menu for Change: Using Behavioural Science to Promote Sustainable Diets Around the World

(2020)

Google Scholar

149. 149

C. Brown, A. Krishna

The Skeptical Shopper: A Metacognitive Account for the Effects of Default Options on Choice

J. Consum. Res., 31 (2004), pp. 529-539, 10.1086/425087
View in ScopusGoogle Scholar

150. 150

J.M.T. Krijnen, D. Tannenbaum, C.R. Fox

Choice architecture 2.0: Behavioral policy as an implicit social interaction

Behavioral Science & Policy, 3 (2017)

i–18

Google Scholar

151. 151

P.G. Hansen, M. Schilling, M.S. Malthesen

Nudging healthy and sustainable food choices: three randomized controlled field experiments using a vegetarian lunch-default as a normative signal

J. Public Health, 43 (2021), pp. 392-397, 10.1093/pubmed/fdz154
View in ScopusGoogle Scholar

152. 152

J. Meier, M.A. Andor, F. Doebbe, N. Haddaway, L.A. Reisch

Can Green Defaults Reduce Meat Consumption?

(2021), 10.2139/ssrn.3903160
Google Scholar

153. 153

A. Buxton

Tables Turned: Customers Had to Request Meat at Burger King Austria as Plant-Based Became the Default

Plant Based News (2022)

https://plantbasednews.org/lifestyle/food/burger-king-austria-meat-the-exception/
Google Scholar

154. 154

S. Wunderlich, M. Smoller

Consumer awareness and knowledge about food sources and possible environmental impact

Int. J. El., 2 (2019), pp. 85-96, 10.2495/EI-V2-N1-85-96
View in ScopusGoogle Scholar

155. 155

G. Borghesi, R. Stefanini, G. Vignali

Are consumers aware of products' environmental impacts? Different results between life cycle assessment data and consumers' opinions: the case study of organic Parmigiano Reggiano and its packaging

Int. J. Food Eng., 18 (2022), pp. 185-192, 10.1515/ijfe-2021-0025
View in ScopusGoogle Scholar

156. 156

B. Boardman

Carbon labelling: too complex or will it transform our buying?

Signif. (Oxf)., 5 (2008), pp. 168-171, 10.1111/j.1740-9713.2008.00322.x
View in ScopusGoogle Scholar

157. 157

F. Schaefer, M. Blanke

Opportunities and Challenges of Carbon Footprint, Climate or CO2 Labelling for Horticultural Products

Erwerbsobstbau, 56 (2014), pp. 73-80, 10.1007/s10341-014-0206-6
View in ScopusGoogle Scholar

158. 158

K.M.R. Taufique, K.S. Nielsen, T. Dietz, R. Shwom, P.C. Stern, M.P. Vandenbergh

Revisiting the promise of carbon labelling

Nat. Clim. Change, 12 (2022), pp. 132-140, 10.1038/s41558-021-01271-8
View in ScopusGoogle Scholar

159. 159

U.A. Schneider, L. Rasche, K. Jantke

Farm-level digital monitoring of greenhouse gas emissions from livestock systems could facilitate control, optimisation and labelling

Journal of Sustainable Organic Agricultural system, 69 (2019), pp. 9-12, 10.3220/LBF1580734769000
View in ScopusGoogle Scholar

160. 160

V.P. Gandhi, Z. Zhou

Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China

Food Res. Int., 63 (2014), pp. 108-124, 10.1016/j.foodres.2014.03.015
View PDFView articleView in ScopusGoogle Scholar

161. 161

J. Karstensen, G.P. Peters, R.M. Andrew

Attribution of CO2 emissions from Brazilian deforestation to consumers between 1990 and 2010

Environ. Res. Lett., 8 (2013), Article 024005, 10.1088/1748-9326/8/2/024005

View in ScopusGoogle Scholar

162. 162

J. Fassler

Lab-grown Meat Is Supposed to Be Inevitable. The Science Tells a Different Story

The Counter (2021)

Google Scholar

163. 163

M. Zurek, A. Hebinck, O. Selomane

Climate change and the urgency to transform food systems

Science, 376 (2022), pp. 1416-1421, 10.1126/science.abo2364
View in ScopusGoogle Scholar

164. 164

European Environment Agency

Greenhouse Gas Emissions from Transport in Europe

(2022)

Google Scholar

165. 165

IEA

World Energy Investment 2022

(2022)

Google Scholar

166. 166

OECD

Investing in Climate, Investing in Growth

(2017)

Google Scholar

167. 167

S. Cairns, L. Sloman, C. Newson, J. Anable, A. Kirkbride, P. Goodwin

Smarter Choices: Assessing the Potential to Achieve Traffic Reduction Using ‘Soft Measures

Transp. Rev., 28 (2008), pp. 593-618, 10.1080/01441640801892504
View in ScopusGoogle Scholar

168. 168

P. Mock

Decoupling Emissions from Growing Traffic Volume

International Council on Clean Transportation (2012)

https://theicct.org/decoupling-emissions-from-growing-traffic-volume/
Google Scholar

169. 169

Department for Transport

Road Traffic Estimates: Great Britain 2021

(2022)

Google Scholar

170. 170

C. Brand, A. Jillian, M. Greg

The Role of Energy Demand Reduction in Achieving Net-Zero in the UK: Transport and Mobility

Centre for Research into Energy Demand Solutions (2021)

Google Scholar

171. 171

L. Castellazzi, P. Bertoldi, M. Economidou

Overcoming the Split Incentive Barrier in the Building Sector

Publications Office of the European Union (2017)

Google Scholar

172. 172

C. Moreno, Z. Allam, D. Chabaud, C. Gall, F. Pratlong

Introducing the “15-Minute City”: Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities

Smart Cities, 4 (2021), pp. 93-111, 10.3390/smartcities4010006
View in ScopusGoogle Scholar

173. 173

OECD

Teleworking in the COVID-19 Pandemic

(2021)

Google Scholar

174. 174

Office for National Statistics

Is Hybrid Working Here to Stay?

(2022)

Google Scholar

175. 175

J. Anable, B. Llinos, I. Docherty, G. Marsden

Less Is More: Changing Travel in a Post-pandemic Society

Centre for Research into Energy Demand Solutions (2022)

Google Scholar

176. 176

Bureau of Transportation Statistics

Transportation Statistics Annual Report 2021

US Department of Transportation (2021)

Google Scholar

177. 177

S. Kraus, N. Koch

Provisional COVID-19 infrastructure induces large, rapid increases in cycling

Proc. Natl. Acad. Sci. USA, 118 (2021), Article e2024399118, 10.1073/pnas.2024399118
View in ScopusGoogle Scholar

178. 178

A. Jáuregui, E.V. Lambert, J. Panter, C. Moore, D. Salvo

Scaling up urban infrastructure for physical activity in the COVID-19 pandemic and beyond

Lancet, 398 (2021), pp. 370-372, 10.1016/S0140-6736(21)01599-3
View PDFView articleView in ScopusGoogle Scholar

179. 179

A. Nelson

Riding in Riverside: The Rail-Bus Divide. Riding in Riverside

(2011)

http://ridinginriverside.blogspot.com/2011/08/rail-bus-divide.html
Google Scholar

180. 180

A. Shrikant

The Bus Gets a Lot of Hate. American Cities Are Trying to Change that

Vox (2018)

Google Scholar

181. 181

TFL

Congestion Charging: Impacts Monitoring

Second Annual Report (Transport for London) (2004)

Google Scholar

182. 182

H. Allcott

Social norms and energy conservation

J. Publ. Econ., 95 (2011), pp. 1082-1095, 10.1016/j.jpubeco.2011.03.003
View PDFView articleView in ScopusGoogle Scholar

183. 183

J. Carroll, S. Lyons, E. Denny

Reducing household electricity demand through smart metering: The role of improved information about energy saving

Energy Econ., 45 (2014), pp. 234-243, 10.1016/j.eneco.2014.07.007
View PDFView articleView in ScopusGoogle Scholar

184. 184

BEIS

Smart Meter Roll-Out: Cost-Benefit Analysis

(2019)

Google Scholar

185. 185

S. Oliveira, E. Prestwood, T. Chatterton, A. Poghosyan, B. Gething

Heating Controls: International Evidence Base and Policy Experiences

Department of Business, Energy and Industrial Strategy (2017)

Google Scholar

186. 186

T. Park

Evaluating the Nest Learning Thermostat-Four Field Experiments Evaluating the Energy Saving Potential of Nest's Smart Heating Control (Behavioural Insights Team)

(2017)

Google Scholar

187. 187

F. Wade, M. Shipworth, R. Hitchings

How installers select and explain domestic heating controls

Build. Res. Inf., 45 (2017), pp. 371-383, 10.1080/09613218.2016.1159484
View in ScopusGoogle Scholar

188. 188

F. Wade

Routinised heating system installation: The immutability of home heating

Energy Efficiency, 13 (2020), pp. 971-989, 10.1007/s12053-020-09867-3
View in ScopusGoogle Scholar

189. 189

C. Ahern, B. Norton

Energy savings across EU domestic building stock by optimizing hydraulic distribution in domestic space heating systems

Energy Build., 91 (2015), pp. 199-209, 10.1016/j.enbuild.2015.01.014
View PDFView articleView in ScopusGoogle Scholar

190. 190

Wunderflats

Green Living Index 2022

(2022)

Google Scholar

191. 191

Tado

UK Homes Losing Heat up to Three Times Faster than European Neighbours

Press Release (2020)

https://www.tado.com/gb-en/press/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours
Google Scholar

192. 192

J. Rosenow, N. Eyre

A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy

Energy Res. Social Sci., 21 (2016), pp. 141-144

View PDFView articleView in ScopusGoogle Scholar

193. 193

IEA

Solar PV

International Energy Agency (2022)

Google Scholar

194. 194

J. Jackman

Which Countries Are Winning the Heat Pump Race? the Eco Experts

(2021)

https://www.theecoexperts.co.uk/heat-pumps/top-countries
Google Scholar

195. 195

European Heat Pump Association

Market Data. European Heat Pump Association

(2022)

https://www.ehpa.org/market-data/
Google Scholar

196. 196

A.S. Gaur, D.Z. Fitiwi, J. Curtis

Heat pumps and our low-carbon future: A comprehensive review

Energy Res. Social Sci., 71 (2021), Article 101764, 10.1016/j.erss.2020.101764
View PDFView articleView in ScopusGoogle Scholar

197. 197

R. Khosla, N.D. Miranda, P.A. Trotter, A. Mazzone, R. Renaldi, C. McElroy, F. Cohen, A. Jani, R. Perera-Salazar, M. McCulloch

Cooling for sustainable development

Nat. Sustain., 4 (2020), pp. 201-208, 10.1038/s41893-020-00627-w
Google Scholar

198. 198

IEA

The Future of Cooling

International Energy Agency (2018)

Google Scholar

199. 199

Buildings Energy Efficiency Taskgroup

Minimum Energy Standards for Rented Properties: An International Review

Department of Climate Change, Energy, the Environment and Water (2020)

Australian Government)

Google Scholar

200. 200

S. Amelang

Germany Splits CO2 Price for Heating between Landlords and Tenants

Clean Energy Wire (2022)

Google Scholar

201. 201

Deutscher Bundestag

Act on the Allocation of Carbon Dioxide Costs (Carbon Dioxide Cost Allocation Act - CO2KostAufG)

(2022)

Google Scholar

202. 202

M. Meissner

Against accumulation: lifestyle minimalism, de-growth and the present post-ecological condition

Journal of Cultural Economy, 12 (2019), pp. 185-200, 10.1080/17530350.2019.1570962
View in ScopusGoogle Scholar

203. 203

A. Parriaux

Do single-use plastic bans work?

(2022)

https://www.bbc.com/future/article/20220711-do-single-use-plastic-bans-work

Google Scholar

204. 204

Ipsos Mori, and King's College London

Public Concern about Plastic and Packaging Waste Is Not Backed up by Willingness to Act

Ipsos (2018)

https://www.ipsos.com/en-uk/public-concern-about-plastic-and-packaging-waste-not-backed-willingness-act
Google Scholar

205. 205

E. Gray

Attitudes towards Single-Use Plastics (Ipsos)

(2022)

Google Scholar

206. 206

European Environment Agency

Paving the Way for a Circular Economy: Insights on Status and Potentials

(2019)

Google Scholar

207. 207

C.E. Cherry, N.F. Pidgeon

Is sharing the solution? Exploring public acceptability of the sharing economy

J. Clean. Prod., 195 (2018), pp. 939-948, 10.1016/j.jclepro.2018.05.278
View PDFView articleView in ScopusGoogle Scholar

208. 208

I. Murphy

Brands Need to Simplify Sustainability

RedC Research & Marketing (2021)

https://redcresearch.ie/sustainability-headlines-march-2021/
Google Scholar

209. 209

Competition and Markets Authority

Global Sweep Finds 40% of Firms' Green Claims Could Be Misleading. GOV.UK

(2021)

https://www.gov.uk/government/news/global-sweep-finds-40-of-firms-green-claims-could-be-misleading
Google Scholar

210. 210

R.A. Howell

Carbon management at the household level: a definition of carbon literacy and three mechanisms that increase it

Carbon Manag., 9 (2018), pp. 25-35, 10.1080/17583004.2017.1409045
View in ScopusGoogle Scholar

211. 211

W. Ejaz, M. Mukherjee, R. Fletcher, R.K. Nielsen

How We Follow Climate Change: Climate News Use and Attitudes in Eight Countries

(2022), p. 45

Google Scholar

212. 212

J.T. Carmichael, R.J. Brulle

Elite cues, media coverage, and public concern: an integrated path analysis of public opinion on climate change, 2001–2013

Environ. Polit., 26 (2017), pp. 232-252, 10.1080/09644016.2016.1263433
View in ScopusGoogle Scholar

213. 213

T. Deryugina, O. Shurchkov

The Effect of Information Provision on Public Consensus about Climate Change

PLoS One, 11 (2016), Article e0151469, 10.1371/journal.pone.0151469
View in ScopusGoogle Scholar

214. 214

Greenpeace

How to Talk about Climate Change with Friends and Family

Greenpeace UK (2021)

https://www.greenpeace.org.uk/news/how-to-talk-about-climate-change-family-friends-conversation/
Google Scholar

215. 215

World Economic Forum

Why We Need a New Social Contract for the 21st Century

World Economic Forum (2022)

https://www.weforum.org/agenda/2022/01/a-new-social-contract-for-21st-century/
Google Scholar

216. 216

The Nature Conservancy

How to Talk about Climate Change

(2018)

https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/can-we-talk-climate/
Google Scholar

217. 217

T. Hargreaves

Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change

J. Consum. Cult., 11 (2011), pp. 79-99, 10.1177/1469540510390500
View in ScopusGoogle Scholar

218. 218

C. Shaw, A. Corner

Using Narrative Workshops to socialise the climate debate: Lessons from two case studies – centre-right audiences and the Scottish public

Energy Res. Social Sci., 31 (2017), pp. 273-283, 10.1016/j.erss.2017.06.029
View PDFView articleView in ScopusGoogle Scholar

219. 219

C. Verfuerth, D. Gregory-Smith

Spillover of pro-environmental behaviour

Research Handbook on Employee Pro-Environmental Behaviour (2018), pp. 455-484

View in ScopusGoogle Scholar

220. 220

C. Verfuerth, D. Gregory-Smith, C.J. Oates, C.R. Jones, P. Alevizou

Reducing meat consumption at work and at home: facilitators and barriers that influence contextual spillover

J. Market. Manag., 37 (2021), pp. 671-702, 10.1080/0267257X.2021.1888773
View in ScopusGoogle Scholar

221. 221

A. Fenton

Millennials Are Looking for Greener Places to Work

Yahoo Finance (2019)

Google Scholar

222. 222

KPMG

Climate Quitting - Younger Workers Voting with Their Feet on Employer's ESG Commitments

KPMG (2023)

https://kpmg.com/uk/en/home/media/press-releases/2023/01/climate-quitting-younger-workers-voting-esg.html
Google Scholar

223. 223

A. Gaskell

Employees Demand that We Become More Sustainable

Forbes (2021)

https://www.forbes.com/sites/adigaskell/2021/10/31/employees-demand-that-we-become-more-sustainable/
Google Scholar

224. 224

OECD

Unemployment Rate (Indicator)

(2023)

https://data.oecd.org/unemp/unemployment-rate.htm
Google Scholar

225. 225

D. Sproull

New Study Shows Employees Seek and Stay Loyal to Greener Companies. swytchX

(2019)

https://medium.com/swytch/new-study-shows-employees-seek-and-stay-loyal-to-greener-companies-f485889f9a7f
Google Scholar

226. 226

I. Tharoor

Analysis | Bolsonaro, Trump and the Nationalists Ignoring Climate Disaster

Washington Post (2019)

Google Scholar

227. 227

C. Wolsko, H. Ariceaga, J. Seiden

Red, white, and blue enough to be green: Effects of moral framing on climate change attitudes and conservation behaviors

J. Exp. Soc. Psychol., 65 (2016), pp. 7-19, 10.1016/j.jesp.2016.02.005
View PDFView articleView in ScopusGoogle Scholar

228. 228

A. Corner, E. Markowitz, N. Pidgeon

Public engagement with climate change: the role of human values

WIREs Clim. Change, 5 (2014), pp. 411-422, 10.1002/wcc.269
View in ScopusGoogle Scholar

229. 229

L. Whitmarsh, A. Corner

Tools for a new climate conversation: A mixed-methods study of language for public engagement across the political spectrum

Global Environ. Change, 42 (2017), pp. 122-135, 10.1016/j.gloenvcha.2016.12.008
View PDFView articleView in ScopusGoogle Scholar

230. 230

S.J. O'Neill, N. Smith

Climate change and visual imagery

WIREs Climate Change, 5 (2014), pp. 73-87, 10.1002/wcc.249
View at publisherView in ScopusGoogle Scholar

231. 231

M.C. McGrath

Experiments on problems of climate change

Advances in Experimental Political Science, Cambridge University Press (2020), pp. 606-629

Google Scholar

232. 232

R. Borghesi

Employee political affiliation as a driver of corporate social responsibility intensity

Appl. Econ., 50 (2018), pp. 2117-2132, 10.1080/00036846.2017.1388911
View at publisherView in ScopusGoogle Scholar

233. 233

D.R. Fisher, S. Nasrin

Climate activism and its effects

WIREs Clim. Change, 12 (2021), p. e683, 10.1002/wcc.683
View at publisherView in ScopusGoogle Scholar

234. 234

T. Bolsen, M.A. Shapiro

The US News Media, Polarization on Climate Change, and Pathways to Effective Communication

Environmental Communication, 12 (2018), pp. 149-163, 10.1080/17524032.2017.1397039
View in ScopusGoogle Scholar

235. 235

UCL

"Let the People Decide" – Is Participatory Democracy the Answer to the Climate Crisis? Global Governance Institute

(2022)

https://www.ucl.ac.uk/global-governance/research/let-people-decide-participatory-democracy-answer-climate-crisis
Google Scholar

236. 236

R. Willis

Too Hot to Handle?: The Democratic Challenge of Climate Change

(1st ed.), Bristol University Press (2020), 10.2307/j.ctvz938kb
Google Scholar

237. 237

J. Boswell, R. Dean, G. Smith

Integrating citizen deliberation into climate governance: Lessons on robust design from six climate assemblies

Public Administration *n/a.*, 101 (2022), pp. 182-200, 10.1111/padm.12883
Google Scholar

238. 238

E.A. Soto, L.B. Bosman, E. Wollega, W.D. Leon-Salas

Peer-to-peer energy trading: A review of the literature

Appl. Energy, 283 (2021), Article 116268

View PDFView articleView in ScopusGoogle Scholar

239. 239

R.D. Longa

Urban Infrastructure: Globalization/Slowbalization

Springer Nature (2023)

Google Scholar

240. 240

Sillito

Tuesday to Thursday Is the New Office Working Week, Data Suggests

BBC News (2023)

Google Scholar

241. 241

Behavioural Insights Team

How to Build a Net Zero Society: Using Behavioural Insights to Decarbonise Home Energy, Transport, Food, and Material Consumption

(2023)

Google Scholar

242. 242

J. Walenta

Climate risk assessments and science-based targets: A review of emerging private sector climate action tools

WIREs Clim. Change, 11 (2020), p. e628, 10.1002/wcc.628
View at publisherView in ScopusGoogle Scholar

Cited by (28)

- Current research practices on pro-environmental behavior: A survey of environmental psychologists

2024, Journal of Environmental Psychology

Citation Excerpt :

For example, civic and leadership behaviors were almost exclusively measured with self-report. Without making any strong claims about typologies of pro-environmental behavior, the most frequently studied behaviors appear to be in the role of consumer rather than citizen or advocate (Hampton & Whitmarsh, 2023; Nielsen, Nicholas, Creutzig, Dietz, & Stern, 2021). All behaviors were considered relatively important to the wider environmental psychology community, Ms (SDs) = 3.5–6.0 (1.1–1.8).
Show abstract

- ## Carbon capability revisited: Theoretical developments and empirical evidence
  2024, Global Environmental Change

  Whereas previous CC scholarship has focused on individuals' adoption of low-carbon behaviours in their own lives (micro-scale), or direct engagement with systems of provision (macro-scale), our study has added to this by highlighting the importance of meso-scale practices, such as those relating to social influence and organisational membership. At this level, businesses are crucial actors in shaping choice environments through 'midstream' measures such as increasing the variety of low-carbon options, introducing low-carbon defaults or other 'nudges' (Behavioural Insights Team, 2023; Hampton and Whitmarsh, 2023). These help to establish low-carbon norms and build communities of CC.
  Show abstract

- ## Affective responses drive the impact neglect in sustainable behavior
  2023, iScience

  Citation Excerpt :

  In addition, a plethora of research studies and perspectives support the view that human behavior is central to how we mitigate the effects of climate change.2,3,4,5,6 Various human behaviors would reduce emissions such as consuming low-carbon products and services as well as supporting policies and technologies aimed at creating sustainable systems.7 Here, our focus lies on the former: mitigative human behaviors aimed at reducing emissions (e.g., purchasing low-carbon products, adopting a plant-based low-carbon diet, reducing air transport, and so forth).1

POLICY , MITIGATION AND LOW CARBON DEVELOPMENT

Policy and mitigation and low carbon development" refers to government strategies aimed at reducing greenhouse gas emissions (mitigation) by promoting economic development pathways that minimize carbon footprint, often achieved through policies that encourage renewable energy, energy efficiency, sustainable transportation, and responsible land use practices, all while considering the needs of economic growth and social development.

Key points about policy and mitigation in low carbon development:

- **Goal:**

  To transition towards a low-carbon economy by actively reducing emissions across various sectors like energy, industry, transportation, and agriculture while still enabling economic progress.
- **Policy instruments:**
- **Carbon pricing:** Implementing carbon taxes or cap-and-trade systems to incentivize emissions reductions.
- **Renewable energy mandates:** Setting targets for the percentage of electricity generated from renewable sources like solar and wind.
- **Energy efficiency standards:** Setting minimum efficiency requirements for appliances and buildings.
- **Investment in clean technologies:** Providing financial support for research and development of low-carbon technologies.
- **Sustainable transportation policies:** Promoting public transport, electric vehicles, and improved fuel efficiency standards.
  Mitigation strategies within low carbon development:
- **Shifting to renewable energy:** Investing in solar, wind, geothermal, and hydropower.
- **Improving energy efficiency:** Implementing measures to reduce energy consumption in buildings and industries.
- **Carbon capture and storage (CCS):** Technologies to capture CO_2 emissions from power plants and store them underground.
- **Sustainable land use practices:** Protecting forests, promoting reforestation, and managing agricultural practices to reduce emissions.
  Challenges and considerations:
- **Economic costs:** Balancing the need for emissions reduction with maintaining economic competitiveness.
- **Social equity:** Ensuring that low carbon policies do not disproportionately impact vulnerable populations.
- **International cooperation:** Addressing the global nature of climate change requiring coordinated efforts between countries.

The Overseas Development Institute (ODI) has reviewed the **low carbon growth and climate change response strategies** of a range of countries with differing economic characteristics to draw out the policy implications for developing countries at different stages of development (Ellis et al., 2009). The study, financed by the UK Department for International Development (DFID), selected a crosssection of high-, middle- and low-income countries to conduct a balanced review of low carbon growth policies. High-income countries (HICs) included Germany and the United Kingdom. Middleincome countries (MICs) included China, Brazil, Guyana, Mexico and Nigeria. Low-income countries included Bangladesh, and Ethiopia. Shorter 'snapshots' were also provided for South Korea, India, Malawi, Rwanda and South Africa. These countries were chosen because they indicate the range of activities being carried out. All have published official documents outlining their climate change policies, such as national strategy documents, National Adaptation Programme of Action (NAPA) reports to the UN Framework Convention on Climate Change (UNFCCC), and national communications to the UNFCCC. Growth has been, historically, highly correlated with carbon emissions. In light of the impact that this has had on climate change, new, low carbon growth strategies are being sought, i.e. policymakers are now seeking to achieve growth pathways that are associated with relatively low increases in carbon emissions. Many developing countries have struggled to achieve any kind of sustained growth however, and have contributed little to the problem of climate change. The question for them will be how to achieve growth at all, particularly in light of climate change and international mitigation policies and the impact these are having on their economies. These countries will need to find climate resilient growth strategies (i.e. growth strategies which are achievable despite the impact of climate change), and identify and manage opportunities (such as new markets) and risks (such as trade barriers) that arise from international mitigation efforts, in order to achieve growth in future. Having an appropriate policy framework in place (such as a NAPA or Nationally Appropriate Mitigation Actions (NAMA)), is likely to help countries secure public and private funding for adaptation and mitigation. Identification of future mitigation opportunities and low carbon growth trajectories could thus be important, even for countries that have achieved only low growth rates to date. This will allow such countries to position themselves to take maximum advantage of new opportunities that may arise. For this reason we have considered both low carbon and climate resilient growth strategies in this report, as well as strategies to maximise growth potential arising from international mitigation efforts going forward. The report draws on the case studies and other relevant literature to identify possible policy lessons and discuss the extent to which low carbon growth challenges traditional growth theory and policies. Achieving low carbon growth clearly has major implications for policy, and implies considerable adjustment of the traditional growth agenda. However, low carbon growth does not present a major challenge to traditional growth theory, it simply requires the internalisation of the environmental costs of growth through the appropriate pricing of goods and services. This can be achieved through a range of mitigation policies, such as taxes on the production or consumption of carbon intensive goods. Policies for Low Carbon Growth vii The potential impact of mitigation policies on growth is unclear. Constraints on emissions raise the cost of energy which, in turn, reduces the output that can be achieved with a given set of inputs. No consensus exists on the costs of mitigation however, which will depend on the efficiency and nature of the policies adopted, and the extent of technological innovation achieved. And mitigation could also generate new growth opportunities, which would offset those costs. This could be the case if, for example, there is fast growth in demand for environmental goods and services. Significant co-benefits associated with mitigation could also occur if there are strong synergies between green technology change and industrial technological progress, which is a key source of growth. Policies designed to promote green technological innovation and technology transfer could thus also potentially increase growth. In addition, some mitigation policies generate revenues (e.g. carbon taxes) and provide opportunities to stimulate growth through the judicious use of the revenues raised. Thus the design of national mitigation policies and the way incentive mechanisms for low carbon growth are created will determine overall growth effects. The literature on this is mixed however, and modelling results depend enormously on the particular assumptions that are used. While much of the literature on mitigation suggests an overall negative impact on growth, a recent report by The Climate Group finds that a global climate agreement could lead to an increase in global GDP of 0.8% by 2020 relative to projected GDP with no climate action. In addition to the overall impact of mitigation on global growth, the distribution of mitigation efforts will be important in determining the growth impacts in different parts of the world. Rich countries may need to accept lower rates of growth in future, if developing countries are to have the necessary space to grow their way out of poverty. The way that revenues from international mitigation efforts are used will also be important. For example, if auction revenue raised from permit sales in carbon cap-and-trade schemes is then used to finance mitigation or adaptation in developing countries, this could generate significant gains for recipient countries. Mitigation policies will affect different sectors in different ways and are likely to imply adjustments to the sectoral sources of growth enjoyed previously by some countries. For example, mitigation policies which drive down the price of oil will generate a net loss for oil exporting countries and net gain for oil importers. Air transport taxes might reduce demand for tourism or for air freighted exports such as fruit and vegetables. Carbon taxes may generate carbon leakage (i.e. the shift of dirty industry to pollution havens) and reduce income associated with carbon intensive products. The impact of these policies will vary significantly by country, depending on their sectoral composition. The analysis of the potential impact of different kinds of mitigation policies is fairly limited to date and the subject of a forthcoming ODI study. A key determinant of the impact of international efforts to mitigate climate change on developing countries' growth paths will be the policies adopted by developing countries to adapt, mitigate and strategically position themselves in order to benefit from these international mitigation responses. This is likely to include the pursuit of a low carbon growth path as a prerequisite for receiving finance either for mitigation or adaptation. Appropriate policies can help to position countries to take advantage of new economic opportunities that may arise and can also help protect countries from threats to their growth arising from climate change or its mitigation. Identifying policy implications To aid comparison across countries, and with conventional growth policies, the review has been structured around the following six key pillars: Policies for Low Carbon Growth 1. Finance for mitigation and adaptation; 2. Human capital; 3. Technological progress in energy, infrastructure and transportation; 4. Investment in agriculture and forestry; 5. Trade and private investment opportunities; 6. Incentives and regulation for low carbon growth. We have reviewed case studies and literature under each of these pillars and identified the following possible policy lessons. (A more detailed discussion of policy implications drawn from the country policy reviews is contained in the full version of this report.) Finance for mitigation and adaptation

• For the international policy community, the achievement of an international agreement on emissions reductions is a priority to help unlock private finance for mitigation.

• Countries can be strategic in how they position themselves to attract finance for mitigation and adaptation. For example, the development of a 'Climate Change Fund'/multi-donor trust fund, and an appropriate policy framework e.g. a NAPA, NAMA, and/or a low carbon growth strategy, can help to convince donors that climate change is taken seriously in that country, and that any funding will be spent transparently and effectively.

• Developing countries need to continue to lobby for financial support for mitigation and adaptation, and for reform that will help them benefit more from carbon markets, including the Clean Development Mechanism (CDM).

• For countries with carbon assets, strategic positioning, policy development, and lobbying for financial support for mitigation and adaptation, may help to both influence the international agenda, and the development of international mitigation mechanisms, such as Reduced Emissions from Deforestation and Forest Degradation (REDD) and CDM, in their favour, both in terms of scope and scale.

• Widening the scope of carbon markets to enable more LICs to benefit, and improving the investment climate in developing countries may also help them to maximise financial inflows of private finance for mitigation.

• Not all developing countries will be able to obtain private finance for mitigation and adaptation. Increasing the availability of public finance will also be important in supporting developing countries' low carbon growth efforts. Human capital

• Broad awareness-raising may help increase public understanding of climate change and its effects, and the implications for people's livelihoods and welfare going forward. This can be implemented formally, for example through schools, or informally, through public awareness campaigns.

• Training in skills relating to green technologies and industries can help position countries to take advantage of any new low carbon growth opportunities and markets.

• Targeted investments in health, water and sanitation may help increase climate resilience by protecting human capital from the potential negative health impacts of climate change. Technological progress in energy, infrastructure and transportation

• Infrastructure improvements and the development of clean energy options should be made as soon as possible to reduce emissions as well as adapt to potential impacts. This will avoid locking in high-carbon technologies and processes as demand for energy rises. The development of decentralised grids may offer co-benefits between greener energy production, and increased access to energy.

• Strategic thinking and strong policy management of patterns of urbanisation may be required to increase climate resilience and facilitate low carbon growth. Policies for Low Carbon Growth ix

• Government can play an important role in clarifying the future direction of policy and the key decisions that will be made on energy production and infrastructure development, to give business the confidence it needs to undertake low carbon investments.

• It is critical for low-income countries to receive international support and technology transfer to facilitate their transition to a low carbon economy. Greater efforts to promote international cooperation on research and development may help to promote technological diffusion. A re-examination of intellectual property provisions in the World Trade Organization (WTO) may also be needed.

• Countries should identify renewable resources that provide the greatest advantage in view of local conditions, resources, and state of development.

• The future development, demonstration and transfer of technology for carbon capture and storage will be very important for countries that continue to develop their large coal reserves.

• Governments in all countries can benefit from working with the private sector and civil society to scale up renewable technologies, from improved cook-stoves to large-scale wind and solar to hydropower.

• Transport is best approached holistically and should include public transport, clean, sustainable fuels, and efficient vehicles.

• Biofuels offer a potentially important new export opportunity for some developing countries, although major developed countries still impose protection on biofuel imports. Investment in agriculture and forestry

• Greater understanding and awareness of the impact of climate change on agricultural productivity, and shifts in demand for agricultural produce will help developing countries to improve climate resilience and take advantage of possible new growth opportunities. Education of farmers will be an important component in this.

• Comprehensive approaches that include improved agronomic practices; climate-resistant crop varieties; water, soil and fertiliser management, and better livestock management are needed.

• Adaptation efforts in agriculture may be most important in poor countries that rely disproportionately on agriculture and are likely to be most affected by climate change.

• Forestry payments present a significant potential financing opportunity for some countries, if international mechanisms such as REDD can be successfully developed.

• Countries that develop a rigorous, comprehensive, transparent and inclusive process around sustainable forest management may be more likely to secure international investments and future CDM benefits and turn them into successful alternative growth strategies and conservation of forests.

• Agriculture offers considerable potential sequestration benefits though there are significant barriers to attracting carbon finance for this sector. Trade and private investment opportunities

• Countries that identify, target and secure new green investment and growth opportunities stand to benefit more from the transition to a low carbon economy.

• There is a role for government leadership to identify low carbon growth sectors which may provide competitive advantage and employment growth.

• The development of new opportunities must be backed by sufficient support and funding from government and the international community. This includes the creation of an appropriate policy environment; provision of the necessary training/education; investment promotion and awareness raising; and collaborative partnerships between the public, private and NGO sectors. Policies for Low Carbon Growth x Incentives and regulation for low carbon growth

• Internationally coordinated action to mitigate climate change can help reduce the risk of a 'race to the bottom' in relation to the taxation and regulation needed to stimulate low carbon growth.

• Donor support for low carbon regulation and taxation could help build developing countries' capacity to implement such policies effectively.

• An ongoing review of the efficacy and cost-effectiveness of measures by different countries to incentivise the necessary changes in behaviour and stimulate low carbon growth, could help improve policy-making in this area.

• Many of the barriers to low carbon growth, mitigation financing and technological transfer in developing countries are the same as the barriers to growth and investment generally i.e. a poor investment climate and uncompetitive markets. Policies to tackle these remain important. Policy processes In our review, we also looked at the policy processes adopted in each country. Possible lessons include:

• Policy statements should go beyond 'statements of intent' to provide a roadmap for specific measures and an implementation plan.

• Policy is strengthened by underpinning studies.

• Consultations help to obtain ideas and include various stakeholder viewpoints; promote coordination and collaboration, and enhance transparency and trust in the process.

• The inclusion of civil society helps build support for policies and thus aids in implementation. Consulting and partnering with the private sector can help increase the feasibility and market-friendliness of policies that are proposed. This can facilitate greater private sector engagement in achieving low carbon growth and improve the sustainability and scale-up of green investments.

• Training and education can help with coordinating different government departments and policies.

• Providing strong policy guidance is crucial to implementation. Progress to date and lessons learned The countries we have reviewed have already taken steps to develop a climate change or low carbon development strategy, and thus are, to a greater or lesser degree, ahead of other countries, within their income category at least. However, there are still a number of issues that most countries either did not address or could not resolve in their policy documents. These include:

• Specification of a (potential) funding source for climate mitigation and adaptation activities;

• An implementation roadmap with specific measures;

• Anti-corruption and pro-transparency measures governing the use of mitigation/adaptation funds;

• A framework for macro management and measures to combat Dutch Disease;

• Identification of new green growth opportunities and the policies needed to achieve them;

• A rigorous consultation process;

• The need for policy alignment and intra-governmental cooperation. So, although many of these countries are, to some extent, ahead of the game in terms of policies to promote low carbon growth and climate resilience, it is clear that improvements can still be made. Policies for Low Carbon Growth Nonetheless, the policies they have set out and the processes they have pursued can provide valuable lessons for other countries only now beginning to think about how they will respond to climate change. While it is too early to judge the efficacy of many of these policies (and indeed many of them are still only being planned), ongoing monitoring of their impact will be important in ensuring that lesson are learned globally, thus speeding up the effective response to this most pressing of problems.

Journal of Applied Biology & Biotechnology Vol. 12(2), pp. 1-12, Mar-Apr, 2024
Available online at http://www.jabonline.in
DOI: 10.7324/JABB.2024.148189

Environment and climate change: Influence on biodiversity, present scenario, and future prospect

Divjot Kour[1], Kanwaljit Kaur Ahluwalia[2], Seema Ramniwas[3], Sanjeev Kumar[4], Sarvesh Rustagi[5], Sangram Singh[6], Ashutosh Kumar Rai[7], Ajar Nath Yadav[8,9]*, Amrik Singh Ahluwalia[10]*

[1]Department of Microbiology, Akal College of Basic Sciences, Eternal University, Baru Sahib, Sirmour, Himachal Pradesh, India.
[2]Department of Zoology, Akal College of Basic Sciences, Eternal University, Baru Sahib, Sirmour, Himachal Pradesh, India.
[3]Department of Biotechnology, University Centre for Research and Development, Chandigarh University, Gharuan, Mohali, India.
[4]Department of Genetics and Plant Breeding, Faculty of Agricultural Science, GLA University, Mathura, India
[5]Department of Food Technology, School of Applied and Life sciences, Uttaranchal University, Dehradun, Uttarakhand, India.
[6]Department of Biochemistry, Dr. Ram Manohar Lohia Avadh University Faizabad, Uttar Pradesh, India.
[7]Department of Biochemistry, College of Medicine, Imam Abdulrahman Bin Faisal University, Dammam, Kingdom of Saudi Arabia.
[8]Department of Biotechnology, Dr. Khem Singh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmour, Himachal Pradesh, India.
[9]Department of Biotechnology, Faculty of Health and Life Sciences, INTI International University, Persiaran Perdana BBN Putra Nilai, Negeri Sembilan, Malaysia.
[10]Department of Botany, Akal College of Basic Sciences, Eternal University, Baru Sahib, Sirmour, India.

ARTICLE INFO

Article history:
Received on: August 01, 2023
Accepted on: December 21, 2023
Available online: February 20, 2024

Key words:
Biodiversity,
Climate change,
Conservation,
Economics,
Environment,
Sustainability.

ABSTRACT

Climate change has become a widespread problem in recent years. It is one of the most important global environmental challenges affecting all the natural ecosystems of the world. Various parameters such as increased CO_2 levels, faster glacier melts, and rainfall variability and severe drought have been associated with climate change. Biodiversity is influenced by climate change in different ways including shifts in ranges, changes in relative abundance within species ranges, and subtler changes in activity timing and microhabitat use. Soil properties and water resources are affected by fast changing climate. All these consequences demand for integrated management approaches, proper planning and designing policies to safeguard the biodiversity and hence environment. The present review describes the effect of changing climate on prokaryotic and eukaryotic communities, environment, and economics, the response of communities to such changes and conservation strategies that could be adopted to respond to these changes.

ARTICLE HIGHLIGHTS

- Changing climate is a global challenge
- It is affecting prokaryotic and eukaryotic biodiversity, environment, and economics
- Conservation and mitigation strategies are of global importance
- Framing policies is important to safeguard biodiversity and environment in present scenario of climate change crisis

1. INTRODUCTION

The super challenges of the 21st century are climate change, energy supply, health and disease invasion, and sustainable environment. The world's climate continues to change at a rate expected to be unprecedented in recent human history. The increase of about 0.6°C in global average surface temperature has been observed during the twentieth-century. In recent years, human activity and natural factors have led to rapid increase in greenhouse gas (GHG) emissions. The influence of emitted GHG on future climate is estimated due to its capability of absorbing available infrared radiation and its persistence in the atmosphere [1]. The effects of global warming are broader which may include arctic shrinkage, glacial retreat, and worldwide sea level rise. The changing precipitation patterns will result in more floods and drought. The changes will also occur in agricultural yields, there may be addition of new trade routes, vast extinction of species and increase in disease vectors range [2].

In fact, the climate change is not only an environmental issue nor is it the only threat to global prosperity rather is a threat multiplier for diverse other urgent concerns including global security, disease and habitat loss. Climate change is unique in its scale and enormous risks it poses. Climate change, if remained unchecked, possibly will redraw the map of the planet. It can create global living conditions beyond

**Corresponding Author:*
Amrik Singh Ahluwalia,
Eternal University, Baru Sahib, Sirmour - 173 101, Himachal Pradesh, India.
Email: amrik.s511 @ gmail.com
Ajar Nath Yadav, Department of Biotechnology, Dr. Khem Sigh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmour, Himachal Pradesh, India. Email: ajarbiotech @ gmail.com

the range, humanity has ever experienced in history. The influence of climatic change is much broader, such as increased frequency of hypoxic events, storm activity, altered rainfall patterns, and flow regimes of freshwater streams and rivers [3]. There is a discernible global pattern of the effects of climate change on crop productivity, which may have implications for food availability. Climate change may jeopardize the stability of entire food systems. The demand for agricultural products has been estimated to increase with increase in global population, which may require a shift toward sustainable intensification of food systems [4].

Rising concentration of atmospheric carbon dioxide is one of the most critical problems as its effects are globally persistent and irreversible on ecological timescales [5]. The primary direct consequences are increasing ocean temperatures [6]. Rising temperatures create additional changes such as increase in ocean stratification, increasing sea levels, reduced sea ice extent, altered ocean circulation patterns, precipitation and freshwater inflows. Acidification is another direct impact of rising CO_2 concentrations on oceans [7]. Climate change also affects global biodiversity in several ways. Movement is an integral part of ecology of many animals, which can affect the fitness of individuals and population survival by enabling foraging and predation, behavioral interactions, and migration [8]. Migration may also be observed in fishes in search of suitable conditions due to increase in temperature. Arrival and hatching date in migrating birds can be strongly affected by global warming [9]. Numerous changes occur in animals due to rising temperature such as increased respiration, decrease in the efficiency of nutrient utilization, decrease in milk production reproductive performance especially in dairy cows [10]. Climate is a major factor determining plant physiology, distribution, and interactions [11]. There might be changes in phenological phases of plants which will lead to prolonged growing season and affect the plant fitness. Evidences are in favor of global climate change and its consequences on different aspects of environment. There is a greater need to develop conservation strategies to respond to such global challenges. This review deals with the influence of climate change on biodiversity and impact on environment.

2. IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

Climate change is increasingly recognized as the serious and widespread threat to biodiversity. The alterations in the environment which will be brought up by the climatic changes will be too rapid for many species to adapt to, and ultimately lead to extensive extinctions. Climate change may lead to migrations which in turn will affect biological diversity at regional and global scales. Stress on populations of whales, ringed seals, and polar bear will continue as a result of changes in critical sea-ice habitat interactions. Crops will fail more often, especially on land at lower latitudes where food supply is scarce [12]. The changes in occurrence of drought, strong winds, and winter storms will bring massive loss to commercial forestry [13]. The species must adapt, move, or face extinction with climate change.

2.1. Animal Biodiversity

Animals had been already subjected to major shifts in the Earth's climate in the past. Some species perished, while others adapted and thrived. Climate change is already having a negative impact on animal life, and the consequences are likely to be disastrous in the future. Climate change is considered a major threat to the survival of many species in changing ecosystems [14-16]. Many studies have taken into account the economic impact of day by day changing climate on livestock production [17]. In general, a combination of rising temperatures and changing rainfall patterns will certainly affect animal husbandry. Feed is an important constraint for livestock production in the tropics, and will continue to be, and crop productivity is a useful proxy for feed availability in most regions. Crop productivity at mid-to high latitudes may increase slightly for local mean temperature increases while at the lower latitudes, it may decrease for even relatively small local temperature increases. In general climate change may affect the animal agriculture in different ways by influencing livestock [18], nammely, the availability and price of feed grain, quality, and production of forage, reproduction, growth and health, as well as distribution of diseases and pests. These changes can lead to redistribution of livestock in an area. There may be shifts in animal types used for instance change from cattle to buffalo, camels, goats, or sheep; there may be genotype shifts which mean the use of breeds which can well handle adverse conditions. Furthermore, there may be changes in housing of animals [17].

Temperature is likely to become hotter in several places and different species due to their physiological differences will show variations in their susceptibility to changing temperatures [19]. Holstein-Friesian dairy cows are primarily susceptible to heat stress as the ambient temperature exceeds 25°C [20]. The first sign of heat stress is an increase in body temperature and rate of respiration ultimately reducing feed intake and milk output [21,22]. Sheep when exposed to high temperatures, weight loss, decrease of average daily gain, growth rate, and total body solids reflected by impaired reproduction have been observed. When the ambient air temperature is high, appetite decreases and growth of pigs is affected [23]. Further, in such changes, some species of animals may expand their ranges whereas others may move towards the poles or upward in elevation. An example of such a shift is population of red fox in Canada which have been advancing north and, on the other hand, population of Arctic fox has been retreating [24]. High temperatures and precipitation have been known to decline the population of British ring ouzel which is a shy species of thrush with a high chirping call.

The decline in Arctic sea ice have a significant impact on Arctic vertebrate populations including polar bears, seals, and walruses which are adapted to live in sea ice for significant periods of the year [25]. If the sea ice breaks and drifts as a result of polar warming, polar bears will have to move north to find a stable platform. Pregnant females will leave the ice to find their preferred land den area have to swim long distances. In case, the pregnancy of malnourished mothers is successful under sub-optimal habitats, the chances of survival of cubs will be greatly reduced [26].

Climate change has a profound impact on the oceans. The upper ocean is warming [27], potentially affecting invertebrate populations including krill, which are important food sources for whales, seabirds, seals, and penguins [28]. Changes in upper ocean temperatures may alter the range of many species, especially marine mammals. Studies show the expansion in the range of common dolphins common in northwest Scotland which are warmer water species whereas contractions in the range of white-beaked dolphins which are a colder water species [29]. Relatively small changes in temperature alter the metabolism and physiology of fishes, affecting their growth, reproduction, feeding behavior, distribution, migration, and abundance [30].

2.2. Bird Biodiversity

Birds are one of the most studied organisms on the planet, and they serve as an important group of indicators for learning about the effects of climate change. The choice of birds for studying climatic changes offer certain advantages such as they are the most well-known kind of organism for climate studies and second, millions of citizen scientists track birds all over the world, contributing to massive datasets [31]. Bird distribution changes have been well described and linked to climate change [32-34]. The vulnerability of species of tropical birds to climate change in particular has been increasingly recognized [35-37]. The weather not only affects the metabolic rate of the birds (e.g., in cold weather where energy expenditure must increase to maintain the body), but also their behavior directly or indirectly [38]. Climate change has been shown to impact breeding. Extreme weather events, such as prolonged freezing spells and droughts, can have catastrophic effects on bird populations, including long-term effects on entire cohorts [39]. The study of Pied Flycatchers *Ficedula hypoleuca* showed increase in their egg size with warmer springs in Germany and Finland [40]. In Siberia, reproductive success in the planktivorous auklets including crested *Aethia cristatella* and parakeet *Cyclorhynchus psittacula* increases at lower sea-surface temperatures. On the other hand, better reproductive success has been observed in the piscivorous puffins such as horned *Fratercula corniculata* and tufted *Lunda cirrhata* at higher, sea-surface temperatures. Long-term changes in sea-surface temperatures can affect the viability of each species' population in different ways and change the seabird population in that area [41].

Storms and snowpack have a significant impact on the reproductive schedules of birds breeding at high altitudes. Climate change is expected to have an impact on reproduction as well as the entire annual cycle of birds. The species that mainly adjust the annual cycle and multiply according to rainfall, temperature, and food supply will face fewer difficulties as compared to those that coordinate their annual cycle by a rigid Zeitgeber, like photoperiod [42]. Migration in birds is affected by changes in climatic conditions. It is expected that the greater the distance of migration of the species, the more likely one or more aspects of the annual cycle may become mistimed with local weather and food supplies on the summering grounds. An advancement of 14 days over 47 years in the timing of egg laying in *Parus major* population in the United Kingdom due to increased spring temperature has been reported [43].

2.3. Plant Biodiversity

Climate change is also affecting the life cycles and distributions of the world's vegetation. The combination of the changes in air quality and composition and climate are producing new bioclimate for food production systems. There is extensive evidence that plant seasonal biological events have changed in recent decades along with the global climate change [44]. Some medicinal and aromatic plants have begun to flower earlier. In Britain, the first flowering date for approximately 385 plant species advanced by 4.5 days on average over the previous four decades [45]. Temperature range between 45°C and 65°C can cause severe damage and even death of crop plants. For instance, rice is most sensitive to temperature change at anthesis stage. Exposure for few hours at flowering can reduce floral reproduction [46].

In medicinal plants, the damaging effects of climate change may include decrease in availability and most dramatically in the extinction of species [47]. A study reported extinction of about 600 plant species in the past 250 years [48].Valuable medicinal plants are likewise one of those species that experience dramatic phenological change [49]. In addition to endangering population growth, phenological changes may have an impact on the predictable or consistent availability of medicines to those who rely on them [50,51]. The medicinal plants of arid zone may also be at special risk. The nival or subnival species in montane ecosystems are most vulnerable to habitat loss [52], and future climate change is expected to be most severe in northern latitude mountains [53]. Alpine meadows are once again among the most threatened plant communities [54], and they are shrinking due to warming-induced upslope shrub encroachment [55]. It is thought that species growing at the highest altitudes are most vulnerable to extinction because they will have nowhere to go if they are outcompeted by lower elevation species that are now expanding their ranges to higher elevations [56].

In a survey of plant distribution in Arizona mountains local extinction of 15 species of plants including *Muhlenbergia porter, Quercus gambelii* and *Urochloa arizonica*, in comparison with 50 years earlier has been observed [57]. In the alpine Himalayas of Sikkim 75 species of plants, including *Rhododendron nivale*, *Potentilla fruticosa* and *Lepidium capitatum* were observed to be locally extinct in comparison with 1850 [58].

Deserts and arid shrublands are expected to experience the fastest rates of climate change, making compensatory migration difficult [59]. For instance, a significant degradation has been observed in the desert steppe habitat of one of the most widely used wild medicinal plants *Glycyrrhiza uralensis*, attributed to increasing climate change and anthropogenic disturbance [60]. Sea grasses are declining globally at a rate of about 7% per year, and global climate change is expected to have a negative impact on them, posing a pressing challenge for coastal management [61]. Water temperature greatly influences the physiology, growth rates and reproduction in sea grasses and determines their geographic distribution based on their temperature tolerance [62]. The species of tropical sea grasses including *Thalassia testudinu*m and *Syringodium filiforme* in the Gulf of Mexico showed reduction in their productivity when summer temperatures were higher [63]. In an investigation in Australia, the leaf growth rates of *Thalassia hemprichii, Halodule uninervis,* and *Cymodocea rotundata* were reduced at water temperature above 40°C [64].

Warming is occurring quickly in the Arctic [65]. The fluctuations in ranges of temperature and changes in ice covers and snow patterns are affecting the distribution of Arctic vegetation. It has been observed that the changes in climate possibly will affect the chemical constituents and thus the survival of the aromatic and medicinal plants in Arctic. Certain reports have revealed the impact of the temperature fluctuations on bioactive compounds of the plants [66,67].

2.4. Microbial Biodiversity

Microbes inhabiting soil play significant roles in nutrient cycling and protecting plants from environmental stresses [68]. The organisms inhabiting the soil interact with each other and plants in many ways that shape and maintain the ecosystem. Climate change is altering the distribution and diversity of species and at the same time affecting the interactions between organisms [69,70]. Numerous studies have shown that changes in species interactions in response to climate change chain alter biodiversity and function of terrestrial ecosystems [24,71]. There are some reports on soil microbial communities (SMCs) and their diversity and distribution during climatic change [72,73]. Alterations in relative abundance and function of soil communities due to climatic changes has been observed as the members of SMCs vary in their physiology, temperature sensitivity, and growth rates [74,75]. A study observed changes in the relative abundances of soil bacteria and increased the bacterial to fungal ratio of the community due to warming by 5°C [76]. Further, the acceleration in fermentation, methanogenesis and respiration among the microbial communities has also been observed in response to increase in temperature. The microbial community composition (MCCs) of soil constantly changes as they respond to changing resource availability. Certain communities grow quickly and utilize the resources as they are available and some communities adapt and grow slowly and utilize more chemically complex substrates. Guo *et al*. [77] carried out study on climate warming accelerates temporal scaling of grassland soil microbial biodiversity. The study suggested that the strategies of soil biodiversity preservation and ecosystem management may need to be adjusted in a warmer world. The study of Wu *et al*. [78] concluded detrimental effects of biodiversity loss might be more severe in a warmer world. Recently, a study has been conducted to measure the effect of climate change in Antarctic microbial communities. The study proposed that climate change studies in Antarctica should consider descriptive studies, short-term temporary adaptation studies, and long-term adaptive evolution studies and concluded that this will help in understanding and managing the effects of climate change on the Earth [79].

A study investigated the effect of temperature on microbes in dry land soil, boreal, temperate, and tropical soil and response of microbial communities to different temperatures. The study concluded that the rates of respiration per unit biomass were lower in the soils collected from the environments having higher temperature and suggested that thermal adaptation of the microbial communities may lessen positive climate feedbacks [80]. Another study reported increased soil biomass and fungal abundance with higher atmospheric CO_2. The study showed a limited effect on bacterial diversity with higher atmospheric CO_2 [81]. Drought conditions have been shown to influence fungi and bacteria, but fungi are known to be more sensitive than bacteria. It has been observed that during drought fungal growth increases [82].

Another study observed the effects of elevated levels of CO_2 and precipitation on soil microorganisms. The study suggested that bacterial growth was negatively affected whereas fungal biomass was observed to show an increase with increasing precipitation [83]. On the other hand, it has been suggested that global warming increases the abundance of bacteria and fungi and leads to the alteration of the soil food web. The rise in temperature also makes changes in the physiology of decomposing microorganisms also [84]. Climate change is known to favor the growth of cyanobacteria [85]. Many bloom-forming cyanobacteria grow at high temperatures [86]. The growth of *Microcystis* sp. has been observed to increase at elevated CO_2 levels [87]. Generally as the environmental conditions change, the resident microbial communities either adapt, become dormant or die [88].

3. BIODIVERSITY RESPONSES TO CLIMATE CHANGE

Climate change is expected to change the diversity of species, the distribution of human pathogens, and ecosystem services around the world. Estimating these changes and designing suitable management strategies for future ecosystem services will need a predictive model that includes the most basic biological responses. One of the key questions in the debate over climate change's ecological impact is whether species can adapt quickly enough to keep up with the rapid pace of climate change [89,90]. Species can, in theory, change in response to climate change, and changes have already been observed. The species can track and follow suitable conditions in space, which is typically accomplished through dispersion. Spatial movement of species tracking appropriate climatic conditions on a regional scale is the best documented response from palaeontological records and recent observations. Over 1000 species of marine invertebrates, insects, and birds have already shown latitudinal and altitudinal range shifts [91], resulting in a decrease in range size, primarily in mountain top and polar species [92]. Furthermore, in order to keep up with abiotic factors that represent cyclic variation, such as on a daily or yearly basis, species may respond to changes by shifting time from daily to seasonal. A meta-analysis of a wide range of plant and animal species found that the average response to climate change was a shift in key phenological events occurring 5.1 days earlier per decade over the last 50 years [93]. The advancement in flowering by more than 10 days per decade has also been observed in some species [91]. Another approach is species may adapt themselves to the changing climate in their local range. Thus, there are multiple responses of the species to cope up with the changing climatic conditions and unable to adapt to new conditions, the species may go extinct either locally or globally [94].

4. GLOBAL BIODIVERSITY SCENARIO FOR THE YEAR 2100

As a result of numerous human-caused changes in the global environment, global biodiversity is changing at an unprecedented rate [95,96]. Quantitative scenarios are emerging as tools to assess the impact of future socio-economic development pathways on biodiversity and ecosystem services. Global marine, freshwater, and terrestrial biodiversity scenarios are analyzed through different measures including change in the abundance of the species, habitat loss, extinction, and distribution shifts [97]. The risk of species extinction address the irreversible component of biodiversity change [98,99]; however, species extinctions have weak links to ecosystem services and respond less rapidly to global change than other factors. Quantitative global extinction scenarios for freshwater and marine organisms are, however, uncommon. According to one of the proposed models based on the relationship between fish diversity and river discharge, 4–22% extinction of fish by 2070 in about 30% of the world rivers, due to reduced river discharge from climate change and increased water withdrawals [100]. Habitat loss and degradation in terrestrial ecosystems encompass a wide range of human-caused changes in natural and semi-natural ecosystems. The distribution shifts are expected to cause the reorganization of ecosystems, including the establishment of novel communities [96]. Scenarios constantly indicate the decline of the biodiversity over the 21st century. The most important factors identified so far to induce changes in biodiversity at global scale includes the changes in the concentration of carbon dioxide, land use, deposition of nitrogen, and on purpose or accidental introduction of alien animals, plants, and microbes in an ecosystem [101].

5. CONSERVATION OF BIODIVERSITY IN CHANGING CLIMATE

The changing temperature and precipitation patterns are expected to interact with other drivers to influence an array of biological processes and distribution of species. Alarming predictions about the potential consequences of future climate change are prompting policy responses ranging from the local to the global [102]. To date emission of greenhouse gases are driving earth to significant climate change in the coming decades [103]. The annihilation of evolutionary potential, possible loss of biodiversity and disturbance of ecological services must be taken seriously. Many countries have conservation plans for threatened species, but these plans have generally been developed without taking into account the potential impacts of climate change. Climate change is greatly influencing the biodiversity and represents a significant future challenge for biodiversity conservation strategies [94].The interaction between climate and land use provides opportunities for adaptation to climate change that increase the ability of species to adapt [104]. Preventing detrimental consequences for biodiversity requires immediate action and strategic conservation plans for years and decades to come [105]. Integration of different approaches and perspectives is required for more accurate information on which species and habitats, which places and how conservation managers can make the most of natural systems' adaptive capacity. In many cases, existing conservation policies and practices are already encouraging measures to reduce vulnerability to climate change such as restoration or creation that improves the functional connectivity of landscapes and habitat management. The assessment of impact of climate change on biodiversity has been especially based on empirical niche models [106]. These models for most species indicate large geographic displacements and widespread extinction. Assessing the biodiversity consequences of climate change is really a multifaceted issue and all aspects of vulnerability such as adaptive capacity, exposure, and sensitivity must be considered for implementation of conservation strategies [Figure 1] [107].

6. IMPACT OF CLIMATE CHANGE ON ENVIRONMENT

In recent years, extensive efforts have been made to monitor and predict climate change in response to fears of global warming. Attention has been focused on the diverse environments including soil and water, and the imminent socio-economic and environmental consequences of rising global temperatures. The fluctuations in temperature will leave a negative impact on organic matter of soil, and diverse physical and chemical properties of soil. Water resources will be greatly affected under changing climate [Figures 2 and 3].

6.1. Soil Health and Fertility

Healthy soil is the foundation of agriculture and a basic resource for meeting human needs in the twenty-first century. It is a critical component of ecosystems and earth system functions that helps to deliver primary ecosystem services [108]. The most recent report of the intergovernmental panel on climate change point outs the average rise in the global temperature between 1.1 and 6.4°C by 2090–2099. The changes in the climate will have impact on precipitation patters at global level and will alter both the amount of precipitation received and the distribution of precipitation over the course of an average year in many locations [109]. Each of these factors will affect soil which is of major importance for the food security [110-112]. Food security will be threatened through its effects on soil processes and different properties [113].

Soil moisture is another important component of the hydrological cycle that regulates precipitation partitioning between runoff, evapotranspiration, and deep infiltration [114]. Fluctuations in temperature will influence moisture content of the soil which in turn may impact infiltration and runoff amounts and rates [115]. Further, as a link between the biosphere and the edaphic zone, soil water is fundamental requirement for the terrestrial ecosystems which determines plant growth. Water stress occurs when the soil water level falls below a critical species-specific threshold, which will then lead to morphological and physiological disturbances in plants [116].

Soil erosion is another phenomenon experienced in different parts of the world under changing climate. It is one of the major threats to the economy and society affecting agriculture. The most common reason predicted for soil erosion is the change in the erosive power of rainfall and changes in plant biomass [117]. Although soil erosion is a natural and inevitable process, the accelerated rates of soil loss, is really a serious environmental issue. The

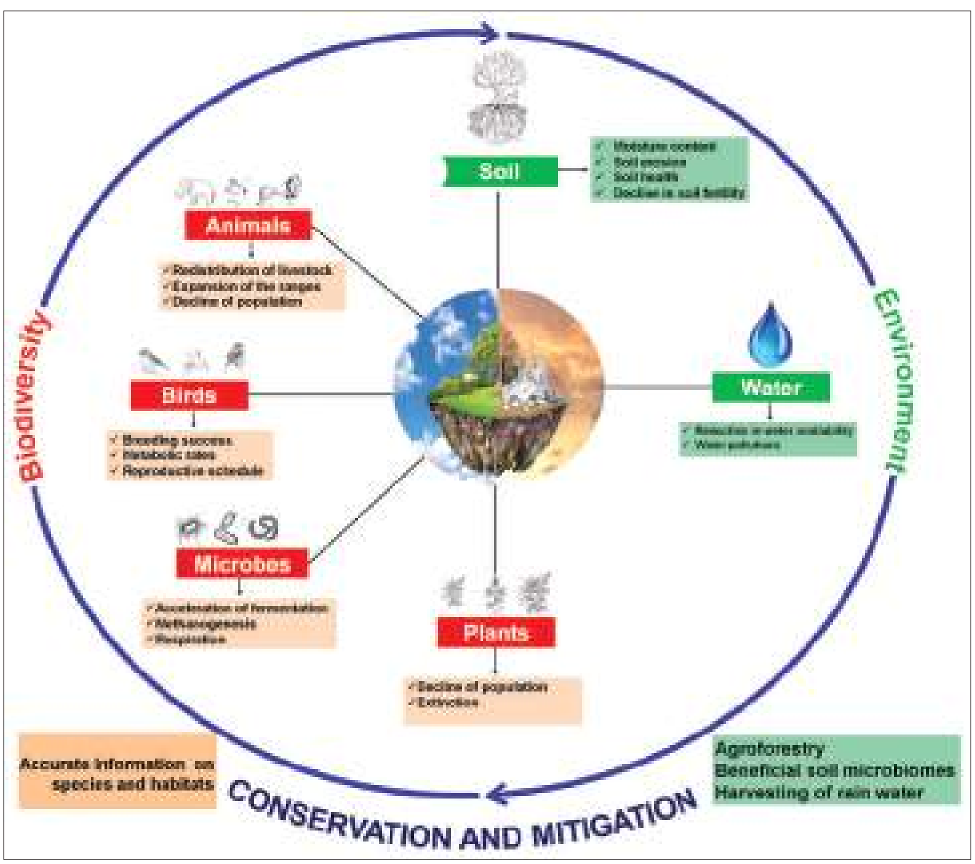


Figure 1: Depicts the effect of climate change on biodiversity and environment and their conservation/mitigation strategies.

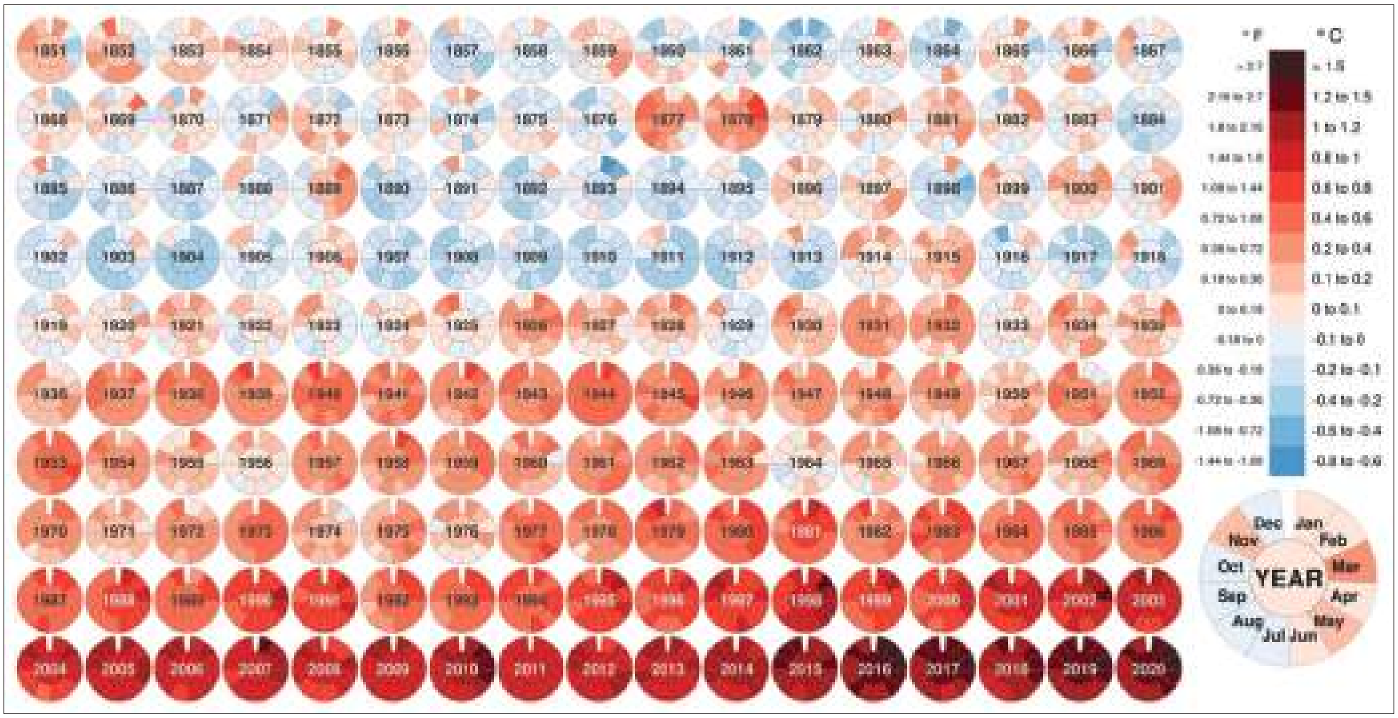


Figure 2: The changes in monthly mean global temperature from 1851 to 2020 (Data HadCRUT5 created by: @neilrkaye).

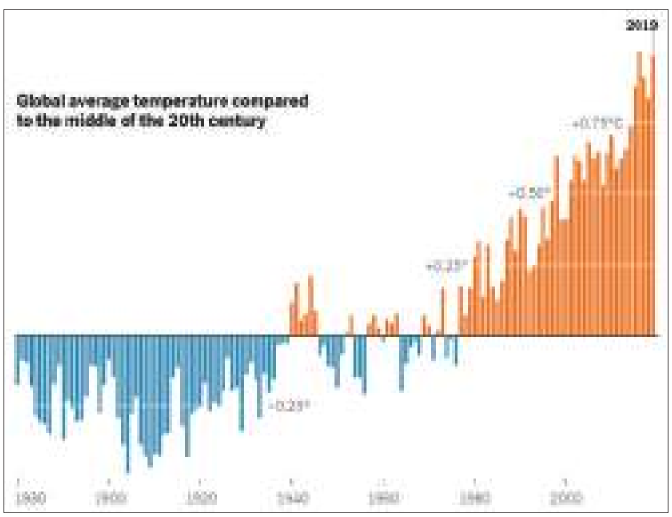


Figure 3: The changes in global average temperature from 1880 to 2019.

increased rates of soil erosion lead to nutrient loss, which affects agricultural productivity [118,119] and cause eutrophication of water bodies' [120]. Advanced stages of soil erosion, such as rill and gully erosion, can devastate entire areas, rendering them unfit for agricultural use [121,122]. Soil erosion is expected to increase with climate change and is the major problem that reduces the useful storage capacity of river dam reservoirs [123]. A study has been conducted to investigate the impact of climate change on soil erosion, runoff, and wheat productivity in central Oklahoma. The study concluded that no-till and conservation tillage systems will be effective in combating soil erosion under projected climates in central Oklahoma [124].

Soil fertility and productivity declines are common in tropical and subtropical areas of Asia, South America, and Africa, where soil loss due to erosion is estimated to be 30–40 t/ha/year [125,126]. Microorganisms present in the soil play important role in nutrient cycling and thus the decrease in MCCs in soil due to climate change affect the soil health and fertility.

Increasing challenges and concerns on global warming and changing climate have led to special attention to soil and its capability in carbon sequestration. In a study, the effect of climate change on soil organic carbon storage using the Rothamsted C model in the agricultural lands of Golestan province has been studied. The results suggested that with increasing temperature, the rate of decomposition of soil organic carbon will increase [127]. Soil organic carbon is an important carbon pool which can alleviate the increasing concentration of atmospheric carbon dioxide as part of the carbon cycling process. A study on the basis of Rothamsted C model concluded soil organic carbon will in general decline during the next decades. Further the rate of decrease of soil organic carbon will be higher over time if there is no addition of organic matter is adopted in China [128].

Another study focused on impact of global climate change on terrestrial soil CH_4 emissions. The meta-analysis in the study suggested that future climate change will decline the natural buffering capability of terrestrial ecosystems on CH_4 fluxes [129].

6.2. Water Resources

Climate change is expected to pose negative impact on water resources and freshwater ecosystems in almost every part of the world. However, the intensity and characteristics of the impact can vary widely from region to region. There may be water shortages in some regions. A study concluded that climate change will lead to water scarcity to meet the rising demand for food. It is estimated to be 60% higher in Africa by 2030, which will spike food prices and worsen food scarcity [130]. The shorter rainy periods and seasonality shifts might affect water resources by reducing water availability with wide ranging consequences for local societies and ecosystems [131].

With the increasing demand, large population will be at risk of water scarcity. The rise in sea level in coastal regions possibly will threaten the livelihood and lives of millions of people. The occurrence of droughts and floods is likely to increase in many parts of the world. All these factors will contribute to high economic cost and decline in the yield ultimately leading to higher risk of hunger and poverty [132].

A study has been conducted to analyze the impact of climate change on stream flow in the Godavari basin simulated using a conceptual model including CMIP6 dataset. The findings highlighted the importance of taking into consideration the potential impacts of future scenarios on water resources so that effective and sustainable water management practices could be developed [133]. Another study investigated the impact of the climate and land-use changes on water balance in 2037, the end of the National Strategy, for the Mun River Basin, NE Thailand. The study recommended soil-water conservation measures to alleviate the adverse effects of bioenergy [134]. The changing climate will also impact the water quality of lakes. A study has been conducted to investigate the effects of climate change on the water quality of Baiyangdian Lake in the past 30 years using correlation analysis, regression analysis, and the generalized additive model. The major conclusions of the study were the increment in the oxygen demand of organic matter in the lake due to rising temperature, increased total phosphorus in the lake due to increased precipitation and altered nitrogen and dissolved oxygen concentration in lake [135].

It is very important for water resources managers to be aware of the impact the climate change will have on hydrological cycle and flow regime and be prepared to find the strategies to cope with it. The better understanding on the link between the change in climate, water resources and the anthropogenic activities will help the water resource managers to make more rational decisions on the allocation and management of the water resources [136]. Social and environmental aspects including agriculture, biodiversity conservation, and tourism are connected to quality and availability of water resources, and consequently adaptation measures will be strongly bound with policies in a wide spectrum of disciplines [137].

7. CONSERVATION OF SOIL HEALTH, FERTILITY, AND WATER RESOURCES IN CHANGING CLIMATE

Soil and water are fundamental and basic necessities. The negative impact of changing climate on these basic resources is major global issue and developing strategies for their conservation is of utmost importance. The major research priorities of current studies are growing more food, conservation of the environment and reduction of global warming. Despite of changes in hydrology, climate, and increasing demand of agricultural commodities, there is a greater need to look further than the traditional approaches of the last century and embracing an expanded view of water and soil conservation to maintain an environmentally sound and sustainable landscape. Most importantly the new strategies must be based on far more effective policies and programs [138]. Agroforestry is one of the emerging technologies for water and soil conservation. It consists of a broad range of the practices including managing and establishing trees purposely around or within croplands, farm animal grounds, and pasture lands with the rationale of managing soil erosion, improving wildlife habitat, developing sustainable agricultural practices, ameliorating the effects of environmental pollution, and also adding to farm economy by harvesting tree based specialty products [139]. Conservation agriculture, another important approach for conservation of soil and water takes into account the conservation of biodiversity, labor and natural resources. It decreases drought stress, raises available soil water and maintains the soil health for a longer term. The strategy is practiced in Argentina, Australia, Brazil, Canada, New Zealand, Paraguay, and USA [140]. Further, it is also becoming popular in China, Kazakhstan, Russia and Ukraine and past decades it is spreading in Africa, Asia, and Europe [141].

Another important approach for maintaining soil health and fertility is the use of beneficial soil microbiomes. Microbes perform countless functions with key role in biogeochemical cycling and sustainability [142]. The utilization of the beneficial microbiomes is an important practice for agro-environmental sustainability. These microbiomes are treasure troves for innovative and potential developments in diverse sectors of agriculture, chemicals, environmental protection, food, and pharmaceuticals. The use of beneficial microbes is the vital practices for the sustainable energy and food production. The current research around the globe is majorly focused on exploring these beneficial microbes for maximizing their application under the limitation of the natural and anthropogenic activities, climate change, use of agro chemicals as these activities are continuously menacing stable agricultural production [143]. In order to fulfill water demand in the near future, it is necessary to rationalize the various means of collecting and storing water. In India, harvesting of rainwater is supposed to contribute in partially meeting the future water requirements. The climate change is expected to make monsoon less reliable as an assured source of water. Thus, efforts are required for more efficient groundwater recharge and rainwater harvesting through adoption and adaptation of technological options. Harnessing excessive monsoon runoff for additional groundwater storage will not only increase the water availability to meet growing demand, but also help to control the damage caused by flooding [144]. Other innovative approaches which may be adopted for water availability include desalination of seawater by evaporation using solar or wind energy which is cost effective and less expensive the cost of tapping groundwater, generation of rainfall using precipitation enhancement such as cloud seeding, and water in surface reservoirs or underground through artificial recharge. Furthermore, increasing irrigation efficiency using another new technology such as sprinkler design with low energy precision application might also be useful [145].

Many NGOs and government organizations are already working on the mitigation strategies for rising climate change. The Indian Council of Agricultural Research under ministry of agriculture and farmers welfare has launched a flagship network project which aims to study the impact of climate change on agricultural sector. The project also takes into account the development and promotion of climate resilient technologies in agriculture which will address vulnerable areas of the country and the output of the projects will help the districts and regions prone to climatic hazards. Rainfed area development scheme is being implemented for promotion of sustainable integrated farming systems. With the help of technological interventions, GOI is preparing efficiently to boost the crop produce and reduce the crop loss. Action against hunger is another important step to cope up with the hunger in scenario of climate crisis. Sankalp Taru Foundation is focusing on protection and conservation of the environment. Mukti is working for the social and economic development and environmental protection of the Sunderbans of West Bengal. Ashoka Trust for Research in Ecology and the Environment is working on issues including biodiversity and conservation, climate change mitigation and development, land and water resources, ecosystem services, and human well-being. Mobius Foundation is working for the environment in Delhi. The Gram Chetna Kendra aims to offer solutions to water problems keeping in mind the frequent damages droughts have induced in

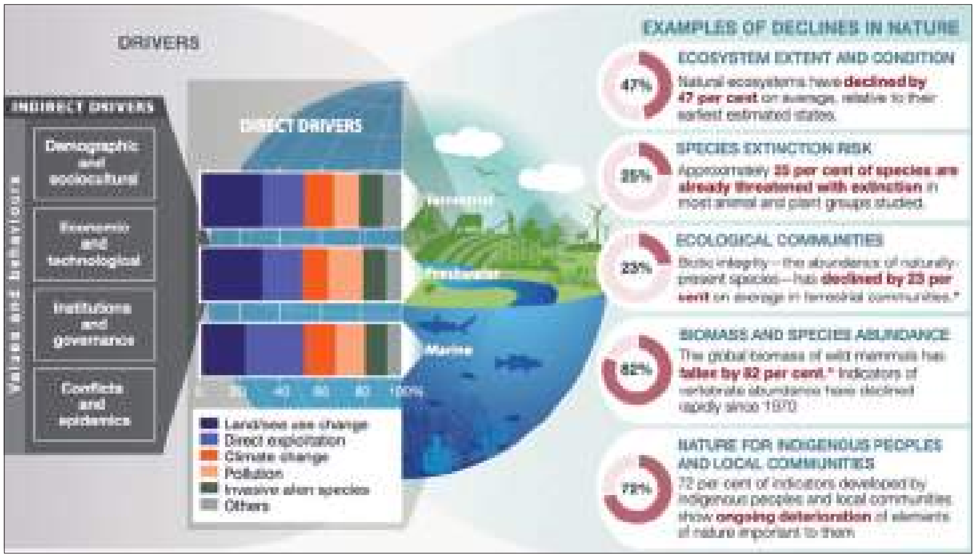


Figure 4: IPBES, global assessment report for policy makers.

Rajasthan. Greenpeace India is working on environment preservation. It has its presence in over 56 countries worldwide across various continents such as Asia, Europe, America, and few others. Greenpeace India promotes four different movements: preserving the oceans, preventing climate change, sustainable agriculture, and preventing another nuclear catastrophe [Figure 4].

8. EFFECTS OF CLIMATE CHANGE ON ECONOMICS

It has long been understood that economic consequences are climate-related. This relationship between climate and economics determines the extent and scale of the market impact of climate change in the next 100 years and beyond. Therefore, recent literature uses panel econometric methods to assess the response of economic results to weather, which is usually defined as implementation based on distribution of climate variables such as precipitation, temperature, and wind [146-148]. This estimation on economically and statistically important effects of weather on an assortment of economic outcomes, including crop yields, industrial output, and labor productivity [149]. The cumulative impact of global climate change is determined by how the world reacts to changes. According to the reports, climate change has already resulted in extreme weather events and a rise in sea level, posing new threats to agricultural production in several parts of the world. Current economic modeling may significantly understate the impact of potentially catastrophic climate change, emphasizing the need for a new generation of models capable of defining a more accurate picture of damages [150-152].

The main dynamic effect is through capital accumulation. Assuming a constant savings rate, if climate change negatively impacts production, the amount of economic investment will be reduced. In the long run, this will lead to lower capital stocks, lower GDP and, in most cases, lower consumption per capita. This effect of capital accumulation can be exacerbated in the context of endogenous growth if low investment slows technological advances while improving labor productivity or human capital accumulation. The second dynamic effect concerns savings. We can expect our forward-thinking agents to predict future climate change and change saving behavior in a perfect world. This, too, will have an impact on capital accumulation, and thus growth and future GDP [153].

Since then, practitioners and academics in development have grappled with the interplay of economic growth and environmental protection. Understanding and acting on these interactions has become critical to development in all countries, particularly in developing ones. The management of the environment has become an essential component of any viable path to poverty reduction and prosperity. Environmental degradation, poor health, and lost economic output result from poor environmental management practices. Poor people are the most vulnerable to these trends, though we must acknowledge that poverty also contributes to them [154,155]. Poor countries and poor people will suffer the most as they rely more on climate sensitive economic activities such as agriculture and possess weaker capability to adapt efficiently. In addition, poor people are also more likely to live in hazard zones and will be more vulnerable to the pests and diseases that follow drought, floods, and heat waves. Climate change can hinder development and growth, increase vulnerability, threaten health and return people to poverty [156]. Given the earth's finite resources, the application of economic principles and empirical findings should be a central component in the quest to meet humanity's aspirations for a good life.

A study investigated that increment in temperature considerably reduces the economic performance in Sub-Saharan Africa. In addition, the relationship between real gross domestic product per capita on one hand, and the climate factors on the other, is intrinsically non-linear has been shown in the study [157]. An integrated assessment model (ENVISAGE), including a CGE-based economic module and a climate module has been used to assess the impact of climate change on economic aspects. Results revealed that the influence of climate change is substantial, particularly for developing countries and in the long run, amelioration and adaptation policies are required to bring about sustainability in economic growth [158]. Another study focused on the impact of the climate change shocks on economic growth. The non-linear autoregressive distributional lag technique has been used for estimation of the asymmetric effect of climate change on the economic growth of Pakistan. The report indicated that at national level, tree planting projects, and safeguard greenery at all costs while at international level, adoption of policies and mitigation strategies to control climate change are of major importance [159]. There is a strong case to be made for greater efforts to increase understanding of the environmental, social, and economic dimensions of sustainable development, which necessitates a greater integration of economics, social sciences, and natural sciences [160].

9. CONCLUSION AND FUTURE PROSPECT

The world is already experiencing the negative effects of climate change from higher temperature to changing precipitation patterns, and severity of natural disasters. Climate change directly or indirectly affects the biodiversity through multitude of pathways. It is extremely challenging to predict the patterns and probabilities of biodiversity loss. Efforts are needed to prevent and manage the negative impacts of changing climate. The uncertainties in global climate changes require integrated multidisciplinary studies to form exact scientific basis for the adapting or lessening the adverse effects of climate change. In fact, the coming decade will be really crucial in determining to what extent humanity can improve the potential devastating effects of climate change. The transition to sustainability will be very difficult, but it is key factor to securing a future for biodiversity. It is important to minimize the ecological and societal consequences of changing biological diversity. The strong initiatives are required for biodiversity conservation, to enhance ecological understanding and ameliorate the consequences.

10. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

11. FUNDING

There is no funding to report.

12. CONFICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

13. ETHICAL APPROVAL

This study does not involve experiments on animals or human subjects.

14. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

15. PUBLISHER'S NOTE

This journal remains neutral with regard to jurisdictional claims in published institutional affiliation.

REFERENCES

1. Montzka SA, Dlugokencky EJ, Butler JH. Non-CO_2 greenhouse gases and climate change. Nature 2011;476:43-50.
2. Mohanty BP, Mohanty S, Sahoo J, Sharma A. Climate change: Impacts on fisheries and aquaculture. In: Simard S, editor. Climate Change and Variability. United Kingdom: IntechOpen; 2010b. p. 119-38.
3. Domenici P, Seebacher F. The impacts of climate change on the biomechanics of animals: Themed issue article: Biomechanics and climate change. Conserv Physiol 2020;8:coz102.
4. Wheeler T, von Braun J. Climate change impacts on global food security. Science 2013;341:508-13.
5. Doney SC, Ruckelshaus M, Emmett Duffy J, Barry JP, Chan F, English CA, *et al*. Climate change impacts on marine ecosystems. Annual Review of Marine Science. 2012;4:11-37.
6. Doney SC, Ruckelshaus M, Emmett Duffy J, Barry JP, Chan F, English CA, *et al*. Climate change impacts on marine ecosystems. Annual Review of Marine Science. 2012;4:11-37.
7. Bijma J, Pörtner HO, Yesson C, Rogers AD. Climate change and the oceans--what does the future hold? Mar Pollut Bull 2013;74:495-505.
8. Nathan R, Getz WM, Revilla E, Holyoak M, Kadmon R, Saltz D, *et al.* A movement ecology paradigm for unifying organismal movement research. Proc Natl Acad Sci U S A 2008;105:19052-9.
9. Seebacher F, Post E. Climate change impacts on animal migration. Clim Chang Responses 2015;2:5.
10. Chase LE. Climate Change Impacts on Dairy Cattle. Fact Sheet, Climate Change and Agriculture: Promoting Practical and Profitable Responses; 2006. Available from: https://climateandfarmingorg/pdfs/factsheets/iii3cattlepdf
11. Walther GR. Plants in a warmer world. Perspect Plant Ecol Evol Syst 2003;6:169-85.
12. McNutt M. Climate change impacts. Science 2013;341:435.
13. Kirilenko AP, Sedjo RA. Climate change impacts on forestry. Proc Natl Acad Sci U S A 2007;104:19697-702.
14. Frankham R. Stress and adaptation in conservation genetics. J Evol Biol 2005;18:750-5.
15. Hulme PE. Adapting to climate change: Is there scope for ecological management in the face of a global threat? J Appl Ecol 2005;42:784-94.
16. King DA. Environment. Climate change science: Adapt, mitigate, or ignore? Science 2004;303:176-7.
17. Gaughan J, Lacetera N, Valtorta SE, Khalifa HH, Hahn L, Mader T. Response of domestic animals to climate challenges. In: Ebi KL, Burton I, McGregor GR, editors. Biometeorology for Adaptation to Climate Variability and Change. Aukland: Springer; 2009. p. 131-70.
18. Rötter R, Van de Geijn SC. Climate change effects on plant growth, crop yield and livestock. Clim Change 1999;43:651-81.
19. Bernardo J, Ossola RJ, Spotila J, Crandall KA. Interspecies physiological variation as a tool for cross-species assessments of global warming-induced endangerment: Validation of an intrinsic determinant of macroecological and phylogeographic structure. Biol Lett 2007;3:695-8.
20. Staples C, Thatcher W. Heat stress: Effects on milk production and composition. In: Encyclopedia of Dairy Sciences. 2nd ed., Vol. 4. Oxford, UK: Academic Press; 2022. p. 561-6.
21. West JW. Effects of heat-stress on production in dairy cattle. J Dairy Sci 2003;86:2131-44.
22. Gaughan J, Cawdell-Smith AJ. Impact of climate change on livestock production and reproduction. In: Climate Change Impact on Livestock: Adaptation and Mitigation. New Delhi: Springer; 2015. p. 51-60.
23. Padodara RJ, Jacob NJ. Climate change: Effect on growth of animals. Basic Res J Agric Sci Rev 2013;2:85-90.
24. Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJ, *et al.* Ecological responses to recent climate change. Nature 2002;416:389-95.
25. Palmer C. Climate change, ethics, and the wildness of wild animals. In: Bovenkerk B, Keulartz J, editors. Animal Ethics in the Age of Humans. The International Library of Environmental, Agricultural and Food Ethics. Vol. 23. Cham: Springer; 2016. Doi: 10.1007/978-3-319-44206-8_9.
26. Hsiung W, Sunstein CR. Climate change and animals. Univ Pa Law Rev 2006;155:1695-740.
27. Gleckler PJ, Santer BD, Domingues CM, Pierce DW, Barnett TP, Church JA, *et al.* Human-induced global ocean warming on multidecadal timescales. Nat Clim Chang 2012;2:524-9.
28. Atkinson A, Siegel V, Pakhomov E, Rothery P. Long-term decline in

krill stock and increase in salps within the Southern Ocean. Nature 2004;432:100-3.
29. MacLeod CD, Bannon SM, Pierce GJ, Schweder C, Learmonth JA, Herman JS, *et al.* Climate change and the cetacean community of North-West Scotland. Biol Conserv 2005;124:477-83.
30. Marcogliese DJ. The impact of climate change on the parasites and infectious diseases of aquatic animals. Rev Sci Tech 2008;27:467-84.
31. Şekercioğlu ÇH, Primack RB, Wormworth J. The effects of climate change on tropical birds. Biol Conserv 2012;148:1-18.
32. Gregory RD, Willis SG, Jiguet F, Vorísek P, Klvanová A, van Strien A, *et al.* An indicator of the impact of climatic change on European bird populations. PLoS One 2009;4:e4678.
33. Niven DK, Butcher GS, Bancroft GT, Monahan WB, Langham G. Birds and Climate Change: Ecological Disruption in Motion. Briefing for Policymakers and Concerned Citizens on Audubon's Analyses of North American Bird Movements in the Face of Global Warming. United States: Audubon; 2009. Available from: https://birdsandclimate.audubon.org/techreport.html [Last Accessed on 2023 Oct 03].
34. Chen IC, Hill JK, Ohlemüller R, Roy DB, Thomas CD. Rapid range shifts of species associated with high levels of climate warming. Science 2011;333:1024-6.
35. La Sorte FA, Jetz W. Projected range contractions of Montane biodiversity under global warming. Proc R Soc B 2010;277:3401-10.
36. Harris JB, Sekercioglu CH, Sodhi NS, Fordham DA, Paton DC, Brook BW. The tropical frontier in avian climate impact research. Ibis 2011;153:877-82.
37. Sodhi NS, Sekercioglu CH, Barlow J, Robinson SK. Conservation of Tropical Birds. Oxford: John Wiley and Sons, Wiley-Blackwell; 2011.
38. Crick HQ. The impact of climate change on birds. Ibis 2004;146:48-56.
39. Stenseth NC, Mysterud A, Ottersen G, Hurrell JW, Chan KS, Lima M. Ecological effects of climate fluctuations. Science 2002;297:1292-6.
40. Jarvinen A. Global warming and egg size of birds. Ecography 1994;17:108-10.
41. Kitaysky AS, Golubova EG. Climate change causes contrasting trends in reproductive performance of planktivorous and piscivorous alcids. J Anim Ecol 2000;69:248-62.
42. Carey C. The impacts of climate change on the annual cycles of birds. Philos Trans R Soc Lond B Biol Sci 2009;364:3321-30.
43. Charmantier A, McCleery RH, Cole LR, Perrins C, Kruuk LE, Sheldon BC. Adaptive phenotypic plasticity in response to climate change in a wild bird population. Science 2008;320:800-3.
44. Luo Z, Sun OJ, Ge Q, Xu W, Zheng J. Phenological responses of plants to climate change in an urban environment. Ecol Res 2007;22:507-14.
45. Fitter AH, Fitter RS. Rapid changes in flowering time in British plants. Science 2002;296:1689-91.
46. Sheehy J, Elmido A, Centeno G, Pablico P. Searching for new plants for climate change. J Agric Meteorol 2005;60:463-8.
47. Applequist WL, Brinckmann JA, Cunningham AB, Hart RE, Heinrich M, Katerere DR, *et al.* Scientists' warning on climate change and medicinal plants. Planta Med 2019;86:10-8.
48. Humphreys AM, Govaerts R, Ficinski SZ, Lughadha EN, Vorontsova MS. Global dataset shows geography and life form predict modern plant extinction and rediscovery. Nat Ecol Evol 2019;3:1043-7.
49. Cavaliere C. The effects of climate change on medicinal and aromatic plants. HerbalGram 2009;81:44-57.
50. Turner NJ, Clifton H. "It's so different today": Climate change and indigenous lifeways in British Columbia, Canada. Glob Environ Change 2009;19:180-90.
51. Ruelle ML, Kassam KA. Diversity of Plant knowledge as an adaptive asset: A case study with standing rock elders 1. Econ Bot 2011;65:295-307.
52. Grabherr G. Biodiversity in the high ranges of the Alps: Ethnobotanical and climate change perspectives. Glob Environ Change 2009;19:167-72.
53. Nogués-Bravo D, Araújo MB, Errea MP, Martinez-Rica JP. Exposure of global mountain systems to climate warming during the 21st century. Glob Environ Change 2007;17:420-8.
54. Salick J, Zhendong F, Byg A. Eastern Himalayan alpine plant ecology, Tibetan ethnobotany, and climate change. Glob Environ Change 2009;19:147-55.
55. Brandt JS, Haynes MA, Kuemmerle T, Waller DM, Radeloff VC. Regime shift on the roof of the world: Alpine meadows converting to Shrublands in the Southern Himalayas. Biol Conserv 2013;158:116-27.
56. Salick J, Ghimire SK, Fang Z, Dema S, Konchar KM. Himalayan alpine vegetation, climate change and mitigation. J Ethnobiol 2014;34:276-93.
57. Brusca RC, Wiens JF, Meyer WM, Eble J, Franklin K, Overpeck JT, *et al.* Dramatic response to climate change in the Southwest: Robert Whittaker's 1963 Arizona Mountain plant transect revisited. Ecol Evol 2013;3:3307-19.
58. Telwala Y, Brook BW, Manish K, Pandit MK. Climate-induced elevational range shifts and increase in plant species richness in a Himalayan biodiversity epicentre. PLoS One 2013;8:e57103.
59. Loarie SR, Duffy PB, Hamilton H, Asner GP, Field CB, Ackerly DD. The velocity of climate change. Nature 2009;462:1052-5.
60. Huang J, Wang P, Niu Y, Yu H, Ma F, Xiao G, *et al.* Changes in C: N:P stoichiometry modify N and P conservation strategies of a desert steppe species *Glycyrrhiza uralensis*. Sci Rep 2018;8:12668.
61. Waycott M, Duarte CM, Carruthers TJ, Orth RJ, Dennison WC, Olyarnik S, *et al.* Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc Natl Acad Sci U S A 2009;106:12377-81.
62. Short FT, Neckles HA. The effects of global climate change on seagrasses. Aquat Bot 1999;63:169-96.
63. Short FT, Kosten S, Morgan PA, Malone S, Moore GE. Impacts of climate change on submerged and emergent wetland plants. Aquat Bot 2016;135:3-17.
64. Collier CJ, Waycott M. Temperature extremes reduce seagrass growth and induce mortality. Mar Pollut Bull 2014;83:483-90.
65. Gore A. An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It. New York: Rodale Books; 2006. p. 328.
66. Zobayed SM, Afreen F, Kozai T. Temperature stress can alter the photosynthetic efficiency and secondary metabolite concentrations in St. John's Wort. Plant Physiol Biochem 2005;43:977-84.
67. Kirakosyan A, Seymour E, Kaufman PB, Warber S, Bolling S, Chang SC. Antioxidant capacity of polyphenolic extracts from leaves of *Crataegus laevigata* and *Crataegus monogyna* (Hawthorn) subjected to drought and cold stress. J Agric Food Chem 2003;51:3973-6.
68. Hashem A, Abd Allah EF, Alqarawi AA, Radhakrishnan R, Kumar A. Plant defense approach of *Bacillus subtilis* (BERA 71) against *Macrophomina phaseolina* (Tassi) Goid in mung bean. J Plant Interact 2017;12:390-401.
69. Wookey PA, Aerts R, Bardgett RD, Baptist F, Bråthen KA, Cornelissen JH, *et al.* Ecosystem feedbacks and cascade processes: Understanding their role in the responses of Arctic and alpine ecosystems to environmental change. Glob Chang Biol 2009;15:1153-72.
70. Van der Putten WH, Bardgett RD, Bever JD, Bezemer TM, Casper BB, Fukami T, *et al.* Plant-soil feedbacks: The past, the present and future challenges. J Ecol 2013;101:265-76.
71. Langley JA, Hungate BA. Plant community feedbacks and long-term ecosystem responses to multi-factored global change. AoB Plants 2014;6:plu035.
72. Schimel J, Balser TC, Wallenstein M. Microbial stress-response physiology and its implications for ecosystem function. Ecology 2007;88:1386-94.
73. De Vries FT, Liiri ME, Bjørnlund L, Bowker MA, Christensen S, Setälä HM, *et al.* Land use alters the resistance and resilience of soil food webs to drought. Nat Clim Change 2012;2:276-80.

74. Castro HF, Classen AT, Austin EE, Crawford KM, Schadt CW. Development and validation of a citrate synthase directed quantitative PCR marker for soil bacterial communities. Appl Soil Ecol 2012;61:69-75.
75. Whitaker J, Ostle N, Nottingham AT, Ccahuana A, Salinas N, Bardgett RD, *et al.* Microbial community composition explains soil respiration responses to changing carbon inputs along an Andes-to-Amazon elevation gradient. J Ecol 2014;102:1058-71.
76. DeAngelis KM, Pold G, Topçuoğlu BD, van Diepen LT, Varney RM, Blanchard JL, *et al.* Long-term forest soil warming alters microbial communities in temperate forest soils. Front Microbiol 2015;6:104.
77. Guo X, Zhou X, Hale L, Yuan M, Ning D, Feng J, *et al.* Climate warming accelerates temporal scaling of grassland soil microbial biodiversity. Nat Ecol Evol 2019;3:612-9.
78. Wu L, Zhang Y, Guo X, Ning D, Zhou X, Feng J, *et al.* Reduction of microbial diversity in grassland soil is driven by long-term climate warming. Nat Microbiol 2022;7:1054-62.
79. Santos A, Gómez-Espinoza O, Núñez-Montero K, Zárate A, Andreote FD, Pylro VS, *et al.* Measuring the effect of climate change in Antarctic microbial communities: Toward novel experimental approaches. Curr Opin Biotechnol 2023;81:102918.
80. Bradford MA, McCulley RL, Crowther TW, Oldfield EE, Wood SA, Fierer N. Cross-biome patterns in soil microbial respiration predictable from evolutionary theory on thermal adaptation. Nat Ecol Evol 2019;3:223-31.
81. Newman C, Macdonald DW. Biodiversity Climate Change Impacts Report Card Technical Paper 2. The Implications of Climate Change for Terrestrial UK Mammals. UK: Natural Environmental Research Council; 2015.
82. Haugwitz MS, Bergmark L, Priemé A, Christensen S, Beier C, Michelsen A. Soil microorganisms respond to five years of climate change manipulations and elevated atmospheric CO_2 in a temperate heath ecosystem. Plant Soil 2014;374:211-22.
83. Blankinship JC, Niklaus PA, Hungate BA. A meta-analysis of responses of soil biota to global change. Oecologia 2011;165:553-65.
84. Schlesinger WH, Andrews JA. Soil respiration and the global carbon cycle. Biogeochemistry 2000;48:7-20.
85. Huisman J, Codd GA, Paerl HW, Ibelings BW, Verspagen JM, Visser PM. Cyanobacterial blooms. Nat Rev Microbiol 2018;16:471-83.
86. Visser PM, Verspagen JM, Sandrini G, Stal LJ, Matthijs HC, Davis TW, *et al.* How rising $CO(_2)$ and global warming may stimulate harmful cyanobacterial blooms. Harmful Algae 2016;54:145-59.
87. Sandrini G, Ji X, Verspagen JM, Tann RP, Slot PC, Luimstra VM, *et al.* Rapid adaptation of harmful *Cyanobacteria* to rising CO_2. Proc Natl Acad Sci U S A 2016;113:9315-20.
88. Jansson JK, Hofmockel KS. Soil microbiomes and climate change. Nat Rev Microbiol 2020;18:35-46.
89. Lavergne S, Mouquet N, Thuiller W, Ronce O. Biodiversity and climate change: Integrating evolutionary and ecological responses of species and communities. Annu Rev Ecol Evol Syst 2010;41:321-50.
90. Salamin N, Wüest RO, Lavergne S, Thuiller W, Pearman PB. Assessing rapid evolution in a changing environment. Trends Ecol Evol 2010;25:692-8.
91. Parmesan C. Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 2006;37:637-69.
92. Forero-Medina G, Joppa L, Pimm SL. Constraints to species' elevational range shifts as climate changes. Conserv Biol 2011;25:163-71.
93. Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds JA. Fingerprints of global warming on wild animals and plants. Nature 2003;421:57-60.
94. Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. Impacts of climate change on the future of biodiversity. Ecol Lett 2012;15:365-77.
95. Pimm SL, Russell GJ, Gittleman JL, Brooks TM. The future of biodiversity. Science 1995;269:347-50.
96. Williams JW, Jackson ST, Kutzbach JE. Projected distributions of novel and disappearing climates by 2100 AD. Proc Natl Acad Sci U S A 2007;104:5738-42.
97. Pereira HM, Leadley PW, Proença V, Alkemade R, Scharlemann JP, Fernandez-Manjarrés JF, *et al.* Scenarios for global biodiversity in the 21st century. Science 2010;330:1496-501.
98. Jetz W, Wilcove DS, Dobson AP. Projected impacts of climate and land-use change on the global diversity of birds. PLoS Biol 2007;5:e157.
99. Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, *et al.* Extinction risk from climate change. Nature 2004;427:145-8.
100. Xenopoulos MA, Lodge DM, Alcamo J, Mäerker M, Schulze K, van Vuuren DP. Scenarios of freshwater fish extinctions from climate change and water withdrawal. Glob Chang Biol 2005;11:1557-64.
101. Sala OE, Chapin FS 3rd, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, *et al.* Global biodiversity scenarios for the year 2100. Science 2000;287:1770-4.
102. Leadley P, Pereira HM, Alkemade R, Fernandez-Manjarrés JF, Proença V, Scharlemann JP, *et al*. Biodiversity Scenarios. Projections of 21st Century Change in Biodiversity and Associated Ecosystem Services. A Technical Report for the Global Biodiversity Outlook 3. Montreal: Secretariat of the Convention on Biological Diversity; 2010. p. 132.
103. Solomon S, Plattner GK, Knutti R, Friedlingstein P. Irreversible climate change due to carbon dioxide emissions. Proc Natl Acad Sci U S A 2009;106:1704-9.
104. Oliver TH, Smithers RJ, Beale C, Watts K. Are existing biodiversity conservation strategies appropriate in a changing climate? Biol Conserv 2016;193:17-26.
105. Dawson TP, Jackson ST, House JI, Prentice IC, Mace GM. Beyond predictions: Biodiversity conservation in a changing climate. Science 2011;332:53-8.
106. Guisan A, Thuiller W. Predicting species distribution: Offering more than simple habitat models. Ecol Lett 2005;8:993-1009.
107. Williams SE, Shoo LP, Isaac JL, Hoffmann AA, Langham G. Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biol 2008;6:2621-6.
108. Borrelli P, Robinson DA, Fleischer LR, Lugato E, Ballabio C, Alewell C, *et al.* An assessment of the global impact of 21st century land use change on soil erosion. Nat Commun 2017;8:2013.
109. Brevik EC. The potential impact of climate change on soil properties and processes and corresponding influence on food security. Agriculture 2013;3:398-417.
110. Brevik EC. Soils and climate change: Gas fluxes and soil processes. Soil Horiz 2012;53:12-23.
111. Lal R. Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security. BioScience 2010;60:708-21.
112. Pimentel D. Soil erosion: A food and environmental threat. Environ Dev Sustain 2006;8:119-37.
113. Brevik EC. Climate change, soils, and human health. In: Burgess LC, editor. Soils and Human Health. Boca Raton: CRC Press; 2013. p. 345-83.
114. Daly E, Porporato A. A review of soil moisture dynamics: From rainfall infiltration to ecosystem response. Environ Eng Sci 2005;22:9-24.
115. O'Neal MR, Nearing M, Vining RC, Southworth J, Pfeifer RA. Climate change impacts on soil erosion in Midwest United States with changes in crop management. Catena 2005;61:165-84.
116. Holsten A, Vetter T, Vohland K, Krysanova V. Impact of climate change on soil moisture dynamics in Brandenburg with a focus on nature conservation areas. Ecol Model 2009;220:2076-87.
117. Nearing MA, Pruski FF, O'Neal MR. Expected climate change impacts on soil erosion rates: A review. J Soil Water Conserv

2004;59:43-50.
118. Bakker MM, Govers G, Jones RA, Rounsevell MD. The effect of soil erosion on Europe's crop yields. Ecosystems 2007;10:1209-19.
119. Maeda EE, Pellikka PK, Siljander M, Clark BJ. Potential impacts of agricultural expansion and climate change on soil erosion in the Eastern Arc Mountains of Kenya. Geomorphology 2010;123:279-89.
120. Istvanovics V. Eutrophication of lakes and reservoirs. In: Likens GE, editor. Encyclopedia of Inland Waters. Vol. 1. Oxford: Elsevier; 2009. p. 157-65.
121. Kirkby M, Bracken L. Gully processes and gully dynamics. Earth Surf Process Landf 2009;34:1841-51.
122. Valentin C, Poesen J, Li Y. Gully erosion: Impacts, factors and control. Catena 2005;63:132-53.
123. Ozsahin E. Climate change effect on soil erosion using different erosion models: A case study in the Naip Dam basin, Türkiye. Comput Electron Agric 2023;207:107711.
124. Zhang XC, Nearing MA. Impact of climate change on soil erosion, runoff, and wheat productivity in central Oklahoma. Catena 2005;61:185-95.
125. Mondal A, Khare D, Kundu S, Meena PK, Mishra P, Shukla R. Impact of climate change on future soil erosion in different slope, land use, and soil-type conditions in a part of the Narmada River Basin, India. J Hydrol Eng 2015;20:C5014003.
126. Taddese G. Land degradation: A challenge to Ethiopia. Environ Manage 2001;27:815-24.
127. Sebti M, Khormali F, Soltani A, Eftekhari K, Ghanghermeh A, Dordipour E. The effect of climate change on soil organic carbon storage using the Roth C model in the agricultural lands of Golestan province. J Agric Eng 2023;45:339-54.
128. Wan Y, Lin E, Xiong W, Li Y, Guo L. Modeling the impact of climate change on soil organic carbon stock in upland soils in the 21st century in China. Agric Ecosyst Environ 2011;141:23-31.
129. Guo J, Feng H, Peng C, Chen H, Xu X, Ma X, *et al.* Global climate change increases terrestrial soil CH_4 emissions. Glob Biogeochem Cycles 2023;37:e2021GB007255.
130. Ayanlade A, Oladimeji AA, Okegbola OM, Eludoyin AO, Eslamian S, Ayinde AF, *et al.* Effect of climate change on water availability and quality: An assessment of socio-resilience in Nigeria. In: Eslamian S, Eslamian F, editors. Disaster Risk Reduction for Resilience. Cham: Springer; 2022. p. 245-62.
131. Koutroulis AG, Tsanis IK, Daliakopoulos IN, Jacob D. Impact of climate change on water resources status: A case study for Crete Island, Greece. J Hydrol 2013;479:146-58.
132. Abbaspour KC, Faramarzi M, Ghasemi SS, Yang H. Assessing the impact of climate change on water resources in Iran. Water Resour Res 2009;45:W10434.
133. Reddy NM, Saravanan S, Almohamad H, Al Dughairi AA, Abdo HG. Effects of climate change on streamflow in the Godavari basin simulated using a conceptual model including CMIP6 dataset. Water 2023;15:1701.
134. Bridhikitti A, Ketuthong A, Prabamroong T, Li R, Li J, Liu G. How do sustainable development-induced land use change and climate change affect water balance? A case study of the Mun river Basin, NE Thailand. Water Res Manag 2023;37:2737-56.
135. Han Y, Bu H. The impact of climate change on the water quality of Baiyangdian Lake (China) in the past 30 years (1991-2020). Sci Total Environ 2023;870:161957.
136. Xu ZX, Chen YN, Li JY. Impact of climate change on water resources in the Tarim River basin. Water Res Manag 2004;18:439-58.
137. Iglesias A, Garrote L, Diz A, Schlickenrieder J, Martin-Carrasco F. Re-thinking water policy priorities in the Mediterranean region in view of climate change. Environ Sci Policy 2011;14:744-57.
138. Garbrecht JD, Steiner JL, Cox CA. The times they are changing: Soil and water conservation in the 21st century. Hydrol Proc 2007;21:2677-9.
139. Blanco-Canqui H, Lal R. Principles of Soil Conservation and Management. Dordrecht: Springer; 2008.
140. Friedrich T, Derpsch R, Kassam A. Overview of the global spread of conservation agriculture. Field Actions Sci Rep 2012;6:1-7.
141. Kassam A, Derpsch R, Friedrich T. Global achievements in soil and water conservation: The case of conservation agriculture. Int Soil Water Conserv Res 2014;2:5-13.
142. Curtis TP, Sloan WT. Microbiology. Exploring microbial diversity--a vast below. Science 2005;309:1331-3.
143. Callaway E. Devastating wheat fungus appears in Asia for first time. Nature 2016;532:421-2.
144. Mall RK, Gupta A, Singh R, Singh RS, Rathore LS. Water resources and climate change: An Indian perspective. Curr Sci 2006;90:1610-26.
145. Ragab R, Hamdy A. 1.1. Climate Change and Water Resources Management in Arid and Semi-arid Regions. In: Sustainable Development in Dry lands-Meeting the Challenge of Global Climate Change. Vol. 7. 2008. p. 279.
146. Dell M, Jones BF, Olken BA. Temperature shocks and economic growth: Evidence from the last half century. Am Econ J Macroecon 2012;4:66-95.
147. Hsiang S. Climate econometrics. Ann Rev Res Econ 2016;8:43-75.
148. Auffhammer M. Quantifying economic damages from climate change. J Econ Perspect 2018;32:33-52.
149. Newell RG, Prest BC, Sexton SE. The GDP-temperature relationship: Implications for climate change damages. J Environ Econ Manag 2021;108:102445.
150. Weitzman ML. GHG targets as insurance against catastrophic climate damages. J Public Econ Theory 2012;14:221-44.
151. Stern N. Economics: Current climate models are grossly misleading. Nature 2016;530:407-9.
152. Kompas T, Pham VH, Che TN. The effects of climate change on GDP by country and the global economic gains from complying with the Paris climate accord. Earths Future 2018;6:1153-73.
153. Fankhauser S, Tol RS. On climate change and economic growth. Resour Energy Econ 2005;27:1-17.
154. Dasgupta P, Maler KG. Poverty, institutions and the environmental resource base. In: Book Poverty, Institutions, and the Environmental Resource Base. United States: The World Bank; 1994.
155. Pearce DW, Warford JJ. World Without End: Economics, Environment, and Sustainable Development. New York: Oxford University Press; 1993.
156. Fankhauser S, Stern N. Climate change, development, poverty and economics. In: Basu K, Rosenblatt D, Sepulveda C, editors. The State of Economics, the State of the World. Cambridge: MIT Press; 2016.
157. Alagidede P, Adu G, Frimpong PB. The effect of climate change on economic growth: Evidence from Sub-Saharan Africa. Environ Econ Policy Stud 2016;18:417-36.
158. Roson R, Van der Mensbrugghe D. Climate change and economic growth: Impacts and interactions. Int J Sustain Econ 2012;4:270-85.
159. Khurshid N, Fiaz A, Khurshid J, Ali K. Impact of climate change shocks on economic growth: A new insight from non-linear analysis. Front Environ Sci 2022;10:1039128.
160. Polasky S, Kling CL, Levin SA, Carpenter SR, Daily GC, Ehrlich PR, *et al.* Role of economics in analyzing the environment and sustainable development. Proc Natl Acad Sci U S A 2019;116:5233-8.

How to cite this article: Kour D, Ahluwalia KK, Ramniwas S, Kumar S, Rustagi S, Singh S, Rai AK, Yadav AN, Ahluwalia AS. Environment and climate change: Influence on biodiversity, present scenario, and future prospect. J App Biol Biotech. 2024;12(2):1-12.
DOI: 10.7324/JABB.2024.148189

India's Long-Term Low-Carbon Development Strategy

Ministry of Environment, Forest and Climate Change
Government of India

India's Long-Term Low-Carbon Development Strategy

Submission to the United Nations Framework Convention on Climate Change

Ministry of Environment, Forest and Climate Change
Government of India

India's long-term low-carbon development strategy

India's long-term low-carbon development strategy

CITATION: MoEFCC. (2022). India's long-term low-carbon development strategy. Ministry of Environment, Forest and Climate Change, Government of India.

Disclaimer: The maps are not to scale and are representative in nature. Citing of trade names or commercial processes does not constitute endorsement. The various examples cited throughout the document are only illustrative and indicative and not exhaustive, nor have they been chosen based on priority.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Units

GJ	Giga Joules
$GtCO_2e$	Gigatonnes of Carbon dioxide equivalent
GW	Gigawatt
km	Kilo meter
kWh	Kilowatt Hours
MT	Metric Tonnes
$MtCO_2e$	Million tonnes of Carbon dioxide equivalent
MW	Megawatt
tCO_2e	Tonnes of Carbon dioxide equivalent
TOE	Tonne of oil equivalent
TWh/BU	Terrawatt hour/Billion Unit

मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
और
श्रम एवं रोज़गार
भारत सरकार

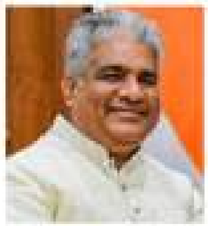
सत्यमेव जयते

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
AND
LABOUR AND EMPLOYMENT
GOVERNMENT OF INDIA

भूपेन्द्र यादव

BHUPENDER YADAV

आज़ादी का अमृत महोत्सव



MESSAGE

India is a nation that has taken on its due share of responsibility for humanity and the planet and has committed itself to climate action. For the warming of the planet by 1-degree C that we are witnessing today, our responsibility is minimal, with our own scientific judgment echoed in the recent assessment reports of the Intergovernmental Panel on Climate Change (IPCC).

India has always been pro-active in its commitments to international cooperation and in keeping abreast of the requirements of the global climate regime that we have collectively agreed to under the United Nations Framework Convention on Climate Change and its Kyoto Protocol and Paris Agreement. In keeping with this commitment, it is now submitting its Long-Term Low-Carbon Development Strategy in accordance with the requirements of Article 4, para 19 of the Paris Agreement.

India's long-term strategy makes clear its commitment to equity and climate justice. In operationalizing these two inter-related principles, fair and equitable access to the global carbon budget is the key.

India's climate policies and actions are robust and adequate, in keeping with the requirements of the Paris Agreement, while seeking cooperation and collaboration, as in the pandemic, to find collective solutions to the challenge that faces us. As announced by Hon'ble Prime Minister Shri Narendra Modi at COP26 in Glasgow, India believes that the world needs to follow the mantra of LiFE, i.e. Lifestyle for the Environment - a global movement to effect a paradigm shift from mindless and destructive consumption to mindful and deliberate utilization.

The journey to a sustainable future is one in which all nations should participate on the basis of equity and in accordance with the principle of common but differentiated responsibilities and respective capabilities, with developed countries taking the lead as has been agreed by all in the United Nations Framework Convention on Climate Change.

The journey to net-zero at 2070 is a five decade long one and India's vision of low-carbon development is one that must be evolutionary and flexible, accommodating new developments in technology, the global economy and international cooperation, while mindful of the risks that such a journey inevitably entails. The imperatives of eradicating our development deficits and ensuring our energy security while rationally utilizing our natural resource endowment are therefore two themes that pervade our low-carbon strategy.

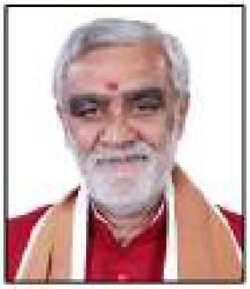
In presenting this submission to the UNFCCC, India once again affirms its commitment and dedication to the cause of fighting climate change.

Date: 1-11-2022

(Bhupender Yadav)

पर्यावरण भवन, जोर बाग रोड, नई दिल्ली–110003, फोन: 011–20819275, 20819225, फैक्स: 011–20819299
Paryavaran Bhawan, Jor Bagh Road, New Delhi-110003 Tel.: 011-20819275, 20819225, Fax: 011-20819299
ई–मेल/E-mail: mefcc@gov.in

अश्विनी कुमार चौबे
Ashwini Kumar Choubey



राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
उपभोक्ता मामले, खाद्य और सार्वजनिक वितरण
भारत सरकार
MINISTER OF STATE
ENVIRONMENT, FOREST AND CLIMATE CHANGE
CONSUMER AFFAIRS, FOOD & PUBLIC DISTRIBUTION
GOVERNMENT OF INDIA

October 31, 2022

MESSAGE

I am gratified to pen this message for the submission of India's Long-term Low-carbon Development Strategy in accordance with the requirements of the Paris Agreement.

India is a committed and pro-active player on the field of climate action. Under the able leadership of our Hon'ble Prime Minister, India has made rapid strides in matching its climate policies to the need of protecting people and the planet. Our renewable energy plans are challenging and ambitious. In areas such as the provision of LEDs for street lighting on a mass scale for domestic and street lighting under our Unnat Jyoti by Affordable LEDs for All (UJALA) and LED Street Lighting National Programme (SLNP), we are pushing forward the concept of development along a low-carbon pathway. Our UJJWALA programme has provided clean cooking fuel to millions of households, benefiting both the conservation of natural resources and the enhancement of women's health. More than 80 million LPG connections have been provided to rural households who were previously using wood or coal as cooking fuel. Initiatives like electric mobility and alternate fuels including biofuel and green hydrogen are being pursued and are at various stages of development.

It is notable that India has thus far undertaken its actions primarily with its own resources. India's submission to the UNFCCC in this document lays out our vision for an equitable and sustainable future. An integral part of this is India's call to all nations to join in LiFE, Lifestyle for Environment, a global movement for planet and the people.

The world will also need much more technological advancement and a serious effort at innovation to achieve a sustainable future. Hence, there is a specific emphasis on research and innovation in the long-term development strategy. With economic growth, technological advance, and radical improvement in the provision of the means of implementation by developed countries, India's long-term strategy for low-carbon development will no doubt evolve further and may be suitably revised as per emerging scenarios in future.

(Ashwini Kumar Choubey)

कार्यालय: 5वां तल, आकाश विंग, इंदिरा पर्यावरण भवन, जोर बाग रोड, नई दिल्ली-110003, दूरभाष: 011-20819418, 011-20819421, फैक्स: 011-20819207, ई-मेल : mos.akc@gov.in
Office : 5th Floor, Aakash Wing, Indira Paryavaran Bhawan, Jor Bagh Road, New Delhi-110003, Tel.: 011-20819418, 011-20819421, Fax : 011-20819207, E-mail : mos.akc@gov.in
कार्यालय: कमरा नं 173, कृषि भवन, नई दिल्ली-110001, दूरभाष : 011-23380630, फैक्स: 011-23380632
Office : Room No. 173, Krishi Bhawan, New Delhi-110001, Tel. : 011-23380630, Fax : 011-23380632
निवास: 30, डॉ. एपीजे अब्दुल कलाम रोड, नई दिल्ली-110003, दूरभाष : 011-23794971, 23017049
Residence : 30, Dr. APJ Kalam Road, New Delhi-110003, Tel.: 011-23794971, 23017049

LEENA NANDAN

FOREWORD

[illegible]

Executive Summary

ES1. Introduction

India is currently one of the fastest growing economies in the world, home to almost one-sixth of humanity. Its growth momentum is an integral part of global development and is essential to meeting the world's sustainable development goals. A number of challenges confront India's development agenda including that of climate change. India's contribution to global warming is minimal. Nevertheless, India is committed to combating climate change, by making development choices that ensure growth and development of the economy along low carbon pathways towards net-zero by 2070. Recognizing that climate change is a global collective action problem, India is committed to addressing the challenge with firm adherence to multilateralism based on equity and the principle of common but differentiated responsibilities and respective capabilities (CBDR-RC), as enshrined in the United Nations Framework Convention on Climate Change (UNFCCC).

Based on climate science, limiting global cumulative emissions within the global carbon budget is the key to limiting global temperature rise. India maintains that operationalizing the principle of equity and climate justice requires that this budget be equitably shared among all countries and used responsibly. Historical and future responsibility of countries is to be framed in terms of limiting their cumulative emissions within their fair share of this budget. The key principle that informs India's climate policy, therefore, is to pursue its development goals according to national circumstances while keeping within its fair share of the global carbon budget.

Parties agreed, under Article 4.19 of the Paris Agreement under the UNFCCC "to strive to formulate and communicate long-term low greenhouse gas emission development strategies (LT-LEDS), mindful of Article 2 taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances." Accordingly, in this document India lays out its approach to its low-carbon development pathway, taking note of the development challenges facing it in the context of climate change and cognizant of its historical traditions and culture that seeks harmony and balance between human society and nature. India's LT-LEDS draws on a review of available quantitative and analytical studies, syntheses of official and academic materials, and the inputs of seven Task Groups established to deliberate on different dimensions of the LT-LEDS for India.

India's approach to low-carbon development

India's approach is based on the following four key considerations that underpin its long-term low-carbon development strategy:

1. India has contributed little to global warming

The Summary for Policy Makers (SPM) of the Working Group III contribution to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) [2022] has noted clearly that the contribution of entire Southern Asia is only about 4% of historical cumulative net anthropogenic emissions between 1850 and 2019, even though the region includes almost 24% of the global population. North America and Europe alone have contributed almost 10 times more to global cumulative emissions in this period, though they have only ~13% of the global population.

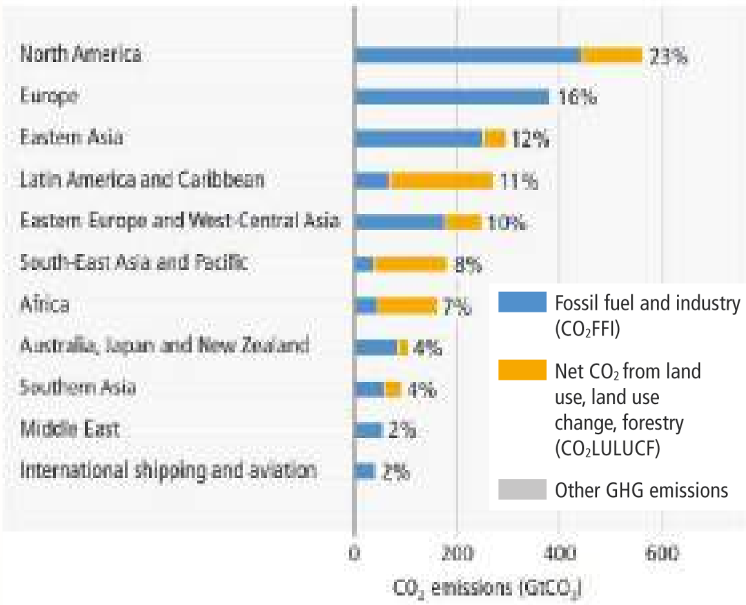


Figure ES.1 Historical cumulative net anthropogenic CO_2 emissions per region (1850–2019)

Source: *IPCC AR6 2022 Working Group III, Summary for Policymakers, Figure SPM.2*

India's historical contribution to cumulative global GHG emissions is therefore minuscule despite having a share of ~17% of the world's population. India's per capita annual emissions are about a third of the global average. From a global carbon equity perspective, India is justified in seeking that developed countries undertake early net-zero, well before 2050, by investing heavily in negative emissions, and providing adequate climate finance, technology transfer and capacity building support.

2. India has significant energy needs for its development

Energy is essential to erasing India's development deficits and meeting its developmental needs and aspirations. India's annual primary energy consumption per capita in 2019 was 28.7 gigajoules (GJ), considerably lower than both developed and developing country peers. Energy is needed for social development, to support India's demographic transition and consequent job creation needs, its agrarian and urban transition, and infrastructure development. India is actively pursuing energy efficiency as one of the key means of promoting low-carbon development. While the extent of decoupling of emissions from growth seen in developed countries is still insufficient in terms of the ambitious emissions reduction required by their historical and current responsibility, India's continued effort at increasing decoupling of emissions from growth proceeds, in contrast, from an already low baseline of emissions.

3. India is committed to pursuing low-carbon strategies for development and is actively pursuing them, as per national circumstances

India's mitigation efforts are driven not just by climate-specific policies, but also by broader development choices. India seeks to identify and explore opportunities to shift to low-carbon development pathways, while ensuring adequate access to household energy, energy security, and energy for the development of all sectors of the economy. Beginning in 2008 with the National Action Plan on Climate Change (NAPCC), the scope for co-benefits between climate and development is recognized by India, while also being mindful of the trade-offs and corresponding costs.

The social and transaction costs of making a low-carbon transition are considerable. While India will pursue low-carbon growth and development strategies, this transition will be in accordance with national circumstances and at a pace and scale that is nationally determined, without compromising development futures. Consequently, the need for climate finance for India's low-carbon transition is considerable.

The global and domestic context, including equity and the need for sustainable development, will guide India's national objectives in the rational utilization of fossil fuel resources, with due regard to India's energy security. India's per capita consumption of coal, its leading natural fossil fuel resource, when normalized for coal quality, was half the world average in 2019 and its natural gas consumption was 30-50 times lower than many OECD (Organisation for Economic Cooperation and Development) countries. Further, global oil and gas emissions are 25% higher than coal emissions, whereas, for India, coal is its main fossil fuel resource.

4. India needs to build climate resilience

India has a diverse geography that encompasses a wide range of ecosystems, from mountains to deserts, from inland to coastal areas, and from plains to jungles, and is vulnerable to impacts of climate change. Adaptation measures and building resilience to potential climate impacts are necessary to maintain India's development gains and human development outcomes and sustain its growth and development.

India's climate actions

India is already making considerable efforts at undertaking climate actions across its entire economy. India also has a long tradition of reverence and respect for Nature that provides broad societal support for India's pro-active climate policies and actions. India has achieved its pre-2020 voluntary contributions and its policies and actions are acknowledged to be compatible with the 2^{o}C warming target of the Paris Agreement. India has consistently made ambitious commitments at the UNFCCC, the key multilateral forum for climate change, and under the Paris Agreement, and has a strong track record of meeting these commitments, despite its minimal responsibility. Building upon Hon'ble Prime Minister Narendra Modi's *Panchamrit* (five nectar elements) pledges at the 26th Conference of Parties (COP26) of the UNFCCC in Glasgow, including the target of net-zero emissions by 2070, India updated its NDC in August 2022 as follows:

i. Meet 50% of India's cumulative electric power installed capacity from non-fossil sources by 2030.

ii. Reduce the emission intensity of GDP by 45% below 2005 levels by 2030.

iii. Put forward and further propagate a healthy and sustainable way of living based on the traditions and values of conservation and moderation, including through a mass movement for LiFE – Lifestyle for Environment as a key to combating climate change.

ES2. Strategic Low-Emissions Development Transitions

India's LT-LEDS rests on seven key transitions to low-carbon development pathways. These transitions to low-carbon development pathways have already been initiated through various significant and specific policies, programmes, and initiatives. However, India's efforts so far have been overwhelmingly undertaken with its own resources. India's current climate actions are comprehensive, covering the entire economy, keeping in view India's development imperatives.

The key elements that constitute each proposed low-carbon development transition are first summarised. In subsequent sections, the domestic and international contexts, current policies and targets and elaboration of the long-term low-emissions development strategies follow. The relevant literature has been taken into account in elaborating the elements of these low-carbon development transitions, including available modelling studies. The output of global models cannot be readily applied to India for the lack of clarity on equity, climate justice and common but differentiated responsibilities and respective capabilities in their assumptions and structure. Various stakeholders, especially academia, are developing the necessary techniques and models with Government support and facilitation, and India is cognizant of the need for the appropriate modelling results.

Elements of Long-term Low-Emissions Development Strategies

Low carbon development of electricity systems consistent with development

Growth in the electricity sector is critical for enabling industrial expansion, enhanced employment and incomes, and achievement of *Aatmanirbhar Bharat* (Self Reliant India). Low carbon options are to be assessed in the context of inclusive growth and expansion needed in the sector.

- Expanding renewables and strengthening the grid
- Exploring and/or supporting other low carbon technologies
- Focusing on demand-side management
- Rational utilization of fossil fuel resources, with due regard to energy security
- Assessing enablers for low carbon development
- Determining green taxonomy and optimum energy mix (complementing national development scenarios)

Develop an integrated, efficient, inclusive low-carbon transport system

Transport is a major contributor to GDP directly and indirectly. Low carbon options are to be assessed in the context of significant expansion needed across transportation modes for passenger and freight mobility.

- Encouraging improved fuel efficiency
- Phased transition to cleaner fuels
- Modal shift towards public and less polluting modes of transport
- Electrification across multiple modes
- Demand side management
- Traffic management and intelligent transport systems

Promote adaptation in urban design, energy and material-efficiency in buildings, and sustainable urbanisation

Exploring and encouraging adaptation measures in urban design will be critical in the context of developing urban areas. This will be a major focus alongside measures to promote sustainable urban design in the context of expanding cities.

- Mainstreaming adaptation measures in the built environment and urban systems
- Promote resource efficiency within urban planning guidelines, policies, and bylaws
- Promote climate responsive and resilient building design, construction, and operation in existing and future buildings and in urban systems
- Promote low-carbon municipal service delivery through resource efficiency, management of water, solid, and liquid waste

Promote economy-wide decoupling of growth from emissions and development of an efficient, innovative low-emission industrial system

Industrial growth is a major objective in the near, medium, and long term with policies directed at increasing the share of manufacturing in the GDP, including *Aatmanirbhar Bharat* and Make in India. Due efforts will be undertaken to recognize the informal sector and the development of the Micro Small and Medium Enterprises (MSME) sector. Low carbon options will be explored in this context, recognizing that there are many hard-to-abate sectors.

- Improve energy and resource efficiency, with efforts to increase the use of natural and bio-based materials
- Process and fuel switching and electrification in manufacturing, as feasible and viable
- Enhance material efficiency and recycling, strengthening the circular economy
- Promote green hydrogen technology and infrastructure
- Explore options for sustainable growth of hard-to-abate sectors
- Low carbon and sustainable growth of micro, small and medium enterprises (MSMEs)

CO_2 removal and related engineering solutions

This is a new sector being explored the world over and may also be explored in the Indian context. This shall require substantial international support through innovation, technology transfer, climate - specific finance and capacity building.

- Training, capacity building and planning to minimize socio-economic, livelihood and ecosystem impacts
- Explore public-private partnership frameworks in view of intensive resource requirements

Enhancing Forest and vegetation cover consistent with socio-economic and ecological considerations

India's national commitment to the enhancement of natural resources, preservation of resource heritage and promoting biodiversity will frame the strategy in this sector. It will also be an inclusive approach taking note of livelihood, social and cultural dependence of the relevant population.

- Restoration, conservation, and management of forests and their plant, animal and microbial genetic resources
- Restoration, conservation, and management of trees outside forests
- Strengthening infrastructure of State forest departments, including upgradation of nurseries

Economic and financial aspects of low-carbon development

Given the priorities of poverty eradication, increasing employment and incomes, increasing resilience to climate change, and reaching a new level of prosperity, low-cost international climate finance is essential to achieve the objectives of low carbon development.

- Assessments of financial requirements
- Mobilizing, accessing and delivering climate-specific finance, especially multilateral climate finance
- Mainstreaming of climate finance
- International climate finance, technology transfer and capacity building
- Linkages to international trade
- New multilateral mechanisms for supporting innovation, and technology development

ES2.1 Low Carbon Development of Electricity Systems Consistent with Enhanced Development Benefits

Domestic and International Context

India's average per capita electricity consumption from utilities alone, ~800 kWh in 2020, is only about a fourth of the global average. The overall per-capita consumption of electricity for the year 2021-22 was 1255 kWh. Across sectors, the supply of electricity in India will grow to support domestic, agricultural, industrial, and other uses. India recently achieved universal household access to electricity, with efforts underway for strengthening the quality and reliability of supply. Enhanced electricity supply will therefore be a focus area for India to develop low carbon strategies as the energy sector contributed 75% of GHG emissions in India, of which electricity contributes more than half. India's development of its electricity system is also seeing a rapid increase in the deployment of renewable sources of electricity generation promoted actively through public policies.

Current Policies and Targets

- Ambitious RE target with 50% of non-fossil capacity by 2030.
- Support for RE through "must run" status for renewable sources and Renewable Purchase Obligations for distribution companies, open access consumers and captive power plants. Policy on Energy Storage Obligations (ESO) has also been introduced.
- Green energy corridors to strengthen transmission networks in eight RE rich States.
- Policy and financial incentives include solar park development, accelerated depreciation on investment, waiver on transmission charges, and capital subsidy for residential solar roof-top and agricultural solar pumps.
- Promotion of hydro power through several policy measures to tap hydro power potential in the country and promote its use through the introduction of Hydro Purchase Obligation.
- Rational use of fossil-fuel based capacity.
- A three-fold rise in nuclear installed capacity by 2032.
- Promoting competition and markets for green electricity and smoother grid integration of Renewable Energy.
- Energy management at household level, including star rating of appliances.

- India has been proactively shutting down inefficient thermal units. A total 241 Units with capacity of 17281 MW have been retired from 10th Plan onwards till September 2021.

Elements of a Long-Term Low-Carbon Development Strategy

1. Expanding renewables and strengthening the grid: India aims to rapidly expand its RE capacity in the short to medium term while strengthening the electricity grid and enhancing its flexibility.
2. Other technologies for low-emissions development: Explore a greater role for nuclear energy and enhance support for R&D into future technologies such as green hydrogen, fuel cells, and biofuels.
3. Appropriate demand-side measures: Strong energy efficiency measures can help meet the growing demand for energy services using less energy, while energy supply to the bulk of the population will increase.
4. Rational utilization of fossil fuel resources: While the share of coal in installed capacity and supply of power will decline, coal will be needed for power and energy, including, inter alia, for grid stabilisation, supply to industry and to guarantee India's energy security.
5. Enablers for a National Development friendly transition: Enabling measures for a development-focused transition include promoting local manufacturing, and fostering capable, agile, and responsive institutions at all levels.
6. Optimum energy mix (complimenting National development scenarios): The role of all non-fossil and fossil fuel sources will be key to supporting the long-term low carbon development strategy in different sectors.

ES2.2 Develop an Integrated, Efficient, Inclusive Low-Carbon Transport System

Domestic and International Context

The transport sector in India contributes around 10% to the GDP. It is an important sector that facilitates the overall development of industries and commercial activities in any economy. In India, therefore, development of the transport sector is a priority area for the Government. Emissions from the transportation sector are mainly driven by fossil fuel consumption in the road sector, even as vehicle ownership in India is far below the world average and much below the levels of other developed and emerging economies. However, the road transport sector accounts for about 87% of passenger traffic and 60% of freight traffic movement in the country and sustainable development of this sector is a critical element in India's long-term development strategy.

Indian Railways is one of the world's largest railway networks, spread over ~68,000 km. It carries nearly 23 million passengers daily, making it the largest passenger carrying system in the world. Other segments such as civil aviation and domestic navigation account for a relatively small but fast-growing share of India's transport mix. Given India's current growth and transport sector trends, the on-road freight segment is likely to be a significant driver of transport emissions in the long-term in a business-as-usual scenario. Emissions from heavy duty vehicles would account for the majority of such emissions. Addressing both passenger and freight transport will therefore be an important goal for India's low-carbon development.

Current Policies and Targets

- Indicative 2025 target: 20% ethanol blending in petrol, with a savings potential of approximately INR 30,000 crore/yr.
- Leapfrogging Bharat Stage V emissions to directly reach Bharat Stage VI emissions.
- Comprehensive package for electric vehicles, including domestic manufacturing in auto parts and batteries, investments in charging infrastructure and demand aggregation.
- Indian Railways to become net-zero by 2030, leading to annual mitigation of 60 million tonnes of CO_2.
- Multiple policies to enhance the share of public, non-motorized transport.
- A National Master Plan for Multi-modal Connectivity – PM Gati Shakti.
- Integrated and optimized freight networks through programmes such as Gati Shakti, Transit-oriented development, Bharatmala, Sagarmala, and dedicated rail freight corridors.
- National Logistic Policy aspires to reduce cost of logistics in India to be comparable to global benchmarks by 2030.

Elements of a Long-Term Low-Carbon Growth Strategy

1. Reducing fuel demand and GHG emissions through improved fuel efficiency: India will achieve this through raised standards, optimized networks, improved technologies, and fleet modernization.
2. Phased adoption of cleaner fuels: There will be continuation of a gradually increased blending of cleaner fuels while managing socio-economic and development of the skilling aspects required for the same. Hydrogen will be used as an energy carrier and alternate fuel in the transportation sector.
3. Modal shift towards public and less polluting modes of transport: India will seek to integrate transport with urban planning, multi-modal connectivity, and enhanced railway capacity.
4. Electrification across multiple modes: A comprehensive package of programmes, policies, and measures for the domestic manufacturing of electric vehicles and batteries and the electrification of railways will be taken up.

ES2.3 Promoting Adaptation in Urban Design, Energy and Material-Efficiency in Buildings, and Sustainable Urbanisation

Domestic and International Context

India is rapidly urbanizing. A sustainable, balanced, and integrated development of urban areas is a central theme in India's future urban growth paradigm. As per Census 2011, 31% of the country's population lived in urban areas. India's urban population is estimated to reach 37% by 2030, and 70% of India's GDP in 2030 is expected to be generated from urban regions. Due to the concentration of economic activity in urban agglomerations, energy consumption, and consequently emissions are higher in cities making these important regions for climate action. In India's current state of development, many initiatives across a wide range of sectors address key urban issues. These include cross cutting schemes and programmes such as those in renewable energy, energy efficiency and sustainable water management. At the same time, given the extent of vulnerable population in cities, climate adaptation and climate resilience are also key requirements for urban India.

Current Policies and Targets

- National Urban Policy Framework (NUPF).
- Town and country planning act and State planning regulations, local area plans.
- Provision of housing for low- and middle-income groups through the Pradhan Mantri Awaas Yojana (PMAY).
- National Building Code, Energy Conservation Building Code, Eco-Niwas Samhita (an energy conservation building code for residential buildings).
- Development Control Regulations (DCR) and model building bylaws.
- India Cooling Action Plan.
- Sustainable public transport including sustainable mobility through national mission on electric mobility and battery storage.
- National Solar Mission.
- National Mission on Sustainable Habitat.
- National Water Policy, National Environment Policy, National Urban Sanitation Policy.
- Jal Jeevan Mission, Atal Mission for Rejuvenation and Urban Transformation (AMRUT).
- Construction and Demolition Waste Management Rules, Extended Producer Responsibility 2021, and Plastic Waste Management (Amendment) Rules 2021.

Elements of Long-Term Low-Carbon Growth Strategy

1. Adaptation measures will be mainstreamed in urban planning.
2. Measures will be promoted for enhancing energy and resource efficiency and low-carbon development within urban planning guidelines, policies, and bylaws.
3. Climate-responsive and resilient building design, construction and operation in existing and future buildings are to be promoted.
4. Low-carbon municipal service delivery through resource efficiency and management of water, solid and liquid waste will be pursued.

ES2.4 Promote Economy-Wide Decoupling of Growth from Emissions and Development of an Efficient, Innovative Low-Emission Industrial System

Domestic and International Context

The industrial sector contributed about 25.9% to India's GVA in 2020-21. Manufacturing alone, contributed 14.4% to GVA this year, with construction and energy and other supply utilities adding another 9.9% (DEA, 2022). The Government of India is focused on expanding the contribution of manufacturing to GDP as this is necessary in a developing country such as India to generate employment, enhance incomes, and create infrastructure and conditions for improved well-being of the population.

Continued growth, plus aspirations to boost domestic manufacturing, is expected to lead to enhanced energy consumption, and significant additional demand for steel and cement in the medium- and long-term and this has implications for emissions from this sector. Low carbon options for the industrial sector in India must be viewed within the overall context of the need for significant expansion of industrial production, the fact that India's contribution to historical emissions is negligible, and that India remains well below its fair share of the carbon budget. Additionally, a shift away from fossil fuels in this sector would require viable fuel and technology alternatives to maintain a healthy growth of India's GDP and employment and repurposing of assets and transition planning in sectors such as mining, petroleum refining, and manufacturing, which may subsequently also lead to impacts in other sectors of the economy. Despite these challenges, India has taken significant strides in ensuring improved energy efficiency in the industrial sector creating the conditions for sustainable growth in this sector in the medium and long term.

The presence of a substantial MSME sector in India's manufacturing is noteworthy and special consideration is required to modernise and enhance the energy efficiency of this sector, especially because of its potential for growth, value addition and employment.

Current Policies and Targets

- National Missions for Enhanced Energy Efficiency and Sustainable Habitat, Standards and Labelling Scheme, and the Energy Efficiency Financing Platform.
- Fuel switching through promotion of natural gas and the National Policy on Bio-Fuels.
- Material efficiency through policies on resource efficiency, plastic and e-waste, and steel recycling.
- Green hydrogen technology and infrastructure promotion.
- Decarbonisation of hard-to-abate sectors such as steel and cement through R&D.
- National Solar Mission.

Elements of a Long-Term Low-Carbon Growth Strategy

1. Improve energy efficiency: Promotion of energy efficient/low carbon technologies, digitization of processes, and creation of trading schemes and other market-based enablers to achieve these goals will be pursued where relevant.
2. Process and fuel switching, and electrification in manufacturing: These will be pursued, as relevant, based upon availability and access to technology and the provision of climate finance.
3. Enhance material efficiency and recycling: Sector-specific material efficiency technologies and strategies will be enhanced through value chains, as material-demand trends shift.
4. Promote green hydrogen technology and infrastructure: R&D in technology and infrastructure for green hydrogen will be given a boost, ramping up electrolyser manufacturing capacity.
5. Explore low carbon options in hard-to-abate sectors: Best available technologies in the steel and cement sectors will be pursued
6. Low-carbon and Sustainable development of MSMEs: Strengthen financial support, knowledge sharing, and awareness of low carbon options and sustainable technologies.

ES2.5 CO_2 Removal and Related Engineering Solutions

The economic, technical and political feasibility of Carbon Capture Utilisation and Storage (CCUS) is highly uncertain. The emphasis in this aspect is on R&D and building human and infrastructure capacity to evolve technologies and methodologies that address issues related to high capital costs, safety, logistics and high auxiliary power consumption. CCUS technology at present is not matured and India can take up only demonstration projects at this stage to assess the viability of the proposed solutions. Retrofitting of existing thermal power generating units for CCUS implementation is not a viable option, until the technology is cost effective and less energy intensive. India requires considerable climate finance and technology transfer with effective international collaboration to enter this arena on any significant scale.

ES2.6 Enhancement of Forest and Vegetative Cover Consistent with Socio-Economic and Ecological Considerations.

Domestic and International Context

In India, 24.62% of the total geographical area is under forest and tree cover. India has among the lowest rates of gross deforestation in the world, in absolute terms, in per capita terms, and in annual rates. The carbon stock in forests is estimated to be 7,204 million tonnes. The forest sector employs around 6.23 million people, and is a source of livelihood for several communities, especially tribal communities.

Current Policies and Targets

- NDC target: to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent by 2030.
- Major policies and institutions: National Mission for a Green India, National Afforestation Programme, Compensatory Afforestation Fund Management and Planning Authority, Nagar Van Yojana, National REDD+ (Reducing Emissions from Deforestation and forest Degradation) Strategy 2018, National Rural Livelihoods Mission, Forest Fire Prevention and Management Scheme and AMRUT (Atal Mission for Rejuvenation and Urban Transformation).
- Other voluntary contributions: To restore 26 million ha degraded land by 2030; 12 National Biodiversity Targets, in line with 20 global Aichi biodiversity goals.
- Major greening efforts of the National Highways Authority of India (NHAI) and Indian Railways.

Elements of a Long-Term Low Carbon Development Strategy

1. Restoration, Conservation and Management of Forest Cover (including mangrove forests) Improving/enhancing density and quality of forests; Improved protection and restoration of forest and green cover in biodiversity hotspots; Improved health of forest and forest hygiene; Improved climate smart monitoring and forest protection against forest fires.
2. Restoration, Conservation and Management of Trees outside Forests and Green Cover Restoration and increasing area under trees outside forests and green cover; Large scale enhancement of tree/green cover in urban and peri-urban areas; Rural greening with a focus on One Forest – One Village; Promote agro-forestry to increase farming income and meet wood products demand.
3. Infrastructure development.

ES2.7 Economic and Financial Aspects of Low-Carbon Development

1. Assessments of Financial Requirements

A transition to a low-carbon development pathway will entail costs, pertaining to the deployment of new technologies, development of new infrastructure, and other transaction costs. In the longer term, such a transition will also have broader economic impacts. Several estimates regarding India's financial needs exist. Many of them focus on the energy sector, including industry, buildings, and transport. Estimates vary across studies due to differences in assumptions, coverage, and modelling approaches, but fall in the range of trillions of dollars by 2050. In general, finance needs – and the domestic financing gap – are considerable, indicating a need for greater international support.

2. Mobilizing, accessing, and delivering climate specific finance, especially multilateral climate finance

Meeting finance needs require mobilising and scaling up financial resources internationally as well as mobilising domestic finance. International sources include multilateral and bilateral sources, dedicated climate funds, international institutional investors, and the private sector. There needs to be a significant enhancement in the scale, scope, and speed of climate finance from public sources to enable ambitious climate action in developing countries. In this regard, it is essential that developed countries should meet their commitments to climate finance, especially their long overdue commitment of USD 100 billion per year by 2020, while also enhancing their commitments under the New Collective Quantified Goals to enable the achievement of climate goals as mandated under the Paris Agreement. Ambition in climate action in developing countries requires ambition in climate finance under the Paris Agreement. Private finance can be channelled through equity investments, debt including loans and bonds, Foreign Direct Investment (FDI), risk mitigation instruments such as insurance and guarantees, and innovative forms of finance.

3. Linkages to International Trade

Financial aspects of the low-carbon transition can affect and in turn be affected by the international trade regime. India will seek to ensure that obligations in international trade agreements will not curtail the existing policy space to nurture domestic producers of environmental goods and services.

The domestic and foreign policies of developed countries, including the moves to address emissions through carbon border adjustment mechanisms, can also impact developing economies like India adversely, without achieving their stated objectives. There is a need to achieve the right balance between the requirements of development, trade, and low-carbon pathways.

ES3. Research and Innovation

India considers research and innovation in new technologies to be essential to meeting the challenge of climate action, including both adaptation and mitigation, either globally or nationally. There are many sectors where such innovation is especially critical for a developing country, for promoting low-carbon development, where the twin challenges of growth as well as the need for progressively decoupling emissions from such growth, must be met.

Chapter 3 of this report provides a detailed list of sectors and relevant technologies, a first list, where innovations are urgently required.

India also notes the example of the COVID-19 pandemic where the advantages of setting aside the intellectual property rights regime, particularly to meet global challenges, became very evident. Such an approach if adopted at the global level will promote research and innovation relevant to climate action.

ES4. Adaptation and Resilience

Development and growth are the first consideration in adaptation and resilience for developing countries. The impacts of climate change in India are multifold. Adapting to climate change will require an understanding of risks and vulnerabilities, economic and infrastructural development, strengthened individual resilience through enhancing livelihoods and incomes, new governance capacities and improved coordination, raising resources for adaptation including in the form of adaptation finance, addressing loss and damage, and ensuring equitable and inclusive strategies. India's adaptation actions attempt to achieve all of these goals.

India's adaptation finance needs are challenging to quantify. While individual estimates are subject to uncertainty, it is clear that the adaptation finance required is significantly higher than current adaptation finance flows.

ES5. Mission LiFE – Lifestyle for Environment

Following from the announcement of LiFE that the Prime Minister, made in the National Statement delivered at COP26, India has updated its Nationally Determined Contributions and, inter alia, updated the first as follows: To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation, including through a mass movement for 'LiFE'– 'Lifestyle for Environment' as a key to combating climate change. LiFE is envisaged as a global movement to effect a paradigm shift from the mindless and destructive consumption to the mindful and deliberate utilization of national resources.

The three key phases of this pro-people and planet centric strategy to combat climate change are i) to promote globally the practice of simple yet effective environment-friendly actions by individuals in their daily lives; ii) consequent response by industry and markets, tailoring supply and procurement, following from large-scale transformation of individual demand; iii) through changes in demand and supply dynamics globally to promote long-term shifts in industrial and Government policies that can support sustainable consumption and production. The collective action towards mindful and deliberate utilisation of resources would certainly contribute in attaining the goal that India has set for itself under the Nationally Determined Contribution Targets namely, reduce the emission intensity of the GDP by 45% below 2005 levels by 2030.

ES6. International Cooperation

India's approach to international cooperation is founded on the principles and commitments of the UNFCCC that climate action should be on the basis of equity and in accordance with common but differentiated responsibilities and respective capabilities, as per national circumstances.

As part of its commitment to a leading role in climate action, well beyond its fair share of responsibility, India has developed several forward-looking and participatory global initiatives, partnerships, and coalitions to combat climate change and foster greater collaboration. These include:

- International Solar Alliance (ISA), launched by India and France, which is a dedicated platform for cooperation between Governments, multilateral organizations, and industry to strengthen global cooperation on solar energy.
- Coalition for Disaster Resilient Infrastructure (CDRI), a partnership of national Governments, UN agencies, multilateral development banks, the private sector, and knowledge institutions to promote the resilience of new and existing infrastructure systems to growing climate risks and disasters.
- India-UN Development Partnership Fund, which aims to contribute to developing countries' efforts to

realize the 2030 Agenda for Sustainable Development Goals, including Climate Action.

- Leadership Group on Industry Transition (LeadIT), co-led by India and Sweden, is a platform for the Governments and the private sector to identify low-carbon business opportunities, cooperate on net-zero technology innovation and exchange knowledge on sectoral roadmaps for hard-to-abate sectors.

India is committed to the principles of cooperation under the United Nations Framework Convention on Climate Change and the Paris Agreement negotiated under the Framework and reiterates the importance of meeting the Nationally Determined Contribution (NDC) under the Agreement. Joint projects, inter-ministerial dialogues, channels for sharing knowledge and experiences, joint development of global technology standards, building networks of research institutions, and strategic technology partnerships are some of the potential avenues for strengthening international cooperation.

India's stated climate goals can be fully realized only if financial assistance, low-carbon technology transfer and capacity-building needs are met under the UNFCCC and its Paris Agreement. Developed nations must take the lead not only in emissions reductions, but in developing international climate finance and technology arrangements that respond to gaps in available resources in the developing world.

India cannot deploy low-carbon climate technologies at a significant scale unless a facilitative global technology transfer regime is in place, and the incremental and associated costs of these technologies are met by international climate funds. A collaborative international mechanism needs to ensure that barriers, such as intellectual property rights, are lowered by developed countries to facilitate technology transfer from developed to developing countries.

India is committed to advancing common sustainable development goals. However, it also emphasizes that international cooperation is necessary to support developing economies through finance, technology and win-win strategies.

Chapter 1 INTRODUCTION

1.1 Outline and Approach for India's LT-LEDS

India is currently one of the fastest growing economies in the world, home to almost one-sixth of humanity. Its growth momentum is an integral part of global development and is essential to global advance in meeting the sustainable development goals. The centenary of India's independence offers a significant milestone to the national effort on sustainable development. The milestone will be met with the provision of basic services to all, the expansion of the economy to a scale appropriate to India's size, and the provision of large-scale productive employment, which together would decisively move India to the status of a developed country.

Alongside the number of challenges that confront India's development agenda, climate change is an unwelcome constraint thrust on India as it is on the entire world. This challenge is not of India's making. India's historical contribution to the accumulation of GHGs is about 4%, even though it is home to ~17% of the global population. Its per capita emissions are well below the global average. India has drawn far less than its fair share of the global carbon budget.

Global warming is a global collective action problem. Its solution, therefore, lies in international cooperation and multilateral processes which are embodied in the United Nations Framework Convention on Climate Change (UNFCCC). India is firmly committed to strengthening the efforts to combat global warming to the UNFCCC on the basis of equity and the CBDR-RC as laid down in the Climate Convention.

Climate science has clearly established that global surface temperature increase is directly proportional to cumulative emissions and limiting the rise in global temperatures requires global GHG emissions to be kept within a specific limit referred to as the global carbon budget. A disproportionately large part of the global carbon budget has been used by developed countries. The world, from 2020, has a remaining carbon budget of 500 gigatonnes of carbon dioxide ($GtCO_2$), to have a 50% probability of limiting global warming to 1.5°C relative to pre-industrial levels and a remaining carbon budget of 1350 $GtCO_2$ to have a 50% probability of limiting global warming to an increase of 2°C (IPCC, 2021).

Operationalizing the principle of equity and climate justice requires that this global carbon budget be equitably shared among all countries and used responsibly. Hence, historical, current and future responsibility of countries is to be framed in terms of limiting cumulative emissions within their fair shares of this budget. The key principle that informs India's climate policy is to pursue development goals along low carbon development pathways, while keeping within its fair share of the global carbon budget on the basis of equity and in accordance with the principle of common but differentiated responsibilities and respective capabilities. India will strive towards net-zero by 2070 through low carbon development in accordance with national circumstances.

As a developing country with a long coastline, vulnerability to monsoon disruption, high dependence on agriculture for livelihoods, and possible impacts on water systems, among other kinds of exposure to climate extremes and consequent hazards, India is likely to bear a considerable added development burden from the impact of global warming.

Nevertheless, in keeping with its responsibilities as a large nation, and in keeping with its traditions and culture, India is committed to a leading role in meeting the challenge of global warming. Hence it has been contributing far more than its fair share of the global effort at climate action. It is in this spirit that India in its National Statement at the 26th Conference of Parties in 2021 at Glasgow declared that it would reach net-zero emissions by 2070. Climate change presents a threat to people everywhere in the planet and a significant challenge to our collective development goals. It is in this context that India in its National Statement at COP26, called for a global movement, LiFE, or Lifestyle for the Environment. The goal of the movement is to push for a paradigm shift in the way the world deals with natural resources, from an attitude of "mindless and destructive consumption" to one of "mindful and deliberate utilization".

As part of the efforts to achieve the goals of the UNFCCC, and its Paris Agreement (PA), all Parties agreed as per Article 4.19 of the PA, "to strive to formulate and communicate long-term low-emissions development strategies, on the basis of equity and in accordance with the principles of common but differentiated responsibilities and respective capabilities and in the light of different national circumstances". Consistent with this, India has prepared this document to lay out India's overarching approach to its low-carbon development pathway, taking note of India's development challenges as well as the necessity for climate action.

The process of preparing India's LT-LEDS included review of quantitative and qualitative studies, syntheses of official and academic materials salient to mitigation, adaptation, finance, and other relevant areas, and the inputs provided by seven inter-ministerial and stakeholder Task Groups to deliberate on long-term low-carbon development strategies for India. These groups reviewed existing policies, deliberated on emergent directions, and analysed linkages of these to development as well as assessed implementation considerations.

This report outlines the context and approaches that India will take toward the development and adoption of its LT-LEDS. The remainder of this section spells out India's framing and approach to its LT-LEDS, keeping in mind the foundation of equity and climate justice and the principle of common but differentiated responsibilities and respective capabilities (CBDR-RC) in the global context. Chapter 2 brings together the extensive effort to examine key development transitions and their potential contribution to a low-carbon future, including through the efforts of the seven Task Groups. Chapter 3 of this report discusses research and innovation for India's low carbon development. This strategy document also includes a short discussion of India's adaptation needs in Chapter 4, in the light of its vulnerability to climate impacts. Chapter 5 of this report is about the global call for climate friendly lifestyles for environment. Chapter 6 focuses on India's approach and contribution to the global cooperation to address climate change.

1.2 National Development, Energy, and Emissions in Global Context

India's approach to the development of its LT-LEDS is underpinned by the following four key considerations, related to the national and context of its energy and emissions future, in a global climate and development situation:

1. India has only a minimal historical contribution to the consumption of the global carbon budget and its annual per capita emissions remains modest.
2. India is a developing country with low per capita energy use, and with considerable energy needs for development.

3. However, mindful of the need to combat climate change and the potential for continued technological and competitive opportunities from a low-carbon development pathway, India will pursue low-carbon development strategies within its fair share of the global carbon budget, aimed at meeting India's 2070 net-zero pledge, on the basis of equity and in accordance with the principle of CBDR-RC and national assessments of its development futures.
4. India's growth and development is also essential to build climate resilience and mitigate the climate risk and vulnerability that India will face with increasing global warming.

1.2.1 India has contributed little to Global Warming

In 2016, India's total greenhouse gas (GHG) emissions, excluding land use and land-use change and forestry (LULUCF), were 2,838 million tonnes of carbon dioxide-equivalent ($MtCO_2e$) (MoEFCC, 2021). India's per capita emissions of 2.46 tCO_2e in 2019 are well below the global average of 4.79 tCO2e. Most pertinently, India's historical contribution to global GHG emissions is about 4% against a share of ~17% of the world's population (Climate Equity Monitor, n.d.), and as such it has contributed little to the accumulation over time of greenhouse gases in the atmosphere.

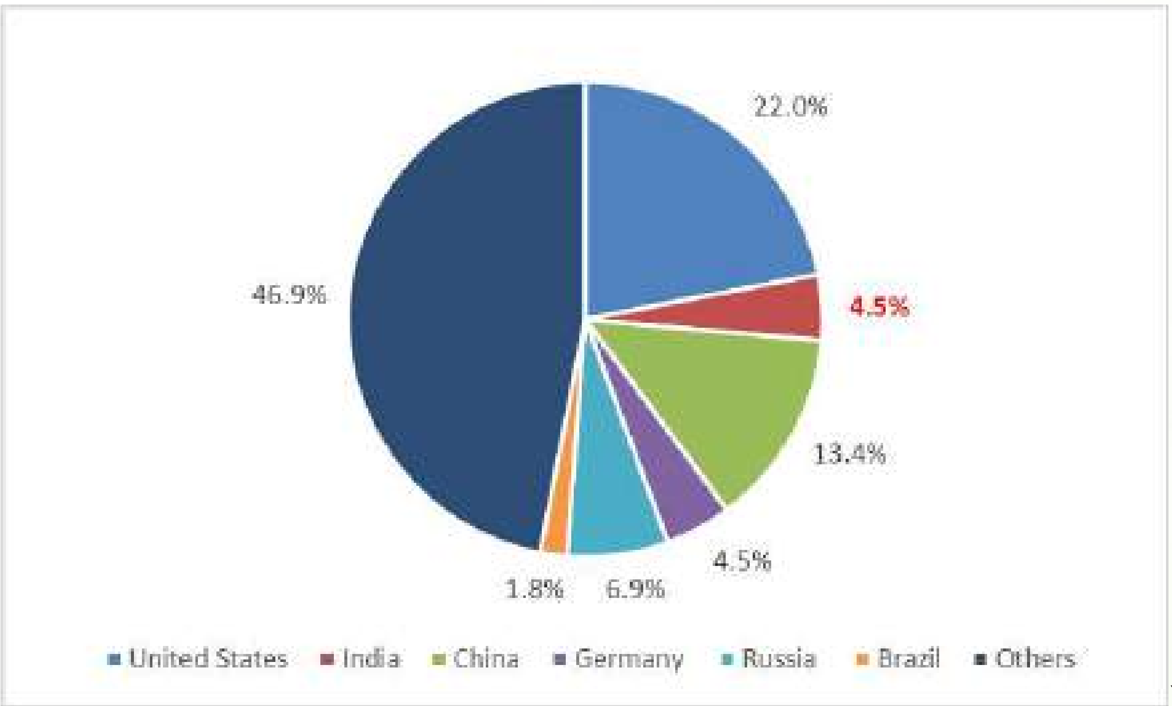


Figure 1.1 Share of Cumulative Emissions for Select Countries, 1850-2019

Source: *(Climate Equity Monitor, n.d.)*

In other words, India has used a far smaller part of its due share of the global carbon budget thus far, compared to developed countries who have exceeded their fair share very significantly, particularly when measured relative to its share of the global population.

From a global carbon equity perspective, therefore, India has adequate rationale to draw on its fair share of the carbon budget, as required for the future, as well as being adequately compensated, physically or otherwise, for its carbon credit from the pre-2020 period. Such compensation may be physically achieved by developed countries undertaking early net-zero, well before 2050, as well as undertaking negative emissions. It is well recognised that global net-zero does not mean that all countries must reach net-zero at the same time, more so for low emitters like India, South Asia, and Sub-Saharan Africa. Given India's low base of emissions and development (for example, the per capita electricity consumption is about a quarter the world average), it is inevitable that its energy use and emissions will need to rise.

Box 1.1 - Climate Equity Monitor

The Climate Equity Monitor (CEM) is an online dashboard developed by various research organizations for assessing international equity in climate action in relation to climate mitigation, energy and resource consumption, and climate policy across the entire world. CEM is the first such initiative from a developing country, comparing the responsibilities and policies and actions of Annex-I and Non-Annex-I Parties from the perspective of equity and CBDR-RC. The Monitor estimates that India's fair shares of the remaining carbon budget for a 50% probability of staying within 1.5°C and 2°C temperature increase are 89.4 $GtCO_2$ and 241.3 $GtCO_2$, respectively. With respect to historical cumulative emissions prior to 2020, it finds that India has a carbon credit of 337.59 $GtCO_2$ due to its unutilized share of the part of the global carbon budget consumed till 2020.

Source: (Climate Equity Monitor, n.d.)

URL: https://climateequitymonitor.in/

Table 1.1 shows the estimates of India's fair share against the total and remaining carbon budget for the world. When historical responsibility is considered, India's fair share is estimated as the difference between the per capita share of the total carbon budget and the actual emissions. When only the remaining carbon budget is considered, ignoring all historical responsibility of developed countries, India's fair share is simply its per capita share of this remaining carbon budget.

Table 1.1: India's Fair Share of the Total Carbon Budget (With Historical Responsibility) and the Remaining Carbon Budget (Without Historical Responsibility) from 2020 to Net-Zero

	Total Global Carbon Budget (1850 to net-zero) ($GtCO_2$)	**Remaining Global Carbon Budget (2020 to net-zero) ($GtCO_2$)**	**India's Fair Share (2020 to net-zero) * [$GtCO_2$]**
1.5° C - 67% Probability	2790	400	71 - 441
1.5° C - 50% Probability	2890	500	89 - 458
2° C - 67% Probability	3540	1150	206 - 574
2° C - 50% Probability	3740	1350	241 - 609

* The lower end of the range is India's fair share without historical responsibility. The upper end is India's fair share if historical responsibility is considered, after deducting India's non-LULUCF CO_2 emissions from 1850 to 2019.

India emphasizes that its current emissions also reflect its commitment to the safety of humanity and the planet, as also revealed in the data on net anthropogenic GHG emissions per capita, by region in 2019. Figure 1.2 from the Summary for Policymakers (SPM) of the Working Group (WG) III contribution to Sixth Assessment Report (AR6) (IPCC, 2022) shows that Southern Asia has the lowest per capita emissions among all regions in the entire world. However, while responsibly staying within its fair share of the global carbon budget, India's current annual per capita emissions will increase to meet its developmental needs and aspirations.

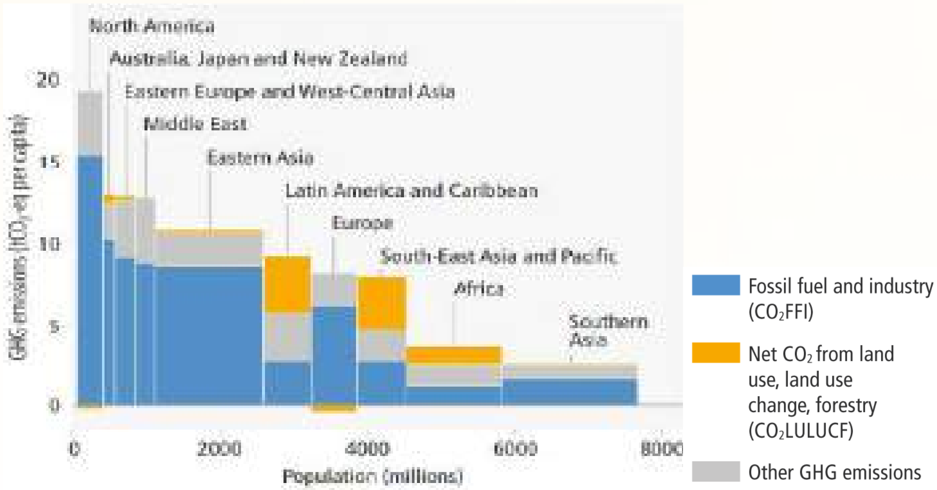


Figure 1.2: Net anthropogenic GHG emissions per capita

Source: *IPCC AR6 2022 Working Group III, Summary for Policymakers, Figure SPM.2*

1.2.2 India has Significant Energy Needs for Development

Through sustained growth and development, India seeks to move rapidly beyond its lower-middle income country status (World Bank, 2020). These and other challenges have been amplified by the socioeconomic impacts of the COVID-19 pandemic. In particular, immediate efforts need to be focused on the sections living below the poverty line (World Bank, 2020), and sizeable population employed in the informal sector (ILO, 2018).

Energy is essential to meeting the development needs and erasing India's development deficits while building for a prosperous future. However, India's primary energy consumption per capita in 2019 was 28.7 gigajoules (GJ), considerably lower than both developed country peers (e.g., 282.2 GJ for the United States, 340.4 GJ for Canada, 106.8 GJ for the United Kingdom) and comparative developing countries (e.g., 58.2 GJ for Brazil, 100.1 GJ for South Africa, 101.3 GJ for China) (IEA, n.d.). Meeting these development needs will require steep increases in overall and per capita energy use even as India implements an effective programme to enhance energy efficiency.

Social development as measured by the Human Development Index (HDI) is closely correlated with growing per capita energy consumption. India is well short of the threshold of per capita energy consumption required to reach an acceptable national level HDI.

Second, India is undergoing multiple transitions – a demographic transition that leads to demands for job creation, an agrarian and urbanisation transition, and rapid infrastructure growth. All three are energy intensive. As with HDI, historical evidence clearly shows that energy use per capita grows strongly during the early years of per capita GDP growth, and India is only beginning to exploit the positive linkages between energy consumption and GDP. The limited extent of decoupling emissions from growth seen in developed countries is still insufficient and their emissions continue to remain at high levels indicative of significantly higher consumption compared to developing countries. In contrast, India's trajectory reflects its low energy consumption and low emissions even currently, as well as the impact of its significant mitigation efforts, with its decoupling beginning at much lower emission levels.

India's growing energy needs are undeniable. The country is making strong efforts to increase the share of installed electric power capacity from non-fossil sources. While India is taking active steps in this direction (See Chapter 2), the transition to a primarily low-carbon energy system is a long-term process that can extend up to 2070. The current energy capacity stock is predominantly fossil fuel based and the financial and transaction costs of a low carbon transition are considerable, as described in Chapter 2. India's emissions will have to increase in line with growing energy demand and overall development, eventually reaching the envisioned goal of net-zero in 2070. It is very clear that India's energy needs for development, which are substantial, cannot be deferred.

1.2.3 India will Pursue Low-Carbon Strategies for Development, as per National Circumstances

In this perspective, India is pursuing low-carbon strategies for development toward a net-zero emissions future by 2070. India recognizes that climate action must be based on multilateralism as well as firm adherence to the core principles of the UNFCCC, namely equity and CBDR-RC. India's approach is also informed by awareness of potential technological and competitive benefits arising out of a low-carbon transition in the long-term, as also the scope for financial and transaction costs in realising any benefits.

While ensuring adequate access to household energy, energy security, and energy for industrial development, India's approach seeks to identify and explore opportunities to shift to low-carbon development pathways. Beginning in 2008, India's National Action Plan on Climate Change (NAPCC) recognised the potential for co-benefits between climate and development, while also noting that there are trade-offs and corresponding costs. India's mitigation efforts are therefore driven not just by climate-specific policies, but also by broader development choices. For example, India faces other development challenges relating to access to critical services such as sanitation, housing, and transport, managing urban growth and rural opportunities, and other environmental issues. Thus, India's LT-LEDS is based upon an economy-wide multiple objectives approach, including integrating dimensions of gender equity and inclusion of marginalised and vulnerable groups, that consciously seeks to move to a low-carbon path of development. Accordingly, this LT-LEDS extends its scope across sectors from the perspective of its economy-wide goals to identify possible development-driven and equitable low-carbon development pathways, as outlined in Chapter 2.

It is critical to recognize the inevitability of not only trade-offs and corresponding costs, but also the need for finance to harness low-carbon opportunities. In a developing country, with its high and continuing need for capital, the opportunity cost of capital is high.

The social and transaction costs of pursuing such a path are also considerable. This is particularly evident when exploring shifts in the primary energy mix, discussed in Chapter 2. Similar challenges also exist in transitioning away from conventional vehicles and many manufacturing and construction processes, among others, which bear implications for social equity and access in a growing economy.

Alongside social and transaction costs, the larger challenge is that of capital costs, and hence ongoing growth and development will need fossil fuel use for varying lengths of time up to 2070 in different sectors. The requisite technologies are for a significant part not available at scale, nor are available technologies deployable without incurring very significant costs. Full substitution of fossil fuels has not even been achieved in developed countries, with their enormous dependence on oil and gas, and hence India will need to transition the use of fossil fuels over an extended period. This is also the significance of India's need for an equitable share of the global carbon budget.

Box 1.2: Unnat Jyoti by Affordable LEDs for All (UJALA) and the Pradhan Mantri Ujjwala Yojana

These two programmes perfectly illustrate India's commitment to transformative developmental action wherever feasible, which also promotes low-carbon growth. Launched in January 2015, the Unnat Jyoti by Affordable LEDs for All (UJALA) scheme provides LED bulbs, LED tube lights, and energy efficient fans at highly subsidized prices. As of November 2021, over 367 million LED bulbs have been distributed, leading to energy savings of over 47,776 million kWh annually, cost savings of INR 19,110 crore, avoided peak demand of about 9.56 GW, and avoided CO_2 emissions of over 38 $MtCO_2$ (PIB, 2022a). The Pradhan Mantri Ujjwala Yojana (PMUY), was launched in May 2016, to make LPG, a clean cooking fuel, available to rural and marginalized households. These households have otherwise used traditional fuels such as firewood, coal, cow-dung cakes, which have severe negative health and local environmental consequences. India has met its target of providing 80 million LPG connections well before the time initially envisaged for this scheme. The Government has now extended the scheme to ensure 10 million more LPG connections and has increased the coverage to include migrant families as well. The PMUY has led to an increase in LPG coverage from 62% on 1st May 2016 to 99.8% as on 1st April 2021.

While India will pursue low-carbon strategies, this transition shall be in accordance with national circumstances and a pace and scale that is nationally determined, without compromising India's development future. Consequently, the need for climate finance for India's low-carbon transition is considerable as well as the need for technology transfer without barriers (See Chapter 6).

As elaborated in Chapter 2, going forward, India's energy and fossil fuel strategy will have several pillars including, inter-alia (i) Focus on electrification of energy services; (ii) low carbon electricity systems, including one of the world's most ambitious programmes for adding wind and solar; and (iii) energy efficiency, both in end-use and energy delivery.

1.2.4 India is a Climate-Vulnerable Country

India has a diverse geography that encompasses a wide range of ecosystems, from mountains to deserts, inland regions to coastal areas and from plains to jungles. A long coastline of over 8,000 kilometres (km) supports a rich variety of marine ecosystems. With varying geographical and topographical conditions, India experiences a range of climates, from tropical to alpine. Its climate is significantly influenced by the Himalayan mountain range and by the Thar Desert; the monsoon – one of the most prominent climate systems of the world – provides nearly 75% of the country's annual rainfall, significantly supporting livelihoods (MoEFCC, 2021).

As such, India is vulnerable to the impacts of climate change. More frequent droughts, higher temperatures, and variabilities in monsoon rainfall are expected by the end of the century (Krishnan et. al., 2020). These changes will challenge India's largely rain-fed and resource-constrained agricultural system, impacting crop yields and incomes (DEA, 2018). Climate change is expected to increase the frequency and intensity of heat waves, which may affect outdoor labour productivity and deepen exposure to adverse health outcomes in urban and rural areas (DST, 2016). In coastal areas, rising instances of climate-induced sea-level rise and extreme flooding events could result in infrastructural losses (NDMA, 2019; Krishnan et. al., 2020). Building resilience to potential climate impacts is, therefore, critical to maintain development gains and human development outcomes.

1.3 India's Progress toward a Low Carbon Future

1.3.1 Current Commitments and Pledges

India has consistently made ambitious commitments at the UNFCCC and its Paris Agreement, the key multilateral platforms for climate change, and has a strong track record of meeting these commitments.

India's Nationally Determined Contribution (NDC) submitted to the UNFCCC in 2015, inter alia, committed to reducing the emissions intensity of its GDP by 33-35% below 2005 levels by 2030, to achieve a 40% share of cumulative electric power installed capacity from non-fossil sources by 2030, and to create an additional carbon sink of 2.5-3.0 $GtCO_2e$ through additional forest and tree cover by 2030 (MoEFCC, 2015).

In line with these commitments, the emissions intensity of India's GDP had already reduced by 24% from 2005 levels until 2016 (MoEFCC, 2021), and as of May 2022, the share of non-fossil fuel sources in the country's installed generating capacity had reached 41.4% (CEA, n.d.). This indicates that India has overachieved one of its Nationally Determined Contributions (NDCs) announced at Paris Climate Summit (2015) by already meeting 40% of its power capacity from non-fossil fuels as of November 2021 almost nine years ahead of its targeted commitment. The country is thus on track to meeting its NDC targets.

Further, building upon Hon'ble Prime Minister Modi's *Panchamrit* pledges (five nectar elements) at COP26 in Glasgow, including the target of net-zero emissions by 2070, India updated three of its NDCs in August 2022 with the following targets (MoEFCC, 2022; UNFCCC, 2022):

1. Meet 50% of India's cumulative electric power installed capacity from non-fossil sources by 2030.
2. Reduce the emission intensity of the GDP by 45% below 2005 levels by 2030.
3. To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation, including through a mass movement for LiFE–Lifestyle for Environment as a key to combating climate change.

The challenge of meeting India's emissions intensity reduction pledge is not inconsiderable and will be made more serious with shifts in the structure of the economy, especially in favour of manufacturing and industry (Kanitkar et. al., 2015).

Box 1.3: Nationally Determined Contributions (NDC)

India's Nationally Determined Contributions to the Paris Agreement, submitted as India's Intended commitment prior to its signature at COP21 in 2015, is a robust and fair contribution to global climate action, on the basis of equity and in accordance with the principle of common but differentiated responsibilities and respective capabilities. The NDC followed India's consistent and successful implementation of its voluntary contribution to pre-2020 climate action. In the light of India's minimal contribution to historical cumulative emissions prior to 2020, and its current per capita emissions that are about one third of the world average for a sixth of humanity, the NDC are fully aligned to the temperature goals of the Paris Agreement and do not fall short of this requirement.

Nevertheless, to reassure the world that is preoccupied with the lack of ambition of the developed countries, India further enhanced and updated its NDC in August 2022. This was undertaken subsequent to India's National Statement at COP26, which announced, inter-alia, the enhancement of India's target in the deployment of renewable energy and the year 2070 as India's target date for net-zero.

The elements of India's NDCs that were enhanced and updated are as follows*:

- To put forward and further propagate a **healthy and sustainable way of living** based on **traditions and values of conservation and moderation**, including through a mass movement for LiFE–Lifestyle for Environment as a key to combating climate change.
- **To reduce Emissions Intensity of its GDP by 45% by 2030, from 2005 level.**
- To achieve about **50 % cumulative electric power installed capacity** from **non-fossil fuel-based energy resources by 2030**, with the help of transfer of technology and low-cost international finance, including from Green Climate Fund (GCF).

*The full submission of India's updated NDC is available at https://unfccc.int/NDCREG

1.3.2 Institutional Framework

Preparing the institutional capacity to appropriately develop and implement policies that are also consistent with development needs is a foundational requirement. Appropriate institutions can help shape the context for development pathways and mainstream low-carbon growth considerations into policy, financial, and administrative process. This will enable India to take a bottom-up, all-of-society approach to low-carbon development.

For Institutional intermediation and execution of India's LT-LEDS, a strong foundation is in place through existing extant agencies – the Executive Committee on Climate Change (ECCC), the Apex Committee for the Implementation of the Paris Agreement (AIPA), and others. Going ahead, the LT-LEDS will be based on coordinated climate action across an economy that spans its several sectors and Ministries, as well as its 28 States and 8 Union Territories, operating in a predictable, federalized structure of governance. India will continue to promote States as engines of climate action further, especially considering States as actors, and to improve their scientific and policymaking capabilities.

Chapter 2 STRATEGIC TRANSITIONS

Chapter 2 discusses seven key low-carbon development transitions, which have been developed through an Inter-Ministerial Task Group process with stakeholders' participation. To support this process, the Ministry of Environment, Forest and Climate Change (MoEFCC) constituted an Inter-Departmental Steering Committee (IDSC) with representation from various relevant Ministries and Government Departments for oversight and a Technical Advisory Committee of Experts (TACE) from academia and research organisations to provide technical guidance.

Each Task Group was steered by a representative from the relevant Ministry. Other members of the Task Groups included representatives from relevant Ministries and Governmental Bodies, Academic and Civil Society Organisations, and the private sector.

Each Task Group was requested to provide through an iterative, consultative process a summary report on developing the perspective for the area of its responsibility. In particular, Task Groups were requested to provide the domestic and international developmental context for these transitions to low-carbon development to indicate the current policies and targets that were already supporting such transitions, to identify the key elements of the long-term strategy in each transition, and the opportunities and challenges in achieving them, as part of the developmental outcomes that these transitions might contribute to.

2.1 Low Carbon Development of Electricity Systems

India has one of the largest power systems in the world catering to a population of 1.3 billion. With a peak demand of about 206 GW (CEA, 2022), the total electricity generation for FY 2021-22 was under 1,500 TWh/BU. The industrial sector accounted for about 43% share of consumption, the residential sector 24% and the agriculture sector 18%. India has an installed generation capacity of 404 GW (July 2022), of which 168 GW (41.6%) is from non-fossil fuels. In India's total electricity generation in FY 2021-22, renewable energy was about 22% including hydro (MoP, 2022a; 2022b). Renewables (esp. wind and solar) have been growing very strongly in recent years (39 GW in 2015 to 110 GW by 2022). For the past seven years, RE is the fastest growing segment of generation capacity at an average CAGR of 15.6%. (Data sourced from CEA, 2022; MNRE, 2022).

India's average per capita electricity consumption from utilities alone, about 800 kWh in 2020, is only about a fourth of the global average. The overall per capita consumption of electricity for the year 2021-22 was 1,255 kWh. The following figure 2.1 illustrates the large gap between India and developed countries whose consumption is more modest than that of the United States which has the largest per capita consumption amongst them.

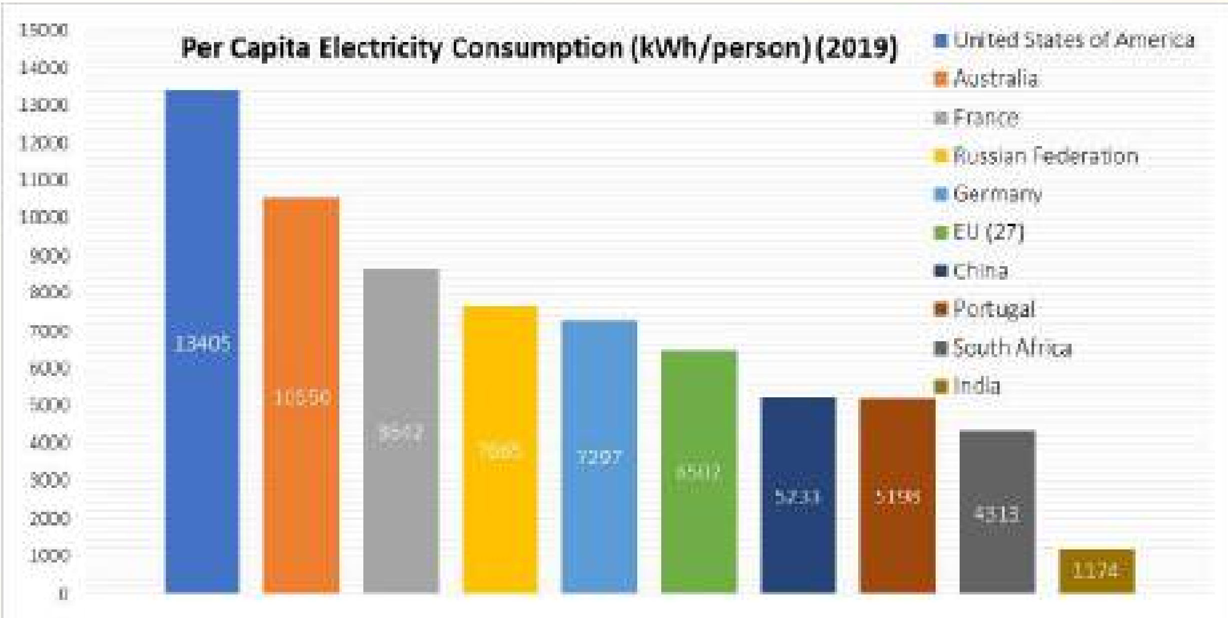


Figure 2.1 Country wise per capita electricity consumption *(Climate Equity Monitor, n.d.)*. The year 2019 is chosen as it provides a better cross-country comparison from the year prior to the pandemic.

India recently achieved universal household access to electricity, (https://saubhagya.gov.in) with current efforts focused on further strengthening the quality and reliability of supply, especially in rural areas. However, with the need for further increase in electricity consumption, India's challenge is reaching optimal, though higher, energy consumption levels even while being mindful of a low-carbon path of growth. India has been proactively shutting down inefficient thermal power units. A total 241 Units with capacity of 17,281 MW have been retired from the 10^{th} Plan period onwards till September 2021.

2.1.1 Current Policies and Programme

Since the initiation of National Action Plan on Climate Change (2008) and its missions on solar energy and energy efficiency, India's policy framework for growth in electricity generation and supply along a low-carbon development pathway has evolved comprehensively and is described here under three categories.

1. Promoting and supporting Renewable Energy and Nuclear

    a. Ambitious RE targets: Targets have been consistently enhanced (MNRE, 2019 & 2021).

    b. 'Must-run' priority dispatch status for renewables: Preference is given to RE power in the merit order despatch, despite costs, which is part of India's investment in mitigation, through increased cost of power, especially for supply from older sources.

    c. Renewable Purchase Obligations (RPO): These are obligations for the purchase of RE power, specified by State Electricity Regulatory Commissions for distribution companies, open access consumers and captive plants (MNRE, 2021).

    d. Promotion of Hydro Power: This is being undertaken through several policy measures to tap hydro power potential in the country, including the introduction of Hydro Purchase Obligation. This will also necessitate increased provision of climate finance.

    e. Energy Storage Obligations: These are being progressively introduced. However, their expansion will depend on decreasing cost of storage technologies, transfer of this type of technology and concessional finance.

f. Green energy corridors: These are being developed to strengthen transmission networks in eight RE rich States (MNRE, 2021).

g. Policy and financial incentives: These include solar park development, accelerated depreciation on investment, waiver on transmission charges, and capital subsidy for residential solar roof-top (MNRE, 2021).

h. A three-fold rise in nuclear installed capacity by 2032.

i. Agricultural solar pumps are being promoted (MNRE, 2021). The consumption of energy in the agriculture sector is an important aspect to ensure the food security aspect of the country and the globe, as large energy consumption is required for irrigation pumps.

j. Supportive policies are being introduced such as net metering, energy banking and waiver of duties and surcharges.

2. Policy and Programme Support

a. Manufacturing support such as production-linked incentives for solar, electric vehicles and battery storage systems (MNRE, 2021).

b. Establishment of a 'Renewable Energy Management Centre' for supervision, monitoring and control of RE.

c. Policy and financial assistance for promotion of waste to energy measures.

d. Enabling bundling of thermal and hydro power with RE to enhance flexibility.

e. Policies to support biomass use for power generation.

f. Roadmap of a sustainable and holistic approach to National Energy Efficiency (ROSHANEE) for Revised National Mission for Enhanced Energy Efficiency: This will enable alignment with the goals of the NDC, mainly through energy efficiency and conservation activities included under standards and labelling programme for appliances, building efficiency programme, industrial efficiency improvement under Perform, Achieve and Trade (PAT) scheme, and market transformation programmes such as UJALA (MoP, 2019).

g. Green hydrogen mission to incentivise green hydrogen production (MoP, 2022).

h. Support to R&D in carbon capture and utilisation.

i. Developing or deploying storage systems (Pumped Storage Plants, Battery Energy Storage Systems, Gravity, Thermal, Compressed Air, etc.).

3. Promoting Markets and Competition

a. Green Term-ahead Market to provide enhanced avenues for sale of RE (PIB, 2020).

b. Day-ahead market for trading of RE to meet green targets (CERC, 2020).

c. Real-time market to manage RE intermittency and demand variation (CERC, 2020).

d. Ancillary services to balance power and manage variation of intermittent RE and enable demand responsiveness.

e. Rules facilitating direct procurement of green energy by open access consumers.

f. Regulation for Renewable Energy Certificates trading and introduction of Renewable Energy Certificates multiplier for new technologies.

2.1.2 Elements of a Long-Term Low-Carbon Development Strategy

This section presents five elements that provide broad directional shifts for the Indian electricity sector, aimed at inclusive, low-carbon development in a manner consistent with India's developmental needs.

2.1.2.1 Expanding Renewables and Strengthening the Grid

Falling RE costs present an opportunity for RE expansion but realising this potential fully requires substantial investment in grid-strengthening in parallel and other enabling conditions.

1. Intermittency of RE: This is a major challenge for India as a developing country. This is particularly onerous for India as it does not have substantial oil and gas-based generation, which provides much greater flexibility in dealing with the intermittency. India will have to substantially rely on coal-based plants. It will also have to commission more storage systems, including pumped hydro, and cope with the challenge of enabling demand responsiveness in the medium/long-term. Flexible operation of thermal power plants (TPPs) to accommodate RE power needs to be developed as a potential strategy.
2. Rapid expansion of RE: India has adopted ambitious RE targets. India's 2022 updated NDCs includes a target of about 50% cumulative non-fossil fuel electric power capacity by 2030 (PIB, 2022b). Going forward, RE expansion will be facilitated by the promotion of offshore wind, centralized solar and onshore wind parks, floating solar photovoltaic installations, and decentralized solutions including rooftop PV, solar agricultural feeders and mini- and micro-grids. A priority will be simultaneous job creation. Offshore wind and greater uptake of other renewables and storage will also take place in the medium and long term as these technologies mature.
3. Hydro power is a significant renewable source of energy. India's policies for encouraging the development of hydropower include promoting hydropower obligations along with renewable power obligations. India envisages use of its hydroelectric potential at a faster pace, including promotion of small and mini hydel projects, strengthening the role of Public Sector Undertakings/State Electricity Boards for taking up new hydel projects and increasing private investment.
4. Assessing and planning for likely demand for green hydrogen (medium to long term): India has plans to promote green hydrogen, necessary for decarbonisation of hard-to-abate sectors. India aspires to expand annual production of green hydrogen several-fold.
5. India aspires to increasing electrolyser manufacturing capacity several fold by 2030 to become a global leader (NITI Aayog, 2022).
6. India envisages becoming a leading exporter of Green Hydrogen (GH) and Green Ammonia (GA) by 2030 (NITI Aayog, 2022). But this requires substantially enhanced RE capacity, which will require careful planning of capacity addition. The roadmap up to 2030 involves reduction of cost of production through technology development and bulk procurement, providing fiscal incentives to accelerate production, promotion of domestic manufacturing of electrolysers, issue of demand-side mandates to encourage adoption of green hydrogen and green ammonia in hard to abate sectors, and ensuring availability of low-cost green electricity for green hydrogen.
7. Promote co-firing of green ammonia in thermal power plants (TPPs). Beyond 2030, this would entail:
    a. Enhancing industrial demand for green hydrogen and green ammonia (fuel switching – GH/GA replacing coke and natural gas).

b. Expanding infrastructure for transporting and storing hydrogen, including pipelines, and storage tanks.

8. Several of the above strategies will require research and development, while all of them would require considerably enhanced provision of climate finance and technology transfer.

2.1.2.2 Other Low-Carbon Technologies

1. Exploring a significantly greater role for nuclear power: Presently (2020-21) nuclear power is saving 41 million tonnes of CO_2 emissions annually, compared to the emissions that would be generated by equivalent electricity generation from coal based thermal power plants. Nuclear power currently provides 3% of electricity generation (PIB, 2021f). Sufficient production and share of nuclear power are highly significant for ensuring country's energy security.
2. The potential for establishment of small modular nuclear reactors is to be explored, and this will require sharing and transfer of relevant technologies.
3. Expanding this share is possible, for example for utility distribution, captive use in industries and for green hydrogen production, but carries challenges.
4. Promoting R&D for frontier technologies: Emergent technologies include coal gasification, carbon capture, utilization and storage systems, biomass co-firing, beneficiation technologies, offshore wind, high efficiency fuel cells, advanced solar materials, methanogen and organo-assisted biological gasification, advanced chemistry cells, off-shore wind, tidal power, small modular reactors, and smart demand response systems. India will promote the R&D of such technologies to be ready to capitalise on such expertise as and when the opportunity arises.

2.1.2.3 Focusing on Demand-Side Measures

India's per-capita electricity consumption is very low by global standards and many Indians need to avail of more energy services from electricity. Per capita consumption, as an overall aggregate measure that also incorporates the use of electricity for production, will rise steadily as India is a developing country. This will also include electricity use in hard-to-abate sectors, or in the informal and MSME sectors, where demand-side measures have little scope in the current and future scenarios. Yet, while India will pursue demand-side measures in select sectors and contexts, such as the large-scale shift to LED lighting in meeting public lighting requirements, the scope for demand-side measures in low-carbon development in India will be circumscribed by socio-economic constraints.

Under the National Mission for Enhanced Energy Efficiency, the Bureau of Energy Efficiency, a nodal institution under the Ministry of Power, has undertaken significant work to improve energy efficiency. Under the ROSHANEE plan, ambitious energy efficiency programmes, spanning multiple sectors are being implemented. These include Standards and Labelling programme for appliances, Energy efficiency in Buildings, and PAT scheme for Industries.

2.1.2.4 Role for Coal

Coal has a predominant role in India's electricity system contributing about 75% of generation currently (MoC, n.d.). While the share of coal in the Indian electricity sector will reduce in the coming years, this will be a gradual process taking due note of its socio-economic implications.

Ensuring adequacy of supply of energy is paramount. India needs to guard against a lack of adequate and reliable energy to meet its economic and developmental needs. This could only be achieved through a judicious mix of supply resources including reliance on coal-based generation. Planning for low-carbon development in the electricity sector must ensure that India's growing electricity demand continues to be met.

Hence, as the overall strategy, the key elements are:

1. Rational utilisation of fossil fuel resources: The management of the share of coal in India's electricity sector will be undertaken in a careful manner to meet multiple objectives, including the deployment of ultra-super critical; meeting the growing demand for electricity; managing the intermittency of renewables; enhancing efficiency outcomes; and avoiding lock-ins as India develops towards net-zero in 2070. It is re-emphasized that India's coal consumption per-capita in 2019 was only half the world average (Tongia & Sehgal, 2016; Tongia, 2020). In contrast, India used only ~22% of the global average of oil and gas. Global oil and gas emissions were 25% more than from coal, even after factoring coal-based emissions from cement. Thus, it is inconsistent to focus disproportionally on lower coal use instead of lower total emissions. Key factors will be the price reduction trajectory of electricity storage systems and financial support and technology transfer from developed countries.
2. Reskilling and redeployment of manpower: This is a crucial requirement. Experienced human resource from fossil fuel sector could be retrained to meet the requirements of non-fossil sector in future, thereby making the transition just, smooth, sustainable and all inclusive.
3. Closing inefficient thermal power: India has been proactively shutting down inefficient thermal units. A total 241 Units with capacity of 17,281 MW have been retired from the 10th Plan onwards till September 2021.

2.1.2.5 Enabling Low-Carbon Development

1. Promoting local manufacturing of clean energy technologies (ongoing): India is promoting manufacture of clean energy technologies at scale. Existing Production-Linked Incentive (PLI) schemes support solar, energy storage systems and electric vehicle technologies. In the medium term, support may be considered for green hydrogen, offshore wind, smart demand-response systems and so on, as these are likely to be the technologies of the future. The aim is to promote indigenous growth and employment generation alongside a green transition.
2. Robust institutions to enable a smooth electricity transition (ongoing): Enabling an equitable, development-friendly low-carbon electricity transition has multiple linkages to other sectors of the economy, including, inter alia, transport, buildings, industry, forestry, and finance. It also requires coordination and planning across levels of Government ranging from the Centre to States to District and local authorities. Consequently, an important requirement is robust and capable institutions to address these complex tasks and associated effective coordination processes.
3. Green taxonomy for India's electricity sector: Considering that the time frame for medium- and long-term actions are 30 and 50 years away from now, India has a clear identification of all non-fossil sources viz., hydro, solar, wind, nuclear and biomass. This is key to supporting evidence-based and actionable policy making. It helps to define the direction/pace of transition, thereby sending reinforcing policy signals to industry and investors, providing clarity regarding which actions are to be considered as sustainable in the longer term.

4. Optimum energy mix: Considerations of optimal energy mix in the near, medium, and long term with the proportion of each energy source including fossil fuels, will be a part of India's low-carbon development strategy in the energy sector. This will enable policy signals that will assist in making informed investment decisions in different sectors over varying time scales and assist in the low carbon development transition.

2.1.3 Potential Benefits and Challenges

Large-scale expansion of RE will depend on the continued availability of critical rare earth minerals for solar, wind and non-fossil fuel technologies, both globally and for domestic production. Large scale RE expansion will also depend on increasing availability of specialised steel, cables and other critical strategic materials and equipment, especially through domestic manufacture under *Aatmanirbhar Bharat* and Make in India.

1. Increase in the contribution of modern energy sources, such as electricity by increasing the share of electricity in industry and transport.
2. Reduced cost of electricity, as the cost of newer technologies such as solar and wind continues to fall and distributed generation can lead to lower transmission and distribution losses, but with implications for consumer pricing and social welfare redistribution. However, an important pre-requisite is a fall in the cost of storage technology and its practical realization. The development of pumped storage facilities using hydro is the world's most widespread storage system by far. The scope of pumped storage in India is acknowledged as part of the country's larger hydro power policy.
3. The possibility of having decentralized, grid-connected renewables can further reduce costs by reducing transmission and distribution losses. However, these considerations do not extend to electricity supply for industry and transport. Current national and global experience shows the key importance of large-scale deployment of RE installations in areas where conditions are favourable.
4. Developing the electricity sector with progressively lower share of fossil fuels, in a just and equitable manner requires significant investments. Resources will be required for investment in high capex, large scale renewables capacity, enhancing the transmission grid and introducing energy storage systems. In addition, financing a just transition will require supporting social and physical infrastructure, ecological restoration of affected areas, building capabilities of communities, and to seed new livelihood generating activities. The challenge is compounded by high capital requirements of other sectors and the relatively high cost of capital in India.
5. India heavily taxes all fossil fuels at various stages from extraction to final consumption. This amounts to an effective carbon tax, higher than many developed countries.

2.2 Develop an Integrated, Efficient, Inclusive, Low-Carbon Transport System

The transport sector in India contributes around 10% to India's GDP (BERPD, 2018). It is an important sector that facilitates the overall development of industries and commercial activities in any economy. In India therefore, the development of the transport sector is a priority area for the Government. Emissions from the transportation sector are mainly from fossil fuel consumption in the road sector, though vehicle ownership in India is far below the world average and much below the levels of other developed and emerging economies. In 2018, the total vehicle penetration per 1000 people in India was 32, in contrast to 134 in China, 619 in Germany, and 804 in the USA (MoRTH, 2021). The road transport sector accounts for about 87% of passenger traffic and 60% of freight traffic movement in the country and the sustainable development of this sector is a critical element in India's long-term development strategy (MoRTH, n.d.).

Overall, transport sector contributes to about 12.1% of India's energy-related CO_2 emissions (MoEFCC, 2021) and 9.7% of the country's total Greenhouse Gas emissions.

In the previous decade, increasing sales of internal combustion engine (ICE) vehicles have more than doubled the fuel consumption and related GHG emissions from the transport sector, even as vehicle ownership in India is far lower than in other developed and emerging economies. Figure 2.2 below shows the growth in total number of registered vehicles in the country between 2000 and 2019, with the two-wheeler and car segments growing at a CAGR of ~10%. Much of this growth has been driven by rapid urbanization. This trend is expected to continue, as urban population is projected to increase from about 370 million in 2011 to 600 million by 2030 (DEA, 2021). India is also home to a thriving domestic auto manufacturing industry.

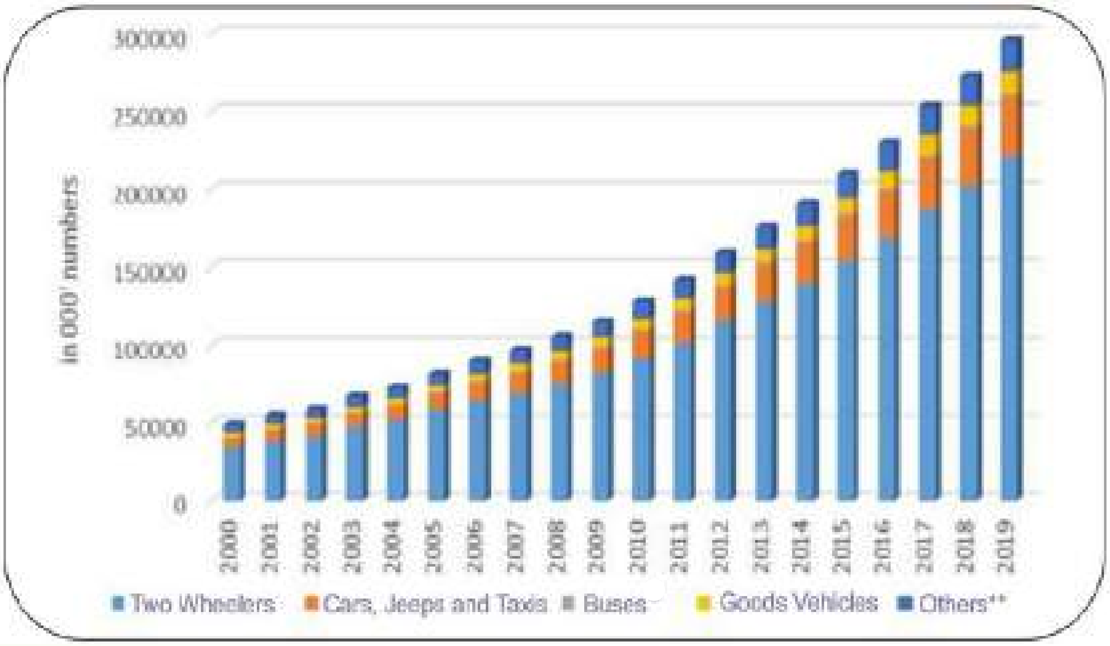


Figure 2.2 Total Number of Registered Motor Vehicles (Category Wise). ***Source:*** *(MoRTH, 2021).*

Note: ** Includes Tractors, trailers, 3-wheelers/LMV and other miscellaneous vehicles

Indian Railways is one of the world's largest railway networks, extending over 68,000 km (MoR, 2022). It carries nearly 23 million passengers daily, making it the largest passenger carrying system in the world (MoR, 2018). Other segments such as civil aviation and domestic navigation account for a relatively small but growing share of India's transport mix.

Given India's current growth and transport sector trends, the on-road freight segment is likely to be a significant driver of transport emissions in the long-term in a business-as-usual scenario. Emissions from heavy duty vehicles would account for the major part of such emissions. Addressing both passenger and freight transport is an important goal for India's low-carbon development.

2.2.1 Current Policies and Programmes

Achieving Improved Fuel Efficiency

1. Vehicle emissions: Leapfrogging from Bharat Stage IV emissions standards for vehicles directly to Bharat Stage VI emission standards.
2. Vehicle scrappage policy: Mandatory scrapping of old, unfit polluting vehicles subject to fitness and emissions tests and replacement of end-of-life vehicles (ELVs) can result in a 15-20% reduction in vehicular air pollutants and increased fuel efficiency (MoRTH, 2022).
3. Corporate average fuel economy norms: Standards imposed upon vehicle manufacturers to ensure fuel efficient design across their portfolio of products.
4. Others:

    a. Three-Phased mainline electric multiple unit (EMU) trains.

    b. Flexible usage of airspace, single engine taxing, continuous descent approach, airport carbon accreditation programmes in the aviation sector, carbon offsetting and reduction scheme in International Aviation.

    c. Green shipping and IT enabled management of ports in the maritime sector.

    d. Behavioural interventions and public awareness programmes.

Use of Cleaner Fuels

1. Use of biodiesel, green diesel, compressed natural gas and liquefied natural gas as fuel alternatives.
2. Natural gas as short-term fuel alternatives: Target to increase the share of natural gas in the country's energy mix to 15% by 2030.
3. National Policy on Biofuels 2018: Indicative 2025 target of 20% blending of ethanol in petrol, with an annual savings potential of INR 300 billion of foreign exchange.
4. For increasing feedstock and augmenting availability of bioethanol Government of India has announced Pradhan Mantri JI-VAN Yojana in March, 2019 for providing financial support in the form of VGF to 12 Integrated Second-Generation Bioethanol Projects using lignocellulosic biomass and other biodegradable feedstock. Under this scheme financial support to 10 demonstration units is envisaged to promote development of new technologies.
5. National Green Hydrogen Mission: The mission is expected to generate a production capacity of five million tonnes of green hydrogen per annum. Phase I of the Mission is focused on demand generation, while Phase II aims at accelerated production of green hydrogen.
6. Others:

    a. Natural Gas Infrastructure Development Plan.

    b. Bio-based Sustainable Aviation Fuel (SAF) programme coupled with:

    (i) short rotation oilseed cultivation as a second crop on existing irrigated mono-cropped land holdings feeding into hydro processed esters and fatty acids (HEFA) based SAF production;

    (ii) integration of gas fermentation technologies with alcohol-to-jet (ATJ) SAF plants. One semi-commercial scale plant of each type is expected to be operational by 2025.

c. Sustainable Alternative Towards Affordable Transportation (SATAT) scheme: Initiative encouraging entrepreneurial ventures in the setting up of compressed biogas (CBG) plants, and production and supply of CBG to OMCs. Significant additional decarbonization is expected as biogas purification systems mature so that biogas can be purified to bio-PNG / biomethane standards, injected directly into existing natural gas pipelines and compressed at the point of use.

Initiatives to Induce Mode Shift

1. Portfolio of urban transport policies and schemes: National Urban Transport Policy 2006, Smart Cities Mission, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Green Urban Mobility scheme, National Transit Oriented Development Policy.
2. Metro Rail Policy 2017: Target of constructing metro rail services in 27 cities across India by 2025 (MoHUA, n.d.).
3. National Rail Plan 2030: Target of increasing modal share of the railways in freight to 45%.
4. Indian Railways to become net-zero by 2030, leading to 60 million tonnes of annual mitigation of CO_2.
5. Gati Shakti National Master Plan: A GIS based digital platform to bring together 25 Central Ministries/Departments and all States/UTs for integrated planning and coordinated implementation of infrastructure projects.
6. Dedicated freight corridors by the railways.
7. Setting up of the National High-Speed Rail Corporation Ltd. to finance, construct and maintain high speed rail corridors.
8. National Logistics Policy providing for adoption of efficient, economical and environmentally sustainable modal-mix.
9. Sagarmala Programme – an initiative by the Government of India for enhancing the performance of country's logistics sector and comprising four pillars, namely, port modernisation, port connectivity, port-led industrialization and coastal community development.

Electrification

1. Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME India) scheme, Stage I and II.
2. National Mission on Transformative Mobility and Battery Storage.
3. Production-Linked Incentive Scheme (PLI) for advanced chemistry cell and advanced automotive technology.
4. Draft National Energy Storage Mission.
5. Charging infrastructure for electric vehicles: Publication of the revised consolidated guidelines and standards, 2022.
6. Alternate Fuels for Surface Transportation Programme.
7. Exemption of electric, ethanol and methanol vehicles from requiring permits to carry passengers/ goods.
8. Mission Electrification by the Railways: A 100% electrified broad-gauge network, transition to head-on generation (MoR, 2021).
9. Green Ports Initiative.

2.2.2 Elements of a Long-Term Low-Carbon Development Strategy

The elements of long-term low carbon growth in the transport sector, are already embedded within the current portfolio of policies and actions to a large extent. These are synthesized and elaborated upon below.

2.2.2.1 Improving fuel efficiency

Fuel efficiency regulation, combined with electrification and expanding the adoption of clean fuels, can prove crucial in slowing down the rise in oil demand in the country. Fuel efficiency is also an important tool for achieving India's Nationally Determined Contribution (NDC) commitment. It is also pivotal in reducing oil import costs and enhancing energy security. Improving fuel efficiency can reduce overall growth in demand for fuel and consequently help in reducing GHG emissions as compared to scenarios where such actions for efficiency improvement are not embedded in plans and policies for the sector.

2.2.2.2 Phased adoption of cleaner fuels

The large imbalance between domestic supply and demand of fuels can be filled by boosting the development of alternative fuels. Alternative fuels are considered a promising replacement for conventional fossil fuels and can help in meeting India's energy security needs and reducing dependence on GHG-intensive fuels. They can help reduce reliance on crude oil imports and contribute to reducing CO_2 emissions in the sector. Alternative fuels are gaining popularity due to their advantages in terms of reduced CO_2 emissions, possibility of being produced using renewable energy, high energy quality, and potential contributions to economic growth.

The expanded use of cleaner fuels comprises of three broad phases:

1. Usage of ethanol, compressed natural gas (CBG), biodiesel and liquified natural gas (LNG) as short-term fuel alternatives.
2. Biodiesel and methanol/dimethyl ether (DME) supplemented by pipeline biogas (Bio-PNG) as medium-term fuel alternatives. For encouraging use of such fuels, the following measures would be adopted:

   a. Boost annual ethanol procurement.

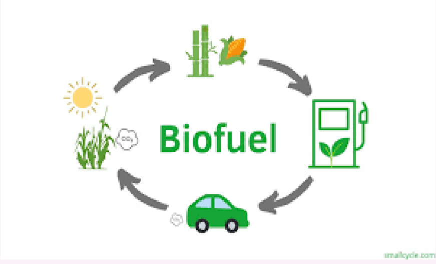
   b. Increase ethanol production facilities and ensure availability of sufficient feedstock.

   c. Augment ethanol storage, handling, blending and dispensing infrastructure.

   d. Support manufacturing and adoption of higher ethanol compatible vehicles through incentives, tax breaks, and such other measures.

   e. Introduce sustainable aviation turbine fuel, and biodiesel at commercial scale.

3. Hydrogen as a long-term alternative: green hydrogen is expected to become a significant fuel in India's transport sector in the medium term, although the scale of its use will be contingent on the availability of low-cost finance to spur innovation in this sector. India is also aiming to emerge as a green hydrogen fuelling hub for maritime transport, with connectivity between ports and hydrogen producing facilities.



Box 2.1: Ethanol blended fuels for transport

India introduced the National Policy on Biofuels in 2018, which aims to achieve 20% blending of ethanol with petrol and 5% blending of biodiesel with diesel, by 2030. With the well-coordinated efforts of India's public sector Oil Marketing Companies, the target of 10% blending of ethanol with petrol has already been achieved, much faster than its envisaged timeline. Considering this encouraging performance, the target date of 20% ethanol blending has been advanced from 2030 to 2025-26. The total reductions in CO_2 emissions achieved in the last seven years due to the programme for Ethanol Blended Petrol are estimated to be 22.6 $MtCO_2$. In 2020-21 alone, a reduction of 6.44 $MtCO_2$ was achieved due to this program.

2.2.2.3 Expanding the availability of and access to public transport

As India rapidly urbanizes, vehicle ownership is expected to grow significantly. Studies have shown that a focus of the development of the Indian transport sector through fuel efficient modes of transport and a focus on expanding public transport can have the maximum impact on avoiding CO_2 emissions in the sector. Understanding the composition of different modes is essential in crafting appropriate policies to induce a modal shift.

India has introduced several initiatives to encourage a modal shift in both passenger and freight transport. The goal is to avoid higher per-capita emissions by encouraging public transport. Within public transport, the goal is to expand the use of less polluting modes with the order of preference being rail over road over airways.

2.2.2.4 Electrification across multiple modes

In a fast-growing country like India, electrification is critical to support low carbon development of the transportation sector. By 2050, both the rail and road transport will be encouraged to achieve high rates of electrification through policies designed to encourage electrification in this sector. Electrification of railways is already well on course with over 80% of the broad-gauge network already electrified till March 2022 (CORE, 2022). With the expansion of electricity generation through non-fossil fuel sources, electric transportation will also become less carbon-intensive in the medium and long term.

2.2.2.5. Increasing adoption of electric vehicles

India has a key goal to significantly expand the market share of electric vehicles (EVs) for passenger transport.

In addition to increasing the domestic manufacturing of EVs and batteries through production-linked incentives (PLI) schemes, India will explore the implementation of vehicle-grid integration options, to enable planning of increased load on the electricity grid (Das & Deb, 2020; FICCI, 2020). Increasing decarbonization of the grid and establishment of off-grid renewable hybrid charging / swapping stations for batteries are planned to keep pace with increasing electric mobility. In the short to medium-term, India will also consider policies related to the management of EV-related waste, and circular economy principles for the EV sector. As the EV industry grows, there will be a requirement for re-skilling of the workforce for manufacture and operation of new technologies and related infrastructure.

2.3 Promoting Adaptation in Urban Design, Energy and Material-Efficiency in Buildings, and Sustainable Urbanisation

According to Census 2011, approximately 377 million Indians comprising 31.1% of the country's population lived in urban areas (Bhagat, 2018). The country had 53 city agglomerations with over a million people, and six city agglomerations with over 10 million population. The urban population is projected to grow to about 600 million by 2030 (DEA, 2021).

There has been an increase in the number and intensity of extreme weather events. India's cities are susceptible to their effects, especially at their current stage of development. Cities are also engines of economic growth and it is estimated that 75% of India's GDP in 2030 will be generated from urban regions (CBRE, 2019). It is evident, therefore, that these will contribute more to total emissions. Currently, the major part of India's emissions are from cities, even as energy consumption in cities is more efficient as compared to rural areas Further, buildings account for more than 40% of India's total energy consumption in cities (Ahuja & Soi, 2020).

Therefore, as hubs of population and economic activity, cities are susceptible to the impacts of climate change, with varying degrees of risk to essential services, infrastructure, housing, livelihoods and health, but also have the potential to reduce vulnerability through increased incomes. Due to the concentration of economic activity in urban agglomerations, energy consumption, and emissions are higher in cities making these important regions for climate action.

2.3.1 Current Policies and Programmes

India already has a comprehensive policy framework for sustainable urban design. The relevant policies and initiatives are described here under three categories.

Urban Planning

1. Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines
2. Town and Country Planning Act
3. National Urban Missions such as the
    a. Atal Mission for Rejuvenation and Urban Transformation (AMRUT),
    b. Pradhan Mantri Awaas Yojana (PMAY) – Housing for all (Urban), providing housing especially for low- and middle-income groups.
    c. Smart Cities Mission (SCM)
    d. Swachh Bharat Mission (SBM)
4. Local Municipal Laws
5. Local Area Plans (LAPs)

Buildings

1. National Building Code, Energy Conservation Building Code, Eco-Niwas Samhita (energy conservation building code for residences)
2. Model building bylaws
3. National Mission on Sustainable Habitat

4. National Mission for Enhanced Energy Efficiency
5. Energy Conservation (EC) Act
6. Development Control Regulations (DCR)
7. Rating systems such as Green Rating for Integrated Habitat Assessment (GRIHA), Leadership in Energy and Environmental Design (LEED) and the Indian Green Building Council (IGBC)

Municipal Services

1. State planning regulations
2. Water Prevention and Control of Pollution Act
3. National Water Policy
4. National Water Framework Bill
5. National Environment Policy
6. National Urban Sanitation Policy
7. Central Public Health & Environmental Engineering Organization (CPHEEO) guidelines
8. Jal Jeevan Mission
9. Construction and Demolition Waste Management Guidelines
10. Extended Producer Responsibility (2021)
11. Plastic Waste Management (Amendment) Rules (2021)
12. Solid Waste Management Rules (2016)

2.3.2 Elements of a Long-Term Low-Carbon Development Strategy

This section presents three elements that provide broad directional shifts to promote adaptation in building design, energy and material efficient buildings and low-carbon urbanisation. These elements, namely city planning, buildings, and municipal services, are identified as focal areas to ensure that urban design in rapidly growing cities in India is climate resilient and can also contribute to India's overall efforts in sustainability.

2.3.2.1. Mainstreaming adaptation measures in urban planning and measures for enhancing energy and resource efficiency within urban planning guidelines, policies and bylaws

Cities are complex systems of natural and built environments. With over 4,000 urban centres and some of the fastest-growing cities, Indian cities face urban planning challenges, with climate impacts posing an additional risk to critical infrastructure. It is therefore important for cities to adopt a climate-sensitive approach to urban planning.

This can include increasing the amount of green space per capita. Conserving, rejuvenating, and increasing blue and green cover in a city can play a critical role in decreasing local temperatures, increasing carbon sequestration, building flood protection, and recharging groundwater.

Subcomponents of this element may include the preparation and revision of regional development master, and zonal level plans and guidelines, as well as introducing regulations and bylaws that are flexible, adaptive, and climate responsive.

2.3.2.2 Promoting climate-responsive and resilient building design, construction, and operation in existing and future buildings

Buildings construction and operations account for 36% of global energy use and 39% of energy-related emissions annually (UNEP-IEA, 2017). In India, the building stock accounts for more than 40% of the country's total energy consumption, and energy use from buildings is increasing by 8% annually (Khosla & Janda, 2019; Ahuja & Soi, 2020). With the urban population projected to increase to 60% by 2050, India's residential electricity demand will likely triple (IEA, 2021). Further, urban India is expected to build 700 to 900 million square meters of residential and commercial spaces (McKinsey Global Institute, 2010).

Buildings rated by voluntary green building rating programmes constitute approximately 5% of the Indian building market share. However, national power demand can be reduced significantly by 2030, by improving the energy efficiency of buildings design, construction, and operations. Subcomponents of this element may include improved building envelope design, choice of sustainable construction materials, methods of construction and other allied strategies such as adaptive reuse of buildings, energy-efficient building systems, usage of renewable energy, and green carbon sinks.

Box 2.2: Energy Conservation Building Code (ECBC)

The ECBC covers all important aspects of energy use in buildings, including the building envelope, comfort systems and controls (heating, ventilation, air conditioning, hot water systems), lighting and controls, and electrical and renewable energy systems. It prescribes standards in accordance with the five major climatic zones of India. The minimum level of energy efficiency that an ECBC compliant building achieves is 20% compared to a standard baseline, by adhering to the mandatory and prescriptive requirements. Buildings achieving energy efficiency of 30-35% are labeled as ECBC Plus and those achieving 40-45% energy efficiency are labeled as Super ECBC Buildings (BEE, 2017). The code is implemented by State Governments, which can make necessary modifications to suit local requirements. Countrywide implementation of ECBC is expected to achieve a 50% reduction in commercial building energy use by 2030, translating into energy savings of 300 billion units and peak demand reduction of over 15 GW in a year, and 250 million tonnes of CO_2 reduction (PIB, 2017).

2.3.2.3 Promoting low-carbon municipal service delivery through resource efficiency and management of water, solid waste, and liquid waste

Stresses on natural resources, unauthorised land use, untreated waste disposal, and problems of access to basic services, are intensifying with the growing urban population. Further, with extreme weather, most cities face the twin challenges of meeting increased demand for potable water, and management of excess water during extreme precipitation events.

A significant increase in Municipal Solid Waste (MSW) generation has been recorded globally, with average waste generated per capita per day at around 0.74 kilogram. Global MSW generation is expected to grow to 3.40 billion tonnes by 2050 from the current 2.01 billion tonnes annually (Kaza et. al., 2018). Waste accumulation and improper disposal severely affect the environment causing air, water, and soil pollution, which affects public health and causes ecological damage. In India, 147,613 metric tonnes (MT) of solid waste are being generated per day as of January 2020. Smaller towns and cities face challenges in managing waste effectively (Singh, 2020).

With city governance determined by Urban Local Bodies (ULBs), rapid urbanisation will require interventions from ULBs to be able to manage resources and deliver municipal services efficiently. These can include mainstreaming efficiency within municipal service delivery through resilient water management, improved water use efficiency, demand management policies and conservation of water sources, circularity in waste management, and recycling and reuse of wastewater.

Box 2.3 – Climate Smart Cities Assessment Framework

To enable a holistic assessment and benchmarking of urban development from a climate lens towards a roadmap for embedding climate change within urban planning, the Ministry of Housing and Urban Affairs has developed a Climate Smart Cities Assessment Framework (CSCAF). The framework aligns with the National Mission on Sustainable Habitat and is intended as a tool for cities to inform investments, showcase evidence of climate actions, and monitor impact. It covers five thematic areas: urban planning, green cover & biodiversity; energy & green buildings; mobility & air quality; water management; and waste management. As of July 2022, 126 cities are using CSCAF to report on their climate actions; this number is expected to grow in the next phase of CSCAF.

2.3.3 Potential Benefits and Challenges

Embarking on a sustainable urbanisation strategy would lead to potential benefits and challenges, with an impact on other developmental indicators.

1. Integrating climate measures into urban planning instruments can potentially contribute to tackling

other local environmental and developmental problems in cities and providing benefits such as reduced air pollution, and improved public health. Additional gains may include energy savings. However, climate-responsive urban planning and building practices (e.g., passive design or efficiency standards) require large investments in innovation and low-carbon technologies. For a developing country with multiple claims on its public finances, mobilising these financial resources can be a significant challenge. The primary focus, therefore, will be in creating climate resilient infrastructure that will ensure the best possible protection from climate impacts in the future.

2. Energy-efficient buildings reduce negative impacts on the environment by utilizing less water, energy, and natural resources.

3. Improving the efficiency of municipal services, which include water supply, waste management and sewage treatment, reduces energy usage associated with processing and delivery. This also, in turn, helps in improved public health and quality of life. Improving the efficiency of municipal services involves an increase in expenditure for service delivery, which can eventually lead to higher tax rates. In early stages of urban development, with a large section of informal workers in the urban economy, this can be challenging for Governments to implement.

4. Implementation of early warning systems and frameworks for addressing impacts from extreme events within urban design and municipal service provision can have many benefits in protecting lives and economic activity in the future and will be a priority for the Government.

5. The use of new and emergent technologies and materials in building construction, ICT and SCADA tools for streamlining efficient municipal service delivery can have the advantage of reducing the costs of these technologies for use in other sectors of the economy.

6. Efficient waste management can potentially provide employment opportunities in areas deploying innovative technologies instead of the current predominance of informal work in the waste sector. The Government will focus on supporting innovative start-ups and models that can address the issue of waste and recycling in cities that have multiple benefits of employment generation, energy production, and waste reduction.

7. Many of the initiatives of efficient and resilient urban design will require a significant enhancement of technical and financial resources at the municipal level. In growing urban agglomerations, peripheries of which are largely dominated by informal settlements and economic activity, enabling processes for climate resilient urban design will be challenging. The Government will focus on building capacities of municipal departments and other regional administrative bodies.

8. Increasing number of private sector start-ups working in the waste sector, including e-waste.

2.4 Promoting economy-wide decoupling of growth from emissions and development of an efficient, innovative, low-carbon industrial system

The industrial sector contributed about 25.9% to India's GVA in 2020-21. Manufacturing alone, contributed 14.4% to GVA this year, with construction and energy and other supply utilities adding another 9.9% (DEA, 2022). The Government of India is focused on expanding the contribution of manufacturing to GDP as this is necessary in a developing country to generate employment, enhance incomes, and create infrastructure and conditions for improved well-being of the population. Continued economic growth and aspirations to boost domestic manufacturing, through initiatives like Make-In-India, are expected to lead to enhanced energy consumption, and significant additional demand for steel and cement in the medium-and long-term. This has implications for emissions from this sector. Low carbon options for the industrial sector in India must however be viewed within the overall context of the need for significant expansion of industrial production, the fact that India's contribution to historical emissions is negligible, and that India remains well below its fair share of the carbon budget. The Industrial Processes and Product Use (IPPU) sector contributes approximately 8% of GHG emissions (MoEFCC, 2021) currently. An analysis of industrial emissions by NITI Aayog suggests an expectation of increase in energy consumption in the sector and consequently of emissions until 2070.

A shift away from fossil fuels in this sector could have a negative impact on India's sustained growth and rise in GDP and a negative impact on employment due to contraction in sectors such as mining, petroleum refining, and manufacturing. These may subsequently also lead to impacts in other sectors of the economy. India also faces the challenge of achieving higher energy access and energy security for its population.

Despite these challenges, India has taken significant strides in ensuring improved energy efficiency in the industrial sector, creating the potential conditions for sustainable growth in this sector in the medium and long term.

2.4.1 Current Policies and Programmes

Energy and material efficiency, process and fuel substitutions, circular economy approaches, electrification and the adoption of low-carbon fuels are important elements of establishing a productive and low-emissions industrial system. Current policies and programmes under these elements are outlined below. These include many listed in other sections of this chapter, but are included here as part of the overall contribution to energy efficiency and the economy-wide decoupling of growth from emissions.

Energy efficiency

1. National Mission on Enhanced Energy Efficiency
   - Perform, Achieve Trade (PAT) Scheme: This energy efficiency scheme for notified industries and industrial units is envisaged to widen its coverage to other energy intensive industries such as ports, chemicals, ceramics, sugar, and mines.
2. Energy Efficiency Financing Platform for capacity-building on energy efficiency.
3. Standards & Labelling Scheme for Industrial appliances and equipment.
4. Industrial processes and fuel switching.
5. Raise in the share of natural gas in energy mix.
6. Target of 20% blending of ethanol in petrol by 2025-26 under the National Biofuels Policy Adoption of Sustainable Mobility Technologies.
7. National Electric Mobility Mission Plan, the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) Scheme, the National Mission on Transformative Mobility and Battery Storage, and production-linked incentives for domestic manufacturing.
8. PLI ACC Battery Storage Scheme, the Battery Swapping Policy and new interoperability standards.
9. India aspires to significant EV adoption over the next few decades.

Material efficiency and recycling

1. Waste management policies for e-waste and single-use plastic
2. Circular economy approaches for 11 economic focus areas

Green hydrogen technology and infrastructure

1. National Hydrogen Mission
2. R&D on hydrogen production, storage and application is being supported by concerned Government departments and research institutions (NITI Aayog, 2022).

Low carbon technologies for hard-to-abate sectors

1. Planned mission on green steel to lay out a green expansion plan for steel
2. Ministry of Steel projects with global partners for technology, capital, and R&D

Micro, Small and Medium Enterprises (MSMEs)

1. Energy conservation and efficiency guidelines for MSME sectors
2. National Programme on Energy Efficiency and Technology Upgradation to address challenges of MSMEs
3. Promoting further investment in energy-efficient and renewable energy use by MSMEs

2.4.2 Elements of Long-Term Low-Carbon Development Strategy

Industrial activities and infrastructure feature a wide range of processes, materials, and technology. This section presents six elements of a long-term low-carbon development strategy towards a productive industrial system in India that can contribute to meeting its development goal and contribute to the global effort for climate change mitigation.

2.4.2.1 Improving Energy Efficiency

Energy efficiency remains a cornerstone of India's overall strategy for low carbon development. India will build on existing policies such as the PAT scheme and will continue R&D on energy efficient technologies, particularly for MSMEs in the short to medium term. It is proposed to widen the PAT scheme to cover significant part of industrial energy consumption by 2030 to eventually reach its maximal potential subsequently. It is also aimed to achieve 100% market penetration of energy efficient appliances mandated under the Standards and Labelling programme. Other components of this element include pursuing electrification, encouraging the use of electricity generated from non-fossil fuel sources, digitisation of processes, creation of a carbon pricing programme to incentivise energy efficiency, and alliances and collaborations across sub-sectors to facilitate circular economy and sector coupling approaches (BEE, 2022).

Box 2.4: Perform Achieve Trade (PAT) Scheme for Industries

The PAT scheme is the flagship programme of the National Mission for Enhanced Energy Efficiency. This scheme identifies designated consumers across select energy-intensive industries who have to meet mandated energy efficiency targets in a given time period. The cement industry has been part of PAT cycles since their inception in 2012, and in every cycle the industry has been able to overachieve its reduction targets. In PAT cycle I, it was able to overachieve the target by 82% and in PAT cycles II and III, it was able to overachieve by 49% and 75% respectively. In the iron and steel sector, a total of 5.013 Mtoe of energy savings were achieved between 2012 and 2020 under the PAT scheme, amounting to total GHG emission reductions of 18.64 million tonne CO_2eq. Similarly, 12 designated consumers from the aluminum industry have successfully achieved an emissions reduction of 5.24 $MtCO_2$ between 2016 and 2019. The fertilizer industry, which plays a key role in ensuring India's food security, is also included under the PAT scheme, with 36 designated consumers. It has achieved energy savings of 0.447 Mtoe between 2016 and 2019 and an emissions reduction of 0.71 $MtCO_2$ in this period. Refining Sector has been included in PAT scheme from cycle-2, commencing 1.4.2016. Against the energy reduction target for refining sector in PAT cycle-2 of 5.49% equivalent to 1.01 Million TOE, the actual energy reduction of 8.05%, equivalent to 1.48 Million TOE was achieved and for current PAT cycle (2018-19 to 2022-23), the target of 5.49% has been retained which is equal to energy saving target of 1.17 Million TOE. The PAT scheme has been similarly successful in reducing energy consumption and avoiding CO_2 emissions across other sectors, including petrochemicals, textiles, paper and pulp, power, among others.

2.4.2.2 Process and fuel switching, and electrification

Given rising energy consumption in industry, natural gas is envisaged to have a prominent role in the energy mix in the near to medium term, and establishing a reliable, effective natural gas network offering access to major industrial zones will be an important aspect of India's strategy for the industrial sector.

The electrification of industrial operations through power generated by renewables will also be prioritised in this element, with attention to the rationalisation of electricity tariffs for industries. Biomass-based energy, including biofuels, could also play a role in avoiding higher coal use in low-heat thermal applications. Finally, hydrogen as a fuel source will be developed to play a key role in driving industrial production in the long term.

2.4.2.3 Enhance material efficiency and recycling

The Steel Scrap Recycling Policy will be a good reference point to address sector-specific issues (MoS, 2019). With the expected expansion of the natural gas network and establishment of a hydrogen network, India will encourage the adoption of circular economy principles and material efficiency in the planning stage of infrastructure development.

2.4.2.4 Promoting green hydrogen technology and infrastructure

Through the National Hydrogen Mission, India envisages being a global leader in the hydrogen market. Pursuing R&D, infrastructure and technology development will be critical in success of this goal. Reducing electrolyser costs and exploring pathways to ensure round the clock RE supply would be crucial for making green hydrogen commercially viable. Demand creation, interventions to strengthen supply side for hydrogen production, setting up of domestic manufacturing of critical equipment, incentives to accelerate initial deployment for domestic and export markets, enabling ecosystem of policies, regulations and standard, development of green hydrogen hubs and infrastructure, and encouragement to innovation through R&D and pilot projects will be elements of the strategy for the promotion of green hydrogen in India. By 2030, India aspires to achieve 5 million tonne of annual production of green hydrogen, increase the electrolyser manufacturing capacity several-fold and put in place mechanisms to enable India to become one of the world's major exporters of green hydrogen.

2.4.2.5 Exploring options for low-carbon growth of hard-to-abate (steel and cement) sectors

For the steel sector adoption of best available technology to increase energy efficiency and increase utilization of scrap are important strategies for reducing emissions. Hydrogen has a key role to play in the long term, but capex requirements are high and would need to reduce substantially to enable increased scale of hydrogen use for steel production. Electrification of the secondary steel industry (SSI) sector through renewable energy could have significant impact on overall emissions from the steel sector and the potential for this will be explored. Green procurement policies could help to establish a pull for green steel thus enhancing efforts for achieving sustainability in this sector. The cement sector in India is already a global leader in terms of sustainable practices and has one of the lowest values of emissions intensity in the world. In India, increasing Alternate Fuels and Raw Materials (AFR) and Refuse-derived fuel (RDF) use would be an important element of continued sustainable development in this sector.

2.4.2.6 Sustainable Development of Micro Small and Medium Enterprises (MSMEs)

MSMEs are essential to the Indian economy. MSMEs constitute about 6.1% of the manufacturing GDP and 24.63% of the GDP from service activities (CII, n.d.). About 45% of the overall exports from India are from the MSME sector which provide employment to around 120 million persons. About 20% of the MSMEs are based out of rural areas, which indicates the deployment of significant rural workforce in the MSME sector. These enterprises promote sustainable and inclusive development as well as generate large scale employment, especially in the rural areas. Sustainable development in this sector is important but also challenging due to smaller scales of production and limited financial flexibility available to the units to invest in energy efficiency and low carbon measures.

A key near term strategy for the MSME sector would be to provide support for knowledge sharing activities and building capacities and awareness of the MSMEs about low carbon technologies. Implementing technology upgradation programmes, providing incentives for RE adoption where possible and relevant, improving electricity connectivity and reliability of supply are key steps that India will take to ensure overall development and sustainability of the MSME sector.

2.4.3 Potential Benefits and Challenges

Enabling the development of an efficient, innovative, and environmentally sustainable industrial system will lead to potential benefits, but will also carry many challenges.

1. Lower industrial reliance on fossil fuels could reduce the costs of purchasing coal and gas in spot markets.
2. Additionally, promoting green hydrogen, and industrial fuel switching and electrification could help create demand for clean electricity powered by renewable energy, indirectly reducing the challenge of renewable energy penetration in the electricity sector. However, the costs of enabling these measures in industry will be substantial.

3. An increase in demand for electric vehicles could drive growth in associated sectors such as semiconductors, information technology (IT), IT-enabled services, or Internet of Things. However, there will be a simultaneous negative impact on the supply chains and related infrastructure of ICE vehicles impacting labour absorption as well as revenues from this sector.
4. The growing dependence of industries on captive renewable energy-based energy technologies would only yield employment benefits if manufacturing of related equipment is domestic. In the absence of the same, higher dependence on renewable energy can lead to higher import dependence which consequently can threaten energy security.
5. A reduction in the use of raw materials and natural resources, and new business models and opportunities to reuse industry wastes as inputs in other sector processes can be a potential benefit. However, actualising this benefit would require improved freight transportation systems to connect regions and industries spread across different geographies in the country to ensure the circular flow of materials.
6. New business opportunities for MSMEs are possible as new sectors and technologies are developed. Skill development of the workforce on new energy efficiency, sustainable mobility, and green hydrogen technologies will be needed.
7. The costs of waste management related to RE development and EV production will be a major factor that must be considered as low-carbon growth plans are developed. The costs can be prohibitive in the near term.
8. The costs of R&D and implementation in improving energy efficiency, sustainable mobility, and green hydrogen technologies will be high. While there are benefits for the world in terms of climate change mitigation if India undertakes these activities, the realisation of the full potential of these policies will be contingent on the availability of, and access to, low-cost finance.
9. With an increased load on the electricity grid, the financial health of DISCOMs may be affected as industrial energy requirements change and reduce. DISCOMs play a crucial role in ensuring access to electricity for multiple purposes. Industrial sales are crucial for the DISCOMs to continue playing this role. Moves to promote grid-independence of industries must take into account this potential trade-off.
10. The near to medium term reliance on the use of natural gas in industries would require significant investments in expanding the natural gas network.
11. Onboarding and integrating MSMEs in a formal financing framework and assessing their credit worthiness may be a challenge. The availability of commercially viable technologies for MSMEs is a critical issue.

2.5 CO_2 Removal and Related Engineering Solutions

The urgency to mitigate climate change and the perception that the adoption of CCUS is inevitable in the long term for certain sectors are driving nations toward the adoption of CCUS technologies, with announcements and investments from several countries, especially developed ones. If successful, and if economic, technological, and political barriers are overcome, the global CCUS industry could possibly become a source of growth in the new low emissions economy. However, few countries have mentioned CCUS in their NDC thus far.

In the long-term pilot projects may be taken up for coal-based methane, carbon capture, utilisation and storage (CCUS), and promotion of technology development for coal-to-gas and coal-to-liquid, with international finance, technology transfer and collaboration. A detailed analysis of costs and probable expenditures for scaling up CCUS will need to be conducted.

The economic and political feasibility of CCUS is highly uncertain. The emphasis in this field is on R&D and building human and infrastructure capacity to evolve technologies and methodologies that address issues related to high capital costs, safety, logistics and high auxiliary power consumption. The CCUS technology at present is not matured and India can take up only demonstration projects at this stage to assess the viability of the proposed solutions. Retrofitting of existing thermal power generating units for CCUS implementation is not a viable option, until the technology is cost effective and less energy intensive. India requires considerable climate finance and technology transfer with effective international collaboration to enter this arena.

2.6 Enhancing Forest and Vegetation Cover

In India, about 24.62% of the total geographical area is under Forest and Tree Cover (i.e., 80.95 million hectares). India has the tenth largest forest area in the world, constituting approximately 2% of the world's forest cover (FSI, 2021). Forest canopy density is classified into four major types: Very Dense Forests (9.978 million hectares), Moderately Dense Forests (30.689 million hectares), Open Forests (30.712 million hectares), Scrub Forests (4.654 million hectares) for a total forest area of 71.378 million hectares, with the remaining area under Tree Cover (FSI, 2021)[2]. Since 1987, Scrub Forests (<10% canopy cover) have declined at an average rate of 0.1721 million hectares every two years, while Open Forests (10-40% cover) increased at an average rate of 0.3495 million hectares every two years since 1987 and Dense Forests (>40% cover), including both moderate and very dense forests, increased at an average rate of 0.2155 million hectares every two years since 1987. Figure 2.3 is a map of the forest cover in India. India's forests and other natural habitats such as grasslands, wetlands and mangroves harbour a rich and fairly intact diversity of plant and animal species, as well as provide the biomass needs of a majority of its human population.

Occupying nearly 10% of the geographical area of the country, Trees Outside Forests (TOF) are also significant natural, renewable resource that make a vital contribution to the agroecology and socio-economic circumstances of rural areas, and environmental amelioration in the urban areas. They also feed wood-based industries with raw materials and thus generate significant employment. In India, mangroves are found in 12 States and Union Territories, covering approximately 4,992 sq. km (FSI, 2021). Mangroves play a crucial role in carbon sequestration, coastal biodiversity, and adaptation to natural hazards such as storm surges.

The country has seen significant growth in the network of protected conservation areas (protected areas, conservation reserves, community reserves, reserve forests and biosphere reserves etc). With well over 20% of its geographical area under biodiversity conservation, India has exceeded the terrestrial component of 17% of Aichi target 11 and 20% of corresponding National Biodiversity Targets relating to areas under biodiversity management (NBA, 2018).

2. VDF – canopy >70%; MDF – Canopy >40 % and <70%; OF- >10% and <40%; and Scrub - <10%

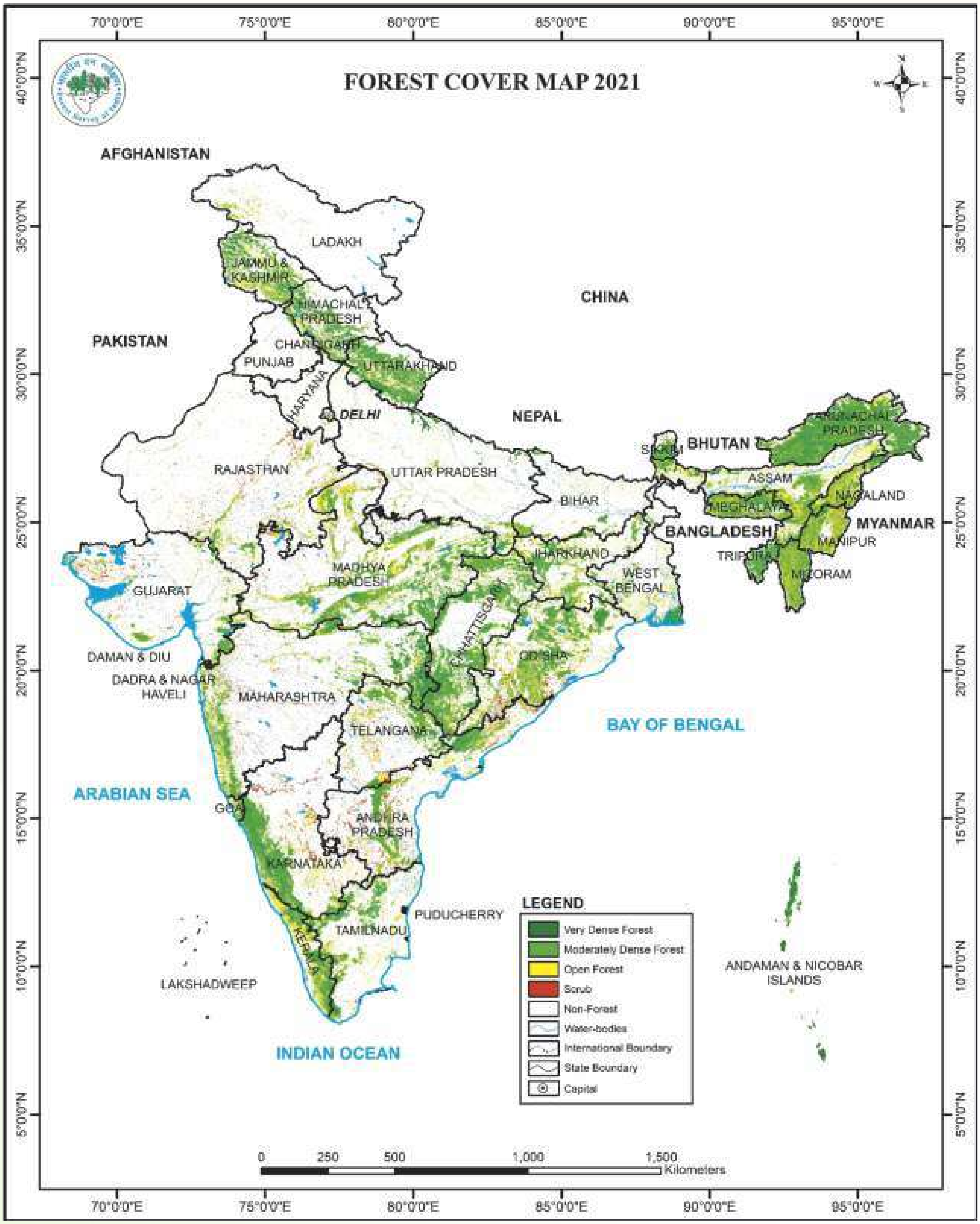


Figure 2.3 Forest Cover Map in India, 2021 *(FSI, 2021)*

India has among the lowest rates of gross deforestation, in absolute terms, in per capita terms, and in annual rates (MoEFCC, 2021). Annual rates of deforestation have also been consistently coming down in the country in recent decades (Reddy et. al., 2018). The carbon stock in forests has been estimated to be 7,204 million tonnes (FSI, 2021). The annual increase of carbon stock during 2019-21 is estimated to be 39.7 million tonnes or 145.6 million tonnes of CO_2 equivalent. This translates into carbon sequestration of 0.44 tonnes carbon per hectare per year which is comparable to or higher than reported for tropical forests globally in recent times (FSI, 2021).

In contrast to the huge emissions from the forest fires in regions such as Western USA and Canada, the Siberian Arctic, the Amazonian basin, Indonesian rainforests, and south-eastern Australia, the emissions from forest fires in India contribute a mere 1-1.5% of all global emissions from wildfires (MoEFCC, 2021). India's forests are teeming with wildlife. They support ~70% of the global tiger population, >60% of Asian elephants, ~80% of the one- horned rhinoceros, 100% of the Asiatic lion population and thousands of endemic species, making India one of the 17 mega biodiverse countries in the world.

While forests formally contribute only 1.7% to India's GDP, yet they employ 6.23 million people, the highest in Asia (FAO, 2020). The intangible benefits provided by forests are often unaccounted. The demands of a growing human population for food, medicine, fibre, fodder, shelter, and fuel, along with the need for economic development, are increasing the pressure on biodiversity and ecosystems throughout the country.

The impacts of climate change on the forestry sector can be attributed to a series of cumulative factors such as loss of habitat due to global temperature increase and changing rainfall patterns which may lead to prolonged droughts. Such conditions enable only drought resistant trees to survive while eliminating tree species with lower resilience which may have been endemic to the region. Hence forest cover, density and biodiversity are affected, which in turn also affects the ecosystem services accessed by the local people and the industries based on forest products. At the national level, 23%, 37%, 24% and 16% of forest grid points show low, medium, high, and very high inherent vulnerability to climate respectively as seen in Figure 2.4 (MoEFCC, 2021).

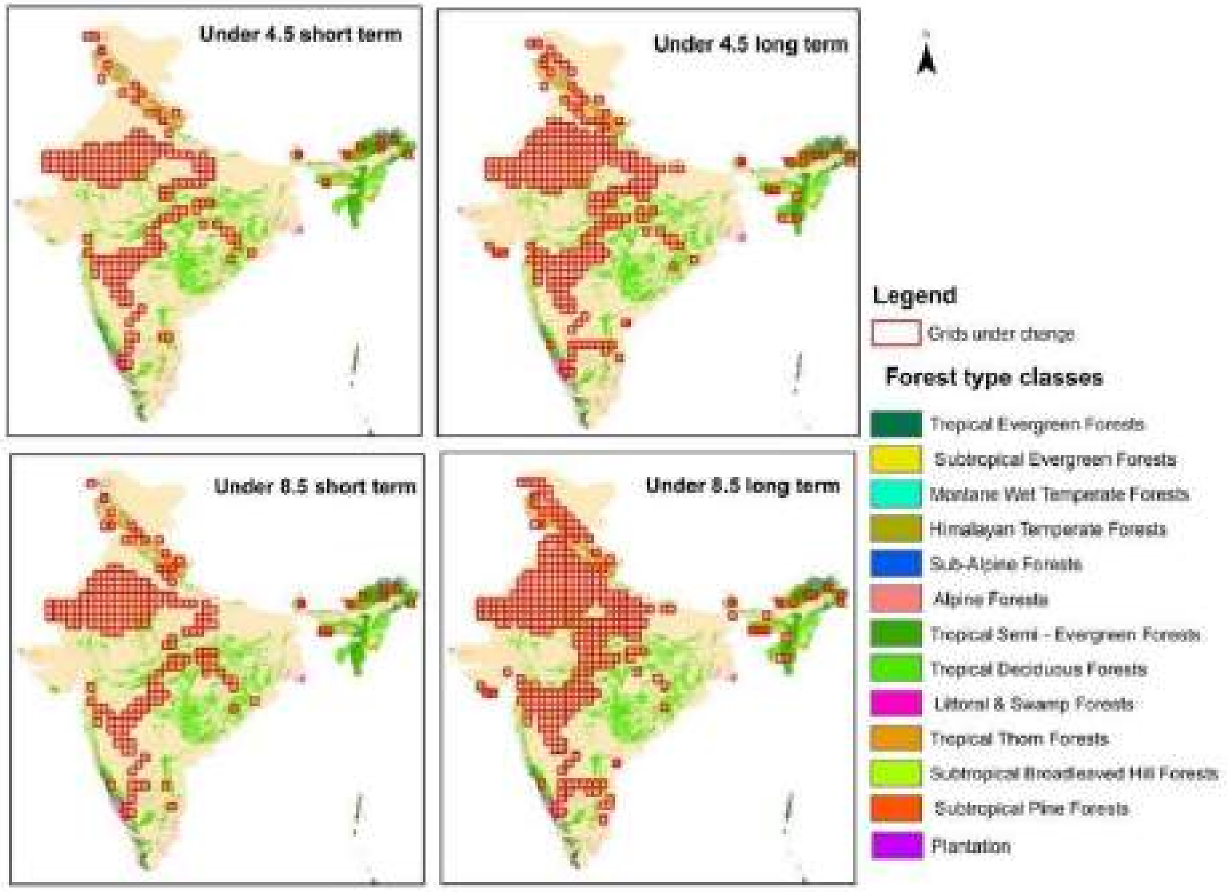


Figure 2.4 Projected impacts of climate change on different forest types and regions of India. Grids in red indicate change in vegetation type in the near term (2030s) and the long term (2080s).

Source: *(Ravindranath & Bala, 2019).*

Forest governance is underpinned by a robust legal framework including the Indian Forest Act, 1927, the Forest (Conservation) Act, 1980, the Forest Rights Act, 2006, the Biological Diversity Act, 2002, Wildlife Protection Act 1972, Panchayats (Extension to Scheduled Areas) Act, 1996 and other Central/State laws as applicable.

2.6.1 Current Policies and Programmes

1. Major policies and programmes: India is undertaking several significant actions in the forest sector, in the light of its firm commitment to preserving its natural resources, heritage and biodiversity.

    a. The National Forest Policy (1988): The policy aims at bringing 33% of the country's geographical area under forest and tree cover. To achieve this goal, India has been actively pursuing a number of strategies and programmes from the National to local levels.

    b. National Afforestation Programme (NAP): The objective of the programme is to "develop the forest resources with people's participation, with focus on improvement in livelihoods of the forest-fringe communities, especially the poor". NAP is being implemented for afforestation of degraded forest lands. NAP has streamlined flow of funds from Centre to States, Districts and Villages.

    c. National Mission for a Green India (GIM): It is one of the National Missions under the NAPCC that was implemented to protect, restore and enhance the decreasing forest cover of India. The mission goals include: improve forest/tree cover by 5 million ha; improve quality of forest/tree cover by another 5 million ha; enhance ecosystem services including carbon sequestration and other services such as hydrological, provisioning and biodiversity; increase livelihood of 3 million households based on forests.

d. Tree cover in urban and peri-urban areas: NAP has been merged with GIM under which there is a specific sub-mission for enhancing tree cover in urban and peri-urban areas. An area over 2 million ha was sanctioned for taking up afforestation in the States/Union Territories (UTs) with an investment of about INR 39,364.1 million till 2020-21 under NAP since its launching year 2000. Under GIM, an amount of about INR 4,550 million has been released to States/UTs from 2015-16 to 2020-21.

e. National REDD+ Strategy 2018: REDD+ aims to achieve climate change mitigation by incentivizing forest conservation. The strategy seeks to address drivers of deforestation and forest degradation and develop a roadmap for enhancement of forest carbon stocks and achieving sustainable management of forests through REDD+ actions.

f. Compensatory Afforestation Fund Management and Planning Authority (CAMPA): This is one of the programmes to ensure that social dimensions of forestry are prioritized. Funds under CAMPA are collected from public and private sector infrastructure developers as compensation for the forest land converted into non-forest land by infrastructure projects. The fund is used to promote afforestation, forest regeneration and ensure maintenance of ecosystem services (MoEFCC, 2022).

g. Forest Fire Prevention and Management Scheme (FFPMS): Ministry of Environment, Forest and Climate Change provides financial support to the States/Union Territories under FFPMS for protection against forest fire.

h. Nagar Van Yojana (NVY): This urban forest scheme intended to create 400 'Nagar Vans' and 200 Nagar Vatikas in the vicinity of urban areas under the National Fund of CAMPA.

i. School Nursery Yojana (SNY): The scheme aims at creating awareness and inculcating a habit of caring for nature, and is to be implemented for a period of five years from 2020-21 to 2024-25.

j. Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS): MGNREGS is a livelihood and employment scheme that guarantees minimum wage and days of employment for needy households. A guideline for convergence of MGNREGS with GIM has been released by the central Government in 2015. This shall lead to guaranteed availability of manpower for forestry related activities.

k. Aajeevika - National Rural Livelihoods Mission (NRLM): One of the strategies under NRLM is to conserve Non-Timber Forest Products (NTFP) species, promote sustainable harvesting practices of NTFP and promote development of NTFP market value chains.

l. Atal Mission for Rejuvenation and Urban Transformation (AMRUT): Creating and upgrading green spaces, parks and recreation centres in Mission cities.

m. Tree plantation, being a multi-departmental, multi-agency activity, is also being taken up cross-sectoral under various programmes/funding sources of other Ministries and also through State Plan budgets. Some such programmes relevant to the long-term transition of forests include the Finance Commission outlays, National Agroforestry Policy and Integrated Watershed Management Programme (IWMP). Further, policies and programmes in the areas of invasive species management, river rejuvenation, water conservation and environment friendly lifestyles also contribute to increasing the quality and quantity of green cover.

2. NDC and other contributions

   a. Forests also form a key element in India's NDC. India has proposed creating an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030 (UNFCCC, 2022). India is also the signatory of various international conventions and intergovernmental fora that guide its forestry sector approach. India targets to restore 26 million ha of deforested and degraded land by 2030 under the Bonn Challenge (IUCN, n.d.). India has also prepared a National Biodiversity Action Plan (NBAP) in 2008, and an Addendum to NBAP was prepared in 2014 with 12 National Biodiversity Targets, developed in line with the 20 global Aichi biodiversity targets.

2.6.2 Elements of a Long-Term Low-Carbon Development Strategy

To achieve the goal of promoting the quality and coverage of forests consistent with their social use and ecological attributes, the following long-term directions are being considered. The "Core Principles" for implementation are discussed in Box 2.5 below.

Box 2.5: Core Principles for implementation

Enhanced implementation of landscape-based approach and improvement of the forest/ecosystem goods and services (carbon stocks, water, and meeting biodiversity conservation and livelihood security needs) with local communities, as mandated in the National Forest Policy (NFP) of 1988. Public forest lands that serve as the life sustaining resource base for the rural communities shall remain in the public domain so that the benefits accrue to all sections of society.

- Empowerment of communities (youth and women) and strengthening of social use through decentralized local governance of forests.
- Integrating traditional ecological knowledge of communities with forestry science and state-of-the-art technology.
- Restoration of native biodiverse species mix at the landscape level.
- Massive afforestation/reforestation at all spatial scales of urban and rural areas, public and institutional lands, river catchments, watershed areas promoting the water-food-energy-forest nexus.
- Promotion of innovative technologies, finance instruments and private sector engagement with focus on youth entrepreneurship.

2.6.2.1 Restoration, Conservation and Management of Forest Cover (including mangrove forests)

The preservation and sustainable management of forests have the potential to offer advantages for both adaptation and mitigation (by lowering emissions from deterioration). Potential strategies and lines of action include:

1. Improving/enhancing density and quality of forests
2. Improved protection and restoration of forest and green cover in critical and biodiversity hotspots (including, but not limited to, Himalayan Ecosystems, North-Eastern Region, Western Ghats)

3. Improved health of forest and forest hygiene
4. Improved climate smart monitoring and forest protection against forest fires

2.6.2.2 Restoration, Conservation and Management of Trees Outside Forests (TOF), Green Cover

Trees Outside Forests (TOF) are essential to rural India's social and economic well-being and provide important ecosystem services both in urban and rural areas. As the primary substitute for timber from forests, TOF-derived wood and panel products have greatly reduced strain on forests. They also act as an important source for timber and fuelwood, contribute in carbon sequestration and conservation of biodiversity, provide habitat for wildlife, and help in micro-climate stabilization. Potential strategies and lines of action include:

1. Restoration and increasing area under trees outside forests and green cover.
2. Large scale enhancement of tree/green cover in urban and peri-urban areas.
3. Rural greening with a focus on One Forest–One Village and promoting agroforestry as a major programme for increasing farming income and meeting demand of wood products.

2.6.3 Potentials and Challenges

Apart from direct benefits such as carbon sequestration, various co-benefits are associated with conservation, protection, restoration and management of forest and tree cover in India. Elements and underlying lines of action may yield specific benefits, although significant challenges exist that will shape the relevant actions and their outcome. Some common features include:

1. Conservation of biodiversity, provision of ecosystem services and associated benefits.
2. Enhanced adaptation capacity, coastal protection and microclimatic regulation.
3. Reduced soil erosion and land degradation, as well as enhanced water retention.
4. Potential for enhanced employment, incomes, and livelihoods.
5. Assisting in improving air quality and reducing pollution, with positive impacts on population health.
6. Better regulation of the hydrological cycle.
7. Land use competition may arise with farming (food security), urbanization, infrastructure, and other land-based mitigation measures.
8. Restriction in the rights and access of local people to forest resources, threatening livelihoods/ subsistence agriculture and local land access.
9. High initial costs especially in case of wetland restoration.

2.7 Economic and Financial Aspects of Low-Carbon Development and Long-Term Transition to Net-Zero by 2070

A transition to a low-carbon development pathway will entail costs pertaining to the deployment of new technologies, development of new infrastructure, and other transaction costs. In the longer term, such a systemic transition will also have broader economic impacts, necessitating consideration of the economic and financial aspects of low-carbon development pathways.

This section discusses recent assessments of financial needs to enable this transition, the potential sources for meeting these needs, how climate change is being mainstreamed through the financial sector more broadly, and how finance flows can interact with international trade considerations. It is noted that these projections have a clearly tentative character, and are likely to be modified or changed over time. They are also likely to be under estimates in several instances as the slow pace of the transition at the global scale suggests. A look backward in history to the transitions that have occurred over periods of a half century or three-quarters of a century, also suggest that these estimates are to be treated with caution and may be far more optimistic than warranted, though this cannot be determined at this stage.

2.7.1 Assessments of Financial Requirements

An important factor in determining transition pathways and their pace of implementation is the level of financial resources available. Various studies focus specifically on estimating India's financial needs; with investment requirements provided at different levels of detail. Estimates vary across studies due to differences in approaches as well as assumptions of growth, technology options, and systemic transitions across different sectors, as well as differential coverage of subsectors and technologies. One of the key requirements for a developing country like India is to assess the additionality in terms of financial resources over BAU (Business as Usual) trajectories of development. This additionality, in relative terms, may be more pertinent, as the overall scale of development may, as one would hope, outperform the BAU considered as the baseline. While such additionality may not be commensurate with disruptive transformations that may arise, there is currently no way of predicting such transformations or projecting their impact on the financial resource dimension.

2.7.1.1 Low-Carbon Development Needs

Vishwanathan and Garg (2020) estimate cumulative investments of up to 6–8 trillion USD (approximately) will be required during 2015–2030 to implement the actions required to transform the current energy systems in India. This contrasts with the USD 10 trillion estimated by CEEW (Singh & Sidhu, 2021) for a 2070 net-zero scenario, of which the investment deficit could be as much as USD 3.5 trillion and the cumulative USD 12.4 trillion for transition to net-zero estimated by Standard Chartered (2022).

Patterns of investment needs are driven by a few key trends. Investments in energy may vary depending on the extent and pace of RE expansion (IEA, 2021). The largest investments in industry are required in iron and steel, mainly due to a transition to green steel. The construction sector also has large investment requirements, since its unorganized nature leads to difficulties in implementing green measures at scale. Hydrogen investments are expected to pick up after 2030, once technology costs come down. Investment needs in transport are driven by public transport infrastructure and electrification. A third of the total investments in the building sector may be used for investments in smart grids, including building automation, microgrids, smart meters, and connected infrastructures, while space cooling may take another 30%. City gas transitions will also require significant investments.

Overall, although the estimates vary widely and are not directly comparable, these are in all cases substantial and of the order of tens of trillions of dollars by 2050.

2.7.1.2 Adaptation and Resilience

Adaptation finance is a critical component of climate finance and a significant priority, to respond to climate change without adversely affecting India's development objectives. Although adaptation is discussed in more detail in Chapter 4, estimates of adaptation finance for all developing countries reach up to USD 300 billion by 2030, and USD 500 billion by 2050 (UNEP-DTU, 2018; UNEP, 2021) and may reach higher in view of the uncertainties in estimating the pervasive demands of adaptation.

2.7.2 Sources of Finance

Meeting the large investment needs for a low-carbon development transition, while balancing other national development needs, is a challenge. This needs mobilising international financial sources and considering the availability of domestic finance. In this, public finance can play an important role in stimulating private sector involvement.

2.7.2.1 International Public and Private Finance

On the basis of equity and the principle of CBDR-RC, the articles of the UNFCCC clearly make provisions regarding who the providers of financial resources would be, and where the resources are to be directed, including inter alia Article 4.3, 4.4, 4.5, and 4.7 of the UNFCCC. Under Article 9 of the Paris Agreement, it is also stated that "Developed country Parties shall provide financial resources to assist developing country Parties with respect to both mitigation and adaptation in continuation of their existing obligations under the Convention… developed country Parties should continue to take the lead in mobilizing climate finance from a wide variety of sources, instruments and channels."

As of 2020, the OECD report claims that developed countries have mobilised and provided 83.3 billion USD in climate finance to developing countries towards meeting developed countries' commitment to jointly mobilise USD 100 billion in climate finance by 2020 (OECD, 2022) . However, only 68.3 billion USD out of 83.3 billion USD was in the form of public finance (OECD, 2022). The OECD figure has been challenged by other independent agencies like OXFAM. The OXFAM report claims that the actual value of public climate assistance provided to developing countries by OECD is only one-third of the claimed amount, that is around 21–24.5 billion USD (OXFAM, 2022). Financially enabling the transition will therefore require a significant scaling up of international cooperation (DEA, 2015; MoF, 2018). It must be emphasised that even grant or concessional finance to developing countries often requires considerable co-financing by the recipient Government, as in the case of India in particular (MoEFCC, 2021). The financing needs are huge and so the finance flows from international sources need to have the scale, the scope and the speed to meet the low-carbon pathways.

Sources of international public finance include multilateral institutions, bilateral financial institutions, and dedicated climate funds, including the Green Climate Fund. Grant and grant-equivalent funding from these sources is expected to be significantly scaled up towards India for meeting its low-carbon development objectives (DEA, 2015; MoF, 2018).

Additional sources of international private finance can include corporates, financial institutions, and institutional investors. Their contribution towards meeting India's climate finance needs should count towards developed countries' commitments only if these are based on clear and harmonised definitions of climate finance.

International climate finance has four pillars that would integrate the needs and requirements of the developing countries, (i) qualitative, (ii) quantitative, (iii) temporal, and (iv) evolving mechanism. This would imply:

- Qualitative - improved access to grants and low-cost finance for climate actions, which conform to Article 4.3 of the Convention. The objective should be that climate action should not be onerous for the developing countries, who already face developmental challenge.
- Quantitative - The magnitude of finance has to cater to the enormity of the needs of finance. The Scope, Scale and Speed of finance need to be augmented substantially. There is a need to develop innovative financing options to improve flow of resources.
- Temporal - Like the actions in climate, the provision, mobilization and flow of finance are of essence as well. Hence a time bound action in resource provision needs to be emphasized.
- Evolving mechanism - The mechanism for estimating the finance needs by developing countries needs to be dynamic. The mechanisms for mobilising financial resources will also need to evolve and deliberation on this is vital. There should be credibility, predictability and reliability in the flow of finance.

2.7.2.2 Domestic Public Finance

Government support plays an important role in the development and maintenance of climate policies and is discussed further. Public finance has so far played a key role in supporting broader finance flows towards increasing the shares of low-carbon electricity and electrification.

Such support from public finance includes, between 2014 and 2021, support for transmission, that increased by 144%, partly due to the introduction of new schemes to strengthen the grid for RE (Aggarwal et. al., 2022). Support for renewable energy increased by 52%, due to a combination of accelerated depreciation and tax breaks on excise and customs duty; these are expected to increase further due to production-linked incentives for solar PV modules and advanced chemistry cell battery storage. This excludes other socialization of RE costs that are borne elsewhere in the system, including support like free inter-state transmission and other substantial system balancing costs. Conversely, support for coal, oil and gas has reduced by 42% and 75% respectively (Aggarwal et. al., 2022). Within limited subsidies in the oil and gas sectors, these are overwhelmingly directed towards ensuring affordable and clean access to energy, including for cooking in line with SDG 7. These have critical positive spill over effects especially for women and children in India. An increase in the LPG subsidy after 2018 is due to the PM Ujjwala scheme, which encourages transitions towards clean cooking in order to reduce indoor pollution (Garg, 2020; Vishwanathan, Panagiotis, & Garg 2021; Aggarwal et. al., 2022). EV subsidies have increased three-fold, largely due to the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, and concessional GST on EV 2-wheelers, 4-wheelers and electric buses. It is noted that the estimation of "subsidies" has several uncertainties and ambiguities due to varying definitions of the scope of the term. Further, in developing countries, financial support from public funds is a well-understood necessity.

2.7.2.3 Instruments of Domestic and International Private Finance

Private finance can be channelled through equity investments, debt including loans and bonds, FDI, risk mitigation instruments such as insurance and guarantees, and new and innovative forms of finance. Greater use of such instruments for low-carbon development can be facilitated by reducing search costs for investors and pooling risks, including through securitization of bank loans that are issued to green sectors, and mobilising resources through green bonds. Meeting India's financing needs will require strategic and scaled-up use of all these avenues, and resources need to be mobilised by developed countries from various sources that are long term, concessional and climate specific. These finance flows are, however, no substitute for the flow of climate finance from public sources that forms the core of the commitment by developed countries in the UNFCCC and its Paris Agreement. It is also essential that there should be early resolution of the New Quantified Goal on Finance at the UNFCCC and appropriate new funds begin to flow. As India noted in its National Statement at COP26, new and ambitious climate action over the long-term requires equal ambition in the provision of climate finance (MEA, 2021e).

2.7.3 Mainstreaming Resources for Climate Actions

The mainstreaming of climate finance implies a shift in financial practices, to make climate change – in terms of opportunities and risks – a key consideration in financing decisions, while paying due attention to prioritising development.

2.7.3.1 Monetary Policy and the Financial Sector

Climate change, and policies to address it, can affect the dynamics of the economy and the financial system, thereby impacting inflation targets, affecting financial stability, and limiting the room available for conventional monetary policy. This suggests the need for caution in climate policy making, paying attention to the implications for monetary, fiscal, and economic policies. Climate change may also weaken the transmission of monetary policy through its effects on financial markets, including for instance via losses generated through the stranding of assets.

BOX 2.6 – Initiatives of the Reserve Bank of India (RBI)

Since April 2021, the RBI has been a member of the Network for Greening the Financial System (NGFS), a group of central banks that contributes to the development of climate risk management in the financial sector, and to mobilize mainstream finance to support the transition toward a sustainable economy (NGFS, n.d.). Subsequently, the RBI also established a Sustainable Finance Group to lead regulatory initiatives in the area of investments linked to climate risk and sustainable finance (Rani & Handoo, 2022).

In parallel, the RBI has been incentivising bank lending towards greener industries and projects. For example, renewable energy projects have been included under Priority Sector Lending (PSL), including off-grid renewable energy solutions for households, solar power generators, wind mills, micro-hydel plants, and non-conventional energy-based public utilities (RBI, 2021).

Box 2.6 shows current initiatives by the Reserve Bank of India. Options to further integrate climate considerations into the financial system and monetary policy include green lending policies, deepening the corporate green bond market, mandating green bonds as a requirement for the Statutory Liquidity Ratio (SLR), allocating Green Asset Ratios, and strategically expanding the PSL scheme towards sustainable sunrise sectors, as well as promoting innovative financial instruments to support nascent low-carbon technologies (D'Souza & Rana, 2020).

Box 2.7: Initiatives of Securities and Exchange Board of India (SEBI)

With a view to bring in greater transparency and enabling identification and assessment of sustainability-related risks and opportunities by investors, SEBI has adopted sustainability reporting for listed entities. In May 2021, SEBI issued new mandatory sustainability reporting requirements on Environmental, Social and Governance (ESG) parameters for the top 1000 listed entities called the Business Responsibility and Sustainability Report (BRSR). The reporting requirements are intended towards having quantitative and standardized disclosures on ESG parameters to enable comparability across companies. It shall enable companies to better demonstrate their sustainability objectives, position and performance resulting in long-term value creation. At the same time, access to relevant and comparable information will enable investors to make better investment decisions. Overall, higher standards of ESG disclosures and transparency will help in attracting more capital and investments.

2.7.3.2 Domestic Public Finance and Fiscal Policy

Integration of climate considerations into fiscal policies can play an important role in climate mitigation and adaptation, and can also boost economic growth (Dilip & Kundu, 2020; Krogstrup & Oman, 2019). A wide range of policy tools exist at both the sector and economy-wide levels for integrating climate considerations into public finance (Dilip & Kundu 2020; Krogstrup & Oman 2019), with however serious knowledge gaps on how climate related policies, especially mitigation, interact with other policy objectives. India is already attempting to use fiscal policy in support of the low-carbon transition. For instance, in 2010 India had introduced a coal cess, the proceeds of which were used to finance clean energy. It is also providing support to the deployment of electric vehicles through its FAME scheme (MHI, n.d.). Other fiscal tools have included support for the development of low-carbon technologies such as solar PV and batteries through production-linked incentives (PLIs) or capital guarantees (PIB, 2021a).

At the economy-wide level, fiscal instruments typically include carbon taxes, carbon trading, feebates, regulations, and public credit guarantees (Calice, 2021; Krogstrup & Oman 2019). Exemplifying the use of such instruments, Gujarat is the first Indian State to be launching a carbon market (Nandi, 2022), while instruments such as the PAT scheme utilise market mechanisms to enhance energy savings for energy intensive industries (Asia Pacific Energy, n.d.). A further expansion of such policies, building upon growing discussions domestically, will however require studying their implications for India's macro-fiscal framework (Box 2.8) and broader developmental needs. For instance, policies that increase the costs of fossil fuels would imply a higher cost of living, which may require either subsidies or recycling of public revenues back into the economy through various support schemes.

BOX 2.8 – Fiscal Losses and Increased Costs from a Low-Carbon Transition

India heavily taxes all fossil fuels at various stages from extraction to final consumption. This amounts to an effective carbon tax, higher than many developed countries, totaling approximately INR 5.5 trillion in FY 2019-20. At a more operational level, the “must-run” status of renewables has led to significant increased costs for State-level distribution companies (Kanitkar et. al., 2021), and the system overall socializes the costs of transmission, which are kept free for many RE technologies. Since public sector distribution companies bear the brunt of affordable electricity supply for weaker sections, the supplementary duty of undertaking Renewable Purchase Obligations (RPO) also adds to costs. Such additional costs constitute further investment by India in climate mitigation.

Further mainstreaming climate into the fiscal architecture can include using policy to promote green investments (including public infrastructure), thereby generating green jobs. This requires coordination among relevant line ministries and adoption of an appropriate budgeting framework.

2.7.4 Linkages to International Trade

Financial aspects of the low-carbon transition can affect, and in turn get affected, by the international trade regime. The Government will seek to ensure that obligation in international trade agreements will not curtail the existing policy space to nurture domestic producers of environmental goods and services.

The domestic and foreign policies of other countries, especially developed ones, to address emissions – through carbon border adjustment mechanisms – can also affect developing economies like India adversely, without achieving their stated objectives. There is a need to strike the right balance between the requirements of development, trade, and low-carbon pathways.

Chapter 3 RESEARCH AND INNOVATION

Innovation is an important part of development and sustainable growth in all sectors of the economy. It is also necessary for sustainability through recycling, reuse, and disposal of materials, waste and residues.

Innovation needs to be backed by institutions and human capital. There is a need to further improve the R&D base for green technologies and climate change mitigation and adaptation, both globally and nationally. India needs to equip institutions involved in R&D with the latest scientific equipment, physical infrastructure and needed skilled resources. R&D institutions need to engage with academia and industry, not only in India but also in other countries, keeping in view India's needs as a developing country facing the double challenge of growth and development and climate resilience.

The achievement of the Paris Agreement temperature targets will require significant new technologies, as noted by the IPCC Working Group III contributions to the Sixth Assessment Report. The process of developing, adapting, and deploying innovative technologies requires large up-front capital investment, but the returns to that investment are influenced by the presence of complementary infrastructure and the conduciveness of the policy framework. Limiting global temperature increase to 1.5°C requires the deployment of new technologies on a massive scale in developing countries. The cost of low-carbon technology is falling amidst large scale deployment and rising investment. "But the benefits have been unevenly distributed across the world, especially due to the lack of enabling conditions in developing countries." (IPCC, 2022)[3].

India's effort in innovation for climate action and sustainable development will be closely linked to its developmental vision for mid-century, and India's vision of *Aatmanirbhar Bharat* and Make in India in the industrial, especially manufacturing, sector. The pursuit of climate action and sustainability needs to be linked to self-reliance, reduced dependence on imports, and development of the innovative capacities of India's economy and society and cannot be driven largely by imports and uncritical adoption of processes and technology developed elsewhere.

India has initiated steps for establishing a National Research Foundation (NRF). The NRF aims to catalyze, facilitate, coordinate, seed, grow, and mentor research in academic institutions around the country, particularly at universities and colleges where research capacity is currently in a nascent stage. This will be the first of its kind foundation to promote research and development across the country. For creation of the National Research Foundation, a total expenditure of Indian Rupees 50,000 crore over a period of 5 years beginning from 2021-22 has been approved (PIB, 2021b).

In general, it is difficult to project future technology requirements in the face of its rapid and continuous development. Access to relevant, affordable, and scalable technologies, along with technical skills, can prove to be a game-changer, provided adequate financial support is received. The study of energy and industry transitions for the future indicates which low carbon technologies may dominate globally.

3. IPCC further says: "Adoption of low-emission technologies lags in most developing countries, particularly least developed ones, due in part to weaker enabling conditions, including limited finance, technology development and transfer, and capacity. In many countries, especially those with limited institutional capacities, several adverse side-effects have been observed as a result of diffusion of low-emission technology, e.g., low-value employment, and dependency on foreign knowledge and suppliers."

Coupled with a roadmap for R&D and investment to scale, such technologies can be developed and commercialized if adequate additional financial support is available. A large section of the population is vulnerable to climate change impacts, and thus adaptation is as relevant to India as mitigation. Most technologies for climate adaptation in sectors like agriculture, forestry, water, and health are available in India only on a very limited scale. These technologies need to be locally adapted and scaled up to ensure climate resilience according to the country's ecosystems and local population needs, an effort that also requires substantial financial support. The issue of technology, finance, and capacity-building needs to be addressed simultaneously and holistically following a comprehensive integrative approach.

Innovative technologies are particularly needed in the following sectors (not exhaustive): Carbon capture and storage (CCS), energy-intensive industries, aviation, biofuel supply, energy storage, and negative emission technologies. Thus by 2070, when emissions will need to be net-zero, India will be heavily reliant on CCS and negative emissions technologies to achieve this goal, and, in particular, to offset emissions from challenging and hard-to-abate sectors. In the following, the innovation requirements in specific sectors are discussed.

Under the UNFCCC, developed countries are committed to provide technology transfer on concessional terms to developing countries. Developing countries make known their specific requirements through several forums and discussions under the UNFCCC, including through their Biennial Update Reports (BURs). A non-exhaustive list of needed technologies has been provided by India to the UNFCCC in its First and Second Biennial Update Reports. Provision of these lists of necessary technologies, however, have not received any response from the developed countries. The details are given below (Table 3.1), as listed in India's Third Biennial Update Report. A majority of these are short- and medium-term requirements, while a further discussion is presented in section 3.1 focusing more on long-term innovation requirements.

Table 3.1 List of additional technology needs

S. No.	Area of Implementation	Technology/Remarks
1	Solar Photovoltaics	• Currently, crystalline Silicon (c-Si) technology contributes 95% of global solar PV installations, and thin films contribute to the remainder. Thus, c-Si is likely to contribute 400 GW by 2050 and is essential for India's future clean energy trajectory. • India lacks technology and manufacturing for the upstream segment of the supply chain, i.e., polysilicon/ingot/wafer. Indian cell manufacturers import wafers, and similarly, cells are imported for module manufacturing. • c-Si technology has made vast advancements, and the Indian manufacturers have not been able to keep pace with technology changes. • Existing module manufacturing plants lack economies of scale, which prevents cost reduction. • India lacks the crucial technologies needed to process/manufacture the raw materials for cell and module manufacturing.

S. No.	Area of Implementation	Technology/Remarks
		• Equipment (assembly line) used for cell, module, and BoM (Bill of Materials) component manufacturing is not available in India and is imported. • India needs next-generation PV technologies, including Perovskites, Multi-Junction Solar Cells, Dye induction photovoltaics and organic/inorganic composites. • China, UK, USA are some of the key countries for technology sourcing.
2	Offshore Wind	• Technology limitation exists in the survey space (oceanographic and geotechnical). • Heavily dependent on imports for rare earth metals. • Potential to increase the capacity factor of domestic manufacturing units. • Need for modelling and simulation tools, including HPC to improve. generation forecasting and performance analysis. • Denmark, the UK, and Germany are the major technology providers.
3	Advanced Ultra Supercritical Coal Technology (AUSC)	• Materials having characteristics of high creep rupture strength and corrosion resistance at elevated temperature and pressures are not available. • Japan and South Korea are potential collaborators for technology transfer (welding technologies).
4	Light Emitting Diode bulb	• LED chip (Wafer Fabrication) is imported.
5	Room Air Conditioners	• Rotary compressors – a key component in room air conditioners is largely imported. • The local availability of propane and isobutane-based refrigerants that have low Global Warming Potential footprints is a constraint.
6	Iron & Steel Manufacturing	Current technology mix dominated by the Blast Furnace-Basic Oxygen Furnace route, which uses coke, coal, and oxygen to produce steel. Through adoption of several energy efficiency measures and low carbon processes, an integrated steel plant can save emissions substantially. These, however, are being acquired through international commercial collaboration or require further technology transfer. Further, the following technologies can be adopted as and when these technologies are available for adoption on commercial scale. • H_2 based iron & steel making technologies. • HISARNA Technology which is being developed under ULCOS (Ultra Low Carbon Dioxide Steel Plant) Programme. • Pilot projects for CCUS in this and other relevant sectors.

S. No.	Area of Implementation	Technology/Remarks
7	Biofuels	• Scaling up issues exist for large scale enzyme production. • Feedstock sourcing has been a perennial problem. • Commercial production of Bio-methanol is cost-prohibitive. • Higher Ethanol compatible Vehicles and Flex Fuel Vehicle to be introduced. • CBG based vehicles is needed. • Technology development for SAF Production in the country.
8	Hydrogen	• Technologies for type III and type IV cylinders, as well as hydride and carbon materials for hydrogen storage. • Catalysts, membranes, and fuel cell manufacturing assemblies. • Hydrogen supply chain infrastructure and dispensing stations. • Green hydrogen utilization in the industry, including ammonia for fertilizers and iron and steel production. • Petroleum sector is planning for utilisation of green hydrogen in the refineries as well as for blending with CNG/CBG in gas pipelines.
9	Lithium-Ion Battery (LiB) & Flow Battery	• Raw materials and technology are barriers to large scale manufacturing of Lithium-Ion Batteries in India. • Advances in battery storage technologies.

Table 3.2 Technologies which need investment

S. No.	Area of Implementation	Technology/Remarks
1	Cement	• Proliferation of technology for waste heat recovery from preheater exhaust and cooler vent for co-generation of power. • Wider adoption of grate cooler technology. • Wider adoption of low-Nox multi-channel burners for combustion.
2	Iron & Steel	• Injection of plastic waste in the blast furnace.
3.	Energy	• Storage system and offshore wind.

In the following, we list some of the key innovative technologies required in particular sectors over the longer term, with a focus on some of the key innovative technologies that are already being developed in India and are available at various levels and stages of development.

3.1 Innovative Technologies in Energy Sector

3.1.1 Smart Grid Developments

The use of smart grid technologies to create both a nimbler and more resilient grid as well as one that is flexible and able to better incorporate clean energy is an essential requirement. India has a roadmap for installing hundreds of millions of smart meters in a few years, and this can then enhance not just utility operations but also greater rooftop solar integration. Complementary to efforts at the consumer or retail level, India is building out more flexible markets for wholesale electricity, with a range of business and regulatory innovations to support greener supply.

3.1.2 Developing Bio-Based Clean Energy Innovations and Carbon Dioxide Removal Technologies

On the mitigation side, biotechnology must play a lead role in the restoration, and conversion of domestic carbon sources (such as those found in agricultural and forest residues, municipal wastes, and sewage, gases feedstock from industries) into bio-based fuels and chemicals to replace fossil-derived fuels and chemicals, specifically for hard-to abate sectors like a long-distance truck, aviation, marine, and polymer industry. India, through the Department of Biotechnology, will be working to develop the technologies in the above areas with the potential to make available sustainable cost-effective biotechnology-based fuels and chemicals.

India being a member country of the Mission Innovation will be supporting the Carbon Dioxide Removal Mission, aimed to enable Carbon Dioxide Removal Technologies. India will be taking initiatives to develop and demonstrate the Intensified CO_2 capture.

3.1.3 Energy Storage Systems

Electricity storage is a key enabling technology, which will be necessary to accommodate the high level of intermittent renewable generation technologies (i.e., wind and solar) required for the development of low-carbon electricity systems. Apart from pumped hydro storage, which is currently the world's most dominant form of energy storage, lithium batteries are also considered significant. The research priorities for electrical batteries include new cell chemistries emerging from the lithium-ion family such as lithium-air, lithium-sulphur or other metals such as sodium and magnesium.

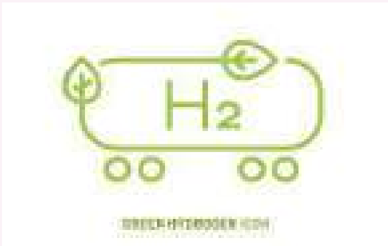
These could improve power and charge density, decreasing cost per unit of energy stored. Improved manufacturing techniques and efficient management of battery packs can provide evolutionary cost and performance improvements. However, as lithium is not available in India, research, and innovation for exploring other battery technologies is a strategic requirement.

Keeping in view the large-scale integration of RE into the grid, the need for Energy Storage Systems (ESS) to cater to the variability and intermittency of RE is highly significant.

3.1.4 Hydrogen Economy

Hydrogen is considered one of the key future energy carriers, having a variety of potential applications. Its applications are foreseen in process industries, fuel cells for power generation, grid balancing functions, steel industry and transportation. There is a need to further develop technologies to produce green hydrogen and its end-use applications. Green hydrogen / green ammonia could be used in co-firing the thermal power plants and later become the sole source of energy.

Box 3.1: Green Hydrogen



India announced the National Hydrogen Mission in 2021 with the objective of meeting mitigation goals as well as making India an export hub for green hydrogen and green ammonia. India aims to achieve production of 5 million tonne of green hydrogen by 2030 and the related development of renewable energy capacity is required (PIB, 2021b). In India, green hydrogen can serve the dual purpose of enhancing energy security as well as contributing to the development of a low-carbon economy. The Government is currently introducing various incentives to promote and scale the production of green hydrogen/ammonia, including the introduction of a PLI scheme for the manufacture of electrolysers, mandating a 'green hydrogen purchase obligation' for industry, allowing green hydrogen /ammonia manufacturers to purchase renewable energy from the power exchange or set up renewable energy capacity themselves or through any other developer, waiver of inter-state transmission charges for a period of 25 years for projects commissioned before 30th June 2025, and priority connection to the grid for green hydrogen projects.

3.1.5 Nuclear Energy

Nuclear energy is a key substitute for delivering base load power free of intermittency in place of energy from fossil fuels. India considers nuclear energy as a significant component of its non-fossil fuel power generation capacity and will continue to pursue research and innovation in this sector.

As India has a declared 'closed fuel cycle' policy, reprocessing of spent fuel is at the center of India's nuclear programme, not only from the perspective of the waste management but also for recovery of fissile material to use it in next stage reactors. With India now having safeguarded reactors using natural as well as enriched uranium as fuel, reprocessing of both types of fuels and development of associated technologies is an ongoing research and innovation area.

Demonstration of advanced reactor technology (sodium-cooled fast breeder reactor) is under progress. India is pursuing research and innovation in this area for over three decades and at present, a test reactor based on the same technology is under operation, while another technology demonstrator is under commissioning. Research and development of reactor fuel cycle technologies is underway.

India's Department of Atomic Energy (DAE) is developing sea water desalination technology using nuclear power. It is also developing technologies for Hydrogen production.

3.1.6 Development of Biomass-to-Liquids Fuel Production from Thermo-Chemical processes

India is an agricultural economy, with agriculture contributing nearly 20% to GDP and providing employment to approximately 50% of the population. The quantum of crop residues for 11 major crops in the country was estimated to be around 683 million tonnes in 2018 (Jain et. al., 2018) . In most places, part of these residues is used as fodder or for energy purposes. These residues are a rich source of renewable organic carbon that can be used to produce fuel, chemicals, or petrochemical feedstocks. Biotechnological or thermochemical routes are being developed for efficient and sustainable use of these biomasses.

The Council of Scientific and Industrial Research (CSIR) - Indian Institute of Petroleum (IIP) has developed a palletization process, whose outputs can be used in a pellet burner, for domestic cooking applications or heating applications in small scale industries. These pellets when produced in larger quantities can also be supplied to heavy duty industries or even to thermal power plants to produce electricity by co-generation. A mobile pyrolysis unit has also been developed by CSR-IIP. Bio-oils can be used for supplementing furnace oil requirement and the testing of these oils for repellent properties is under progress. Once more avenues for utilization of different fractions of bio-oil are identified, it will increase the economic viability of the process. The modified oils have found application as bio-binder for flexible pavement construction.

Overall, this will reduce the burden to import fossil fuels as it will be supplemented by the domestic carbon resources available within our borders and lead the country on to a path of self-reliance and low-carbon development.

3.1.7 Commercialization and Initiatives of Cellulosic Ethanol

India's Council of Scientific and Industrial Research (CSIR) has been working on 1G (first generation), 2G, and 1.5G bioethanol programmes for the last 10 years. Under the PANCSIR2GE program, CSIR is working on developing an integrated process for 1G, 2G, as well as 1.5G bioethanol, starting from sugary, starchy, as well as vegetal/lignocellulosic biomass feedstocks.

3.1.8 Integrated Gasification Combined Cycle (IGCC) Technology

IGCC technology has shown capability of power generation at higher efficiency and lower emission levels as compared to pulverized coal combustion technologies as demonstrated in some developed countries. Research in IGCC technology may be focused to open up new product areas along with electricity generation like liquid fuel generation, hydrogen production, pre-combustion CO_2 capture and integration of fuel cell which may provide future options of zero emission coal technologies with higher efficiency.

3.1.9 Waste Heat Recovery Systems for Utilizing the Flue Gas

Many industries make use of waste heat recovery system for capturing the high temperature flue gases in many industries and reusing it for producing power is equally important for environmental protection since lower quantity of fossil fuels shall be burnt for same quantum of useful energy. Further, research and innovation in Indian context may be made in developing technologies where waste heat can be efficiently and economically recovered and applied to produce refrigeration/air-conditioning using vapour absorption/adsorption machines (VAM) based on Li–Br, Ammonia absorption system.

3.2 Innovative Technologies in Industrial Systems

3.2.1 Low-carbon development of the industrial sector

Low carbon development of the industrial sector is particularly challenging now owing to competitiveness issues, and its inherent heterogeneity, especially in view of the large presence of the MSME sector. Except for biomass usage in certain applications, currently all of these options are still in the concept phase and there is an urgent need for the development of breakthrough processes (e.g., steel production based on hydrogen or electrolysis), which can result in a step-change in emissions reductions.

3.2.2 Aviation Industry

According to India's Third BUR civil aviation constituted 6% of the total transport emissions in India in 2016. Globally emissions from the aviation sector in 2018 was 903 $MtCO_2$ which was 2.48% of the total global emissions (Graver, et. al., 2020) .

Currently, the options for low (or zero) carbon airplanes are extremely limited. These include, inter alia:

1. Radical new aircraft designs (e.g., the 'blended wing' concept) that could improve fuel efficiency by 25% compared to the most efficient planes today.
2. Biofuel-powered planes have been proven to be technically feasible and blending of up to 50% is now allowed for commercial use.
3. New engine designs that can cope with the low aromatics' composition of biofuels
4. Hydrogen powered aircraft, which however face significant technical challenges for commercial scale use to become a reality.

Technology Information Forecasting and Assessment Council (TIFAC) has taken up assessment of Indian industries for identifying potential technologies and imparting requisite capacity building towards low carbon development. The sectors taken up include steel, cement, transport, MSMEs. TIFAC has also initiated a major study for designing of an innovative cooperative based model for enhancing utilization of biogas and demonstration of biogas grid in Punjab.

3.2.3 Steel and Cement Industry

In the Indian steel industry low carbon development is a big challenge as opposed to developed economies. It needs R&D intervention for seamless transition to non-coal-based technologies with alternate fuels like hydrogen. This transition needs to be over a period considering the high capital expenditure and readiness of befitting technology. During this transition period innovative R & D technology may be there to reduce the carbon footprint of existing technologies.

Some of these technology options include:

1. Cooling tower energy consumption optimization
2. Chiller Plant energy consumption optimization
3. Coke Oven Gas (COG) Consumption reduction by installing tail gas cleaning system
4. By-product fuel gas optimization in a steel industry
5. Integrating cutting-edge technologies like additive manufacturing and Artificial Intelligence, to make products and production smarter and more sustainable

Development of alternative building materials to steel and cement is an important research priority, which can reduce emissions from both industry and the built environment. Alternative cement chemistries (i.e., not based on limestone) could provide a low-carbon solution for cement; however, extensive testing is required to provide the construction industry with the necessary confidence for wide-scale acceptance.

3.3 Sustainable Bioresource & Marine Biotechnologies to Reduce Emissions

Marine bioresources such as Micro- and Macroalgae are getting attention due to their potential to capture the carbon(C) to mitigate the GHG emission and climate change. Exploration the role of managed ecosystems of marine bioresource in mitigating climate change by promoting carbon sequestration and storage and by buffering against uncertainty in management, environmental fluctuations, directional change, and extreme events will be considered. Marine bioresources are a viable low-tech, cost-effective adaptation strategy that would yield multiple co-benefits from local to global scales, improving the outlook for the environment and people into the future. Oceans are a major reservoir of carbon sink, either through absorption of carbon dioxide from the atmosphere or assimilation of inorganic carbon.

3.4 Gaps in Research and Innovation

Gaps in Industrial Long-Term Transitions

There are several structural issues related to industrial long-term transitions. These include the increased speed of technological and organizational change, the impact of general-purpose technologies (such as ICT and AI), the diffusion of innovation, challenges arising from the globalization of technologies and the role of technology in profound socio-economic transitions required by ambitious climate mitigation and adaptation. Some of the major gaps in technology, development and innovation related to climate mitigation and adaptation with respect to different industrial elements are listed in the table below:

Table 3.3 Gaps in Industrial Long-Term Transitions

Element	Gaps
Improving Energy Efficiency	• CAPEX requirement for energy efficiency projects (especially MSMEs) • R&D cost to innovate new technologies
Sustainable Mobility Technologies	• Lack of Infrastructure, technology standards, data standards and Guidelines
Enhance material efficiency and recycling	• Industry needs sector specific solutions to address waste – budgets need to be allocated to pursue R&D • As India transitions to a clean technology frontier, there is proliferation of new technologies and products with associated waste issues that need to be urgently addressed
Green hydrogen technology and infrastructure	• Costs of production are currently high, making all green hydrogen-based products more expensive than fossil fuel-based alternatives. • Transporting and storing hydrogen is costly, and significant build-out of infrastructure is required to bring down the costs of delivered hydrogen. • IPR clearance for the technologies (e.g., Electrolysers)
Hard-to-abate sectors	• High financial costs of implementation of new technologies and alternate fuels (NG, H_2 etc.) • Hydrogen technologies still require R&D and are economically not viable • Lack of financing for R&D, piloting and demonstration of Hydrogen based technologies

MSMEs	• Financing the MSMEs sector • Availability of commercial technologies • Unskilled workers

Several technologies to achieve energy productivity improvement are not yet commercially ready. The steel and plastics sectors face the problem of "downcycling" due to contamination of the primary material by other materials (copper for steel, additives for plastics), limiting the increase of recycling rates. Accelerating development of key technologies is therefore vital (chemical recycling of plastics, better collection and dismantling processes, design for disassembly). High upfront investment costs in infrastructure and higher costs of zero-carbon feedstock are strong impediments to the deployment of energy efficient and material-efficient environments. Many industries (e.g., cement, plastics) are so fragmented that incentives to build an end-to-end circular and efficient value chains are ineffective. Collaboration across the value chain and between the private and public sector is key to build synergies and support a comprehensive innovation and deployment agenda (Agrawal & Sonkusare, 2021).

Chapter 4 ADAPTATION AND RESILIENCE

Development and growth are the first lines of adaptation and resilience for developing countries. Strengthening basic infrastructure such as sanitation systems, irrigation networks, and disaster resilient buildings, as well as institutional infrastructure such as disaster response teams are pre-requisites for successful adaptation and resilience. These cannot be achieved in the absence of rapid growth and development and must also be facilitated by adequate international financial support for adaptation.

As a developing nation, India is facing several socio-economic challenges, which contribute to the vulnerability of its population to climate impacts. Building resilience implies addressing specific vulnerabilities as well as raising incomes to bolster the capabilities of individuals and communities to adapt to long-term changes in the climate. Similarly, raising farmer incomes is necessary to strengthen farmers' capacity and allow them the flexibility to adapt to changes in their micro-climates. The remainder of this chapter reviews climate impacts in India, adaptation strategies, and linkages between adaptation and mitigation.

4.1 Climate Change Impacts in India

India has a diverse geography with landscapes varying from snow-capped mountain ranges to deserts, plains, hills, plateaus, coastal regions and islands. The diverse geography of India manifests varied climate regimes ranging from continental to coastal, from extremes of heat to extremes of cold, from extreme aridity and negligible rainfall to excessive humidity and torrential rainfall. India's climate is significantly influenced by the presence of the Himalaya and the Thar Desert. India receives nearly 80% of its annual rainfall during the southwest monsoon season of June to September. Rainfall distribution and intensity have a significant impact over different socio-economic sectors, especially agriculture and hydrology, besides impact on other aspects of various ecosystems.

For India, 2019 was the seventh warmest year on record since 1901, and 11 out of 15 warmest years were recorded during the fifteen years from 2005 to 2019. The duration of heat waves over central and north-west India has increased by about five days over the past 50 years (MoEFCC, 2021). India's average surface air temperature has risen by around 0.7°C during 1901–2018, largely on account of GHG-induced warming, and is estimated to rise by 2.0-2.8°C under Representative Concentration Pathway (RCP) 4.5 relative to the recent past (1976-2005 average), by the end of the century (Krishnan et. al., 2020). The steric sea level rise in the North Indian Ocean by the end of the century is projected to be 300mm relative to average over 1986-2005 under the RCP 4.5 scenario (Krishnan et. al., 2020).

Alongside such physical impacts, several expected impacts are projected to affect vulnerable ecosystems and human-managed systems, an illustrative set of which are summarized in Table 4.1.

Table 4.1 Illustrative list of expected climate impacts and associated vulnerabilities

Human-managed systems and ecosystems	**Illustrative expected impacts and associated vulnerabilities**
Agriculture	• Rain-fed rice yields in India are projected to reduce marginally (<2.5%) in 2050 and 2080 and irrigated rice yields by 7% in 2050 and 10% in 2080 scenarios. (PIB, 2021c). • Wheat yield may reduce by 6-25% in 2100 and maize yields by 18-23%. (PIB, 2021c). • Impacts on production of wheat, mustard and chickpeas in the Indo-Gangetic plains in the rabi season. (Kumar and Viswanathan, 2019). • Increasing soil erosion, crop water requirement and land degradation. (Kumar and Viswanathan, 2019).
Water	• Substantially altered water flow in Himalayan rivers – increased short-term stream flow but long-run downstream dry-season shortages (Srinivasan, 2019). • Increase in the annual and summer monsoon mean rainfall, as well as frequency of heavy rain occurrences over most parts of India during the twenty-first century. (Krishnan et. al., 2020).
Coasts and marine systems	• High risk of coastal inundation along parts of the east coast. (Krishnan et. al., 2020) • Phytoplankton have reduced by up to 20% in the Indian Ocean as a result of ocean warming (Roxy et. al., 2016). • Vulnerability to strong storm surge activity due to sea-level rise coupled with unusually severe (albeit less frequent) cyclonic activity (Arthur, 2019).
Himalayan ecosystem	• Rise in surface air temperature over the Hindu-Kush Himalaya (HKH) region by 2.2-3.4°C by the end of the century (RCP4.5). (Krishnan et. al., 2020). • Significant decline in snowfall and glacier retreat over several regions of the HKH, except in the Karakoram Himalayas. (Krishnan et. al., 2020). • Hydrological and agricultural impacts in the HKH region. (Krishnan et. al., 2020).
Forestry and grasslands	• 18-28 % forests grids are expected to be impacted by projected climate change under different emission scenarios in the short (2030s) and long (2080s) term. (MoEFCC, 2021). • Wildfires are projected to increase, although estimates vary significantly. About 36% of country's forests are highly prone to fires. (MoEFCC, 2021). • Encroachment of woody-shrubs into grassland biomes, impacting wildlife species specialized to living on grasslands. (MoEFCC, 2021). • Loss of habitat for particular species such as the grizzled giant squirrel (Ratufa macroura), the snow leopard (Panthera uncia), the blue sheep (Pseudois nayaur), and the Nilgiri tahr (Nilgiritragus hylocrius). (Lele and Krishnaswamy, 2019).

Extreme weather events	• Increase in frequency, spatial extent and severity of droughts, while flood propensity is projected to increase over the major Himalayan river basins (Krishnan et al., 2020). • Increase in the frequency of extreme precipitation events especially over the central and southern parts. (Krishnan et. al., 2020).

4.2 India's adaptation strategies

4.2.1 Adaptation actions and priorities

India is undertaking a variety of adaptation actions across sectors and scales. A brief account of India's current adaptation actions and goals are presented in India's first NDC and its Third Biennial Update Report to the UNFCCC. A sample list of key actions (policies, missions, plans, projects) is presented in Table 4.2 below.

Table 4.2 Key existing adaptation actions.

Category	Key Institutions/Initiatives/Policies/Programmes
National Action Plan on Climate Change	National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustainable Agriculture, National Mission for Sustaining the Himalayan Ecosystem, National Mission for a Green India, National Mission on Strategic Knowledge for Climate Change
Agriculture	Mission for Integrated Development of Horticulture, Pradhan Mantri Krishi Sinchayee Yojana, National Innovations in Climate Resilient Agriculture (NICRA), National Agroforestry Policy (NAP), National Crop Insurance Programme, National Mission for Sustainable Agriculture (NMSA)
Water	Namami Gange programme, Jal Jeevan Mission, National Water Policy
Disaster Management	National Disaster Management Plan (NDMP), National Disaster Relief Fund, National Disaster Management Authority
Health	National Action Plan on Climate Change and Health
Coastal Regions and Islands	Environmental and Social Management Framework (ESMF), Coastal Regulation Zones/Island Protection Regulations, Integrated Coastal Zone Management Programme
Ecosystems	Schemes for conservation of corals and mangroves; Wetlands (aquatic ecosystems)
Cities	Atal Mission for Rejuvenation and Urban Transformation, Smart Cities Mission, National Mission for Sustainable Habitat
Sub-national action	State Action Plans on Climate Change, Heat Action Plans in leading cities, Tripura Forest Environmental Improvement and Poverty Alleviation Project, Tamil Nadu Climate Change Mission
Cross-cutting	National Adaptation Fund for Climate Change, Mahatma Gandhi National Rural Employment Guarantee Scheme, India Cooling Action Plan, National Green Highways Mission

Source: *(MoEFCC, 2021) and (Patra, 2016)*

Alongside actions by the Indian State across scales, various stakeholders participate in delivering adaptation in practice through adaptation projects and local initiatives. The National Adaptation Fund for Climate Change (NAFCC) was established to support adaptation activities in the States and Union Territories (UTs) of India that are vulnerable to the adverse effects of climate change.

The India Cooling Action Plan (ICAP) provides an integrated vision towards cooling across sectors encompassing, inter alia, reduction of cooling demand, refrigerant transition, enhancing energy efficiency and better technology options by 2037-38 through forging synergies with on-going programmes/ schemes of the Government. The ICAP seeks to: (i) reduce cooling demand across sectors by 20% - 25% by 2037-38; (ii) reduce refrigerant demand by 25% - 30% by 2037-38; (iii) Curtail cooling energy requirements by 25%-40% by 2037-38; (iv) recognize “cooling and related areas” as a thrust area of research under National S&T Programme; (v) organise training and certification of 100,000 servicing sector technicians by 2022-23, synergizing with Skill India Mission. These actions will have significant climate benefits (PIB, 2019c).

4.2.2 Adaptation Finance

India’s adaptation finance needs are substantially challenging to quantify. In its NDC in 2015, India had put forward a preliminary estimate that it would need around USD 206 billion (at 2014-15 prices) between 2015 and 2030 for implementing adaptation actions in agriculture, forestry, fisheries, infrastructure, water resources and ecosystems.

A more recent analysis by a sub-committee of India’s Ministry of Finance has estimated that the cumulative total expenditure for adapting to climate change in India would amount to INR 85.6 trillion (at 2011-12 prices) by the year 2030 (DEA, 2020). ‘Financial needs’, as defined in this analysis, focus on the linkages between adaptation, SDGs and basic needs, and may therefore differ from the definitions typically used for adaptation finance. Climate change impacts are expected to worsen with the passage of time. Hence, India’s adaptation needs will have to be intensified and so the adaptation costs will increase beyond official estimates.

While individual estimates are subject to uncertainty, the broad trend is clear that the adaptation finance required is likely to be significantly higher than current adaptation finance flows. The 2021 UN Adaptation Gap Report found that estimated adaptation costs in developing countries were 5-10 times greater than current public adaptation finance flows, and that the adaptation gap was widening. Urgently increasing adaptation finance flows to India is a crucial requirement for India to be able to meet its long-term sustainable development and low emission growth goals.

4.2.3 Loss and Damage

A wide range of estimates exist regarding the economic losses and damages caused by climate impacts to the Indian economy. Isolating the climate component of total losses due to extreme weather events continues to remain a challenge. Developed countries fulfilling their commitment in providing adaptation finance to minimise further losses, and adequate compensation for unavoidable loss and damage, is critical for developing countries.

4.2.4 Governance and Institutional Arrangements for Adaptation

India's governance approach to adaptation operates within the division of powers laid out in the Constitution of India and long-standing practices in India's fiscal federalism. Adaptation responsibilities are divided between three levels of Government – the National Government, the States, and local Governments. Long-term, sustainable reductions in climate vulnerability therefore require significant coordination between these levels.

Responsibility for several core adaptation areas rests with India's States – areas such as water, agriculture, health, and managing local Government. This has led to a diversity of adaptation-related policies across the States. Such actions are often listed in State Action Plans on Climate Change, drawn up by the States, which list local vulnerabilities and policy actions to address them. Box 4.1 illustrates the adaptation approaches taken by States in relation to managing heatwaves.

Box 4.1 Sub-national Heat Action Plans

In order to build resilience against increasing heat stress, some cities and States in India have introduced Heat Action Plans (HAPs), which are now proliferating rapidly. HAPs are comprehensive extreme heat warning systems and preparedness plans. There are now 23 State level HAPs at various stages of development (NRDC, 2022), with support from the IMD and India's National Disaster Management Authority (NDMA). HAPs are examples of sub-national innovation for adaptation.

Existing HAPs are tailored to State and city contexts. Most States' HAPs include short-term responses to extreme heat as well as building long-term capacity and awareness against heat stress. (Hess et. al., 2018).

At the same time, Indian federal practice vests the National Government with significant financial and agenda-setting powers that influence the adaptation policy landscape. Centrally-Sponsored Schemes, have emerged as an important channel through which vulnerabilities are addressed. Additionally, several of the climate-specific adaptation Missions under the NAPCC are implemented with key participation of States, including the National Water Mission, the National Mission for Sustainable Agriculture, and the National Mission for Sustainable Habitats.

The National Adaptation Fund for Climate Change is an important source of funding adaptation governance, and was set up to disburse project-specific grants to address State-determined vulnerabilities. The Finance Commission, tasked with recommending the devolution of monies to the States, has also increasingly taken environmental conditionalities into account, focusing on improving disaster-preparedness among other climate-related subjects.

Finally, the Central Government has also played an increasingly evident, and important, role in establishing national frameworks (see Table 4.2) and assessments that inform State adaptation policies. The National Disaster Management Authority (NDMA) has, for example, led the creation of guidelines for several different types of extreme events, from heatwaves to glacial lake outburst flooding, while national institutions like the Department of Science and Technology and the Indian Institute of Tropical Meteorology make disaggregated information about climate vulnerability available to sub-national actors.

4.3 Interlinkages between Mitigation, Adaptation, and Development

Both mitigation and adaptation strategies are crucial to manage climate change, but neither approach is sufficient by itself. Mitigation, at the global level, reduces the most severe of potential climate hazards first, in terms of both occurrences and magnitude. Adaptation activities, best targeted at the local level, increase the ability to cope with climate hazards of lesser magnitude at the lower end of the potential range. The crux of mitigation clearly lies in the developed world, with high per capita emissions and continuing over-use of the global carbon budget beyond their fair share. On the other hand, the burden of adaptation is significantly higher for developing countries, which have historically and in the present contributed little to global warming.

There are potential interlinkages between the climate change impacts, mitigation and adaptation activities, and the developmental outcomes, recognition of which can help identify climate-resilient development pathways.

Adaptation is already being mainstreamed in many development actions in India across sectors and scales, (Singh et al., 2014). India is pursuing both hard (e.g., disaster resilient infrastructure) and soft forms of adaptation (capacities, institutions, knowledge sharing mechanisms) within the ambit of its development projects.

While climate-resilient development is a normative aspiration, it is extremely challenging in practice for developing countries. Many trade-offs exist between adaptation, mitigation and development. The extent to which synergies can be feasibly pursued are constrained by availability of climate finance. Further, pursuing climate-resilient development pathways also depends on future climate risks, socio-economic inequalities, national and subnational circumstances (resources, vulnerability, culture, and values), adaptation responses and access to a fair share of the global carbon budget. Foregrounding the needs of vulnerable and marginalized communities, equity, and social justice through integrated planning processes are important for achieving climate-resilient development.

Chapter 5 LiFE - LIFESTYLE FOR ENVIRONMENT

LiFE, Lifestyle for Environment was announced by Prime Minister Narendra Modi, at COP26 in Glasgow on 1st November 2021 in India's National Statement. Speaking on the occasion, Prime Minister said: "This One-Word, in the context of climate, can become the basic foundation of One World. This is a word - LiFE…L, I, F, E, i.e., ***Li***festyle ***F***or ***E***nvironment. Today there is a need for all of us to come together, with collective participation, to take Lifestyle For Environment (LiFE) forward as a campaign. This can become a mass movement of Environmental Conscious Life Style. What is needed today is Mindful and Deliberate Utilization, instead of Mindless and Destructive Consumption. These movements together can set goals that can revolutionize many sectors and diverse areas such as fishing, agriculture, wellness, dietary choices, packaging, housing, hospitality, tourism, clothing, fashion, water management and energy."

The underlying philosophy of LiFE has its roots in India's ancient saying:, प्रकृतिः रक्षति रक्षिता, (Nature protects if she is protected), that has been inscribed as the motto on the seal of India's Ministry for the Environment, Forests and Climate Change. LiFE aims to promote globally the practice of a lifestyle that is synchronous with nature and does not harm it, by individuals and communities. It proposes to bring about a fundamental change in both the way we produce and the way we consume. India has updated the first of its Nationally Determined Conclusions to include LiFE as follows: "India will put forward and propagate a healthy and sustainable way of living based on its traditions and the values of conservation and moderation, including through a mass movement for LiFE, as a key to combating climate change".

Subsequently India's Prime Minister, in his address to the World Economic Forum, referring to India's commitment to combating climate change, further elaborated on this theme.

" 'Throw away' culture and consumerism have made the climate challenge more serious. It is very important to rapidly shift today's 'take-make-use-dispose', economy towards a circular economy. The same spirit is at the core of the idea of Mission LiFE that I discussed at COP26. LiFE – means Lifestyle for Environment, a vision of such a Resilient and Sustainable Lifestyle that will be useful in not only dealing with Climate Crisis but also with futuristic unpredictable challenges. Therefore, it is important to transform Mission LiFE into a global mass movement. A public participation campaign like LiFE can be made into a big base for, P-3 'Pro Planet People' ".

Mission LiFE was launched by Hon'ble Prime Minister and Mr. Antonio Guterres, Secretary General at Ekta Nagar, Gujarat, India on October 20, 2022 as a global initiative to combat climate change and make it a people's movement across the world.

5.1 Three Core Shifts in Mission LiFE

As a global programme, Mission LiFE envisions three core shifts in our collective approach towards sustainability. These are:

1. Change in Demand (Phase I): Nudging individuals across the world to practice simple yet effective environment-friendly actions in their daily lives.

2. Change in Supply (Phase II): Changes in large-scale individual demand are expected to gradually nudge industries and markets to respond and tailor supply and procurement as per the revised demands.
3. Change in Policy (Phase III): By influencing the demand and supply dynamics of India and the world, the long-term vision of Mission LiFE is to trigger shifts in large-scale industrial and Government policies that can support both sustainable consumption and production.

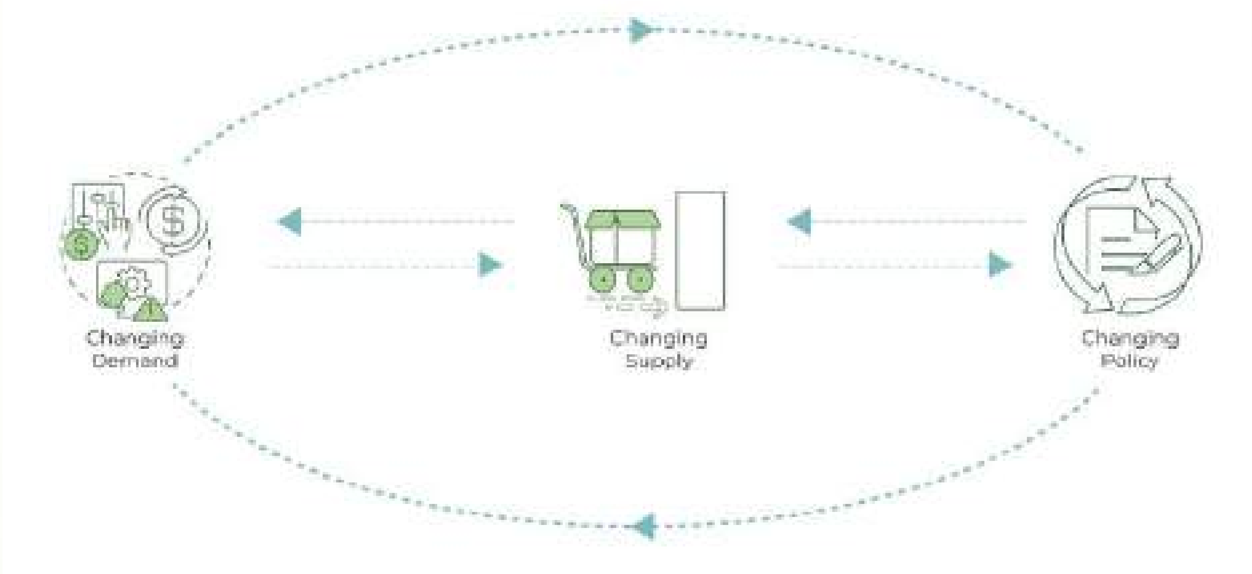


Figure 5.1 Inter-relationship between three Core Shifts in Mission LiFE

Source: *NITI Aayog, 2022a.*

In 2022-23, Mission LiFE will focus on Phase I, Change in Demand, by nudging individuals, communities and institutions to practice simple environment-friendly actions (LiFE actions) in their daily lives. In view of Mission LiFE being launched in the 75th year of India's independence, a comprehensive and non-exhaustive list of **75 individual LiFE actions** across **7 categories** is identified such that most actions are:

1. Specific and measurable
2. Easy to practice by individuals, communities and institutions, with minimal supply-side dependencies
3. Non-disruptive to ongoing economic activity, and, in fact, promoting economic activity in the foreseeable future

The identified 7 categories are:

1. Energy consumption
2. Water consumption
3. Reduced consumption of single use plastic
4. Adopting sustainable food systems
5. Reduction of wastes (Swachhata actions)
6. Adoption of healthy lifestyles
7. Reduction in e-waste

5.2 LiFE and Sustainable Development Goals (SDGs)

The SDGs, focused on sustainable cities and communities (SDG 11), responsible production and consumption (SDG 12), climate change (SDG 13), life on land (SDG 15), and life under water (SDG 14), all promote the sustainable use of natural resources. Further, bold environmental action could create large scale employment by 2030 (SDG 8: Decent Work and Economic Growth). SDG 12 entails decoupling economic growth and environmental degradation and demands more efficient and environmentally friendly management of resources, including improving energy efficiency, sustainable infrastructure, access to basic services, and providing green and decent jobs to ensure a better quality of life for all. The societal responsibility towards SDG 12 goes beyond businesses, to involve individual consumers as active participants in the process of achieving this goal. Given the global commitment to achieving the SDGs by 2030, it is important to note that Mission LiFE contributes directly and indirectly to almost all the SDGs.

5.3 Impact of Collective Action – Lifestyle for Environment

When estimated against a business-as-usual scenario the impact of LiFE actions globally can be significant. According to the United Nations Environment Programme (UNEP), if 1 out of 8 billion people worldwide adopt environment-friendly behaviours in their daily lives, global carbon emissions could drop up to 20%. The 2020 UNDP report 'The Next Frontier: Human Development and the Anthropocene' says that, "Humans wield more power over the planet than ever before. In the wake of COVID-19, record-breaking temperatures, and spiraling inequality, it is time to use that power to redefine what we mean by progress, where our carbon and consumption footprints are no longer hidden".

India has rich experience in implementing large-scale behavioural change programmes. While the world is focusing on policy and regulatory measures to address the environmental crisis, India has demonstrated success in harnessing the power of collective action to solve complex problems. LiFE builds upon India's environment-friendly culture and traditional practices, noting that India's per capita annual emissions are only a third of the world average (MoEFCC, 2021).

Taking LiFE forward as a global mission, India has, in a global call for ideas and papers, invited Ideas and research proposals from leading global scholars on how environment-friendly actions can be adopted by individuals, communities and institutions in a measurable and attributable manner. Partnering with other countries, MoEFCC and the Ministry of External Affairs, with the support of NITI Aayog, will coordinate efforts to continually identify and build capacity of countries worldwide to implement Mission LiFE for their respective populations.

Preparing a LiFE Compendium of Global Best and Traditional Practices, the NITI Aayog and MoEFCC, in partnership with United Nations India, will create a comprehensive repository of traditional and contemporary best practices from around the world that facilitate the adoption of environment-friendly lifestyles by individuals and communities.

Chapter 6

INTERNATIONAL COOPERATION

6.1 Strengthening global climate action

India has demonstrated a longstanding commitment to multilateral cooperation, which is critical to addressing the global climate challenge (MEA, 2018a). While India's historical responsibility for climate change – both in terms of its cumulative emissions contribution and its per capita emissions contribution – is low compared to that of developed nations and in absolute terms (See Section 1), it has nonetheless contributed substantially to global climate action. As the Indian economy continues to grow rapidly, meeting India's developmental needs will require scaling up infrastructure development and energy use. However, as a responsible global actor, India will ensure efficient and low-carbon growth that will allow for achievement of its development goals and contribute to mitigating greenhouse gas emissions, in accordance with its Nationally Determined Contribution (NDC) under the Paris Agreement.

As a developing country representing ~17% of the world's population, India has taken significant steps to implement climate mitigation measures to further global climate action (MEA, 2021e). Despite its development challenges, India is one of the few large economies on track to achieve its climate mitigation commitments under the Paris Agreement (MEA, 2021c). In addition, at COP26, Prime Minister Modi announced the *Panchamrit* ('five nectar elements') pledges, a series of new and forward-looking climate pledges to enable progress on India's energy transition and laying the groundwork for net-zero emissions by 2070 (MEA, 2021e). India is working with other countries to strengthen multilateral initiatives and foster strategic bilateral partnerships to meet these climate goals. It is also supporting other developing countries to do the same by advocating for a fair international climate regime that acknowledges the principle of equity and CBDR-RC under the UNFCCC and provides vulnerable populations with access to financial and technical assistance to meet their climate obligations without sacrificing their development and poverty alleviation goals.

6.2 International Leadership and Collaboration

6.2.1 Developing multilateral climate initiatives and platforms

Climate change is a global collective action problem that can only be tackled through multilateralism and international cooperation (MEA, 2021c). As a responsible international actor, India has recently developed several forward-looking and participatory global initiatives, partnerships, and coalitions to combat climate change and foster greater collaboration. These multilateral initiatives have focused largely on the experiences of vulnerable developing countries such as India, where climate impacts pose developmental and infrastructural risks to populations and livelihoods (MEA, 2021b).

1. Through the creation of the International Solar Alliance (ISA), a dedicated platform for cooperation between Governments, multilateral organizations, and industry, India together with France helped strengthen global cooperation on solar energy. The ISA aims to increase the use and quality of solar energy to meet energy needs in an affordable manner (MEA, 2018a). The ISA, to which India is providing financial, capacity-building and organizational assistance, is among the fastest-growing international organisations, with 107 signatory countries and 87 countries that have ratified the Framework Agreement (MEA, 2021b; ISA, 2022). In 2018, the Indian government announced

nearly USD 1.4 billion worth of lines of credit (LoCs) covering 27 solar projects in 15 countries, which are under various stages of implementation (MoEFCC, 2021). At COP26 in Glasgow, India and the United Kingdom also announced the first international network of interconnected transnational solar grids, called the Green Grids Initiative-One Sun One World One Grid (GGI-OSOWOG) (ISA, 2021). The ISA will continue to mobilize member countries to address technical, financial and capacity-building barriers to the deployment of solar energy (MEA, 2021a).

2. India launched the Coalition for Disaster Resilient Infrastructure (CDRI) at the 2019 Climate Summit. More than 25 countries – many from the G20 – and eight international organizations have joined the CDRI (CDRI, 2022). This international partnership of National Governments, UN agencies, Multilateral Development Banks, the private sector, and knowledge institutions will promote the resilience of new and existing infrastructure systems to growing climate risks and disasters. The Government of India has allocated US$70 million to support the work of the CDRI (MEA, 2021b). At COP26, India co-launched the Infrastructure for Resilient Island States (IRIS) Initiative, which aims to improve the resilience of infrastructure to climate change and disaster risk in Small Island Developing States (SIDS), strengthen knowledge and partnerships to integrate resilience, and promote gender equality and disability inclusion through resilient infrastructure (CDRI, 2021).
3. In the spirit of south-south cooperation, the India-UN Development Partnership Fund aims to contribute to developing countries' efforts to realise the 2030 Agenda for Sustainable Development Goals, including on Climate Action. Established in 2017, the fund continues to support countries in the Pacific Islands, Africa, and the Caribbean with climate early warning systems, solar home systems, solar pumps, and projects to repair damage due to climate-induced weather events. The fund has supported projects in 48 countries for various SDGs through a US$150 million multi-year pledge by the Government of India (MEA, 2021b).
4. At the 2019 Climate Summit, India and Sweden launched the Leadership Group on Industry Transition (LeadIT), supported by the World Economic Forum and the Stockholm Environment Institute. This initiative provides a platform for Governments and the private sector to identify low-carbon business opportunities, cooperate on net-zero technology innovation and exchange knowledge on sectoral roadmaps for hard-to-abate sectors (MEA, 2019). Currently, the LeadIT initiative includes 19 industry leaders and 18 member countries (MEA, 2021b; LeadIT, 2022).
5. These collaborations reflect the continuation of India's longstanding commitment to global climate cooperation under the UNFCCC. Reflecting this commitment, India is also a signatory to numerous international agreements, conventions, protocols, and treaties on climate and environmental issues (UNEP, 2005).

6.3 Towards an Equitable Global Climate Response

The United Nations Framework Convention on Climate Change establishes that "the largest share of historical and current global emissions of greenhouse gases has originated in developed countries"; that "per capita emissions in developing countries are still relatively low" and that the "share of global emissions originating in developing countries will grow to meet their social and development needs" (United Nations, 1992). The principles and commitments of the Convention also establish that climate action should be determined on the basis of equity and in accordance with common but differentiated responsibilities and respective capabilities, with adequate consideration of socioeconomic conditions, development priorities, and national objectives and circumstances (UN, 1992). Based on climate science, the operationalization of equity and climate justice requires that all countries have access to an equitable and fair share of the global carbon budget.

BOX 6.1: India's International Climate Actions

India has taken leadership in launching Coalition for Disaster Resilient Infrastructure (CDRI) to promote resilience of new and existing infrastructure systems to climate and disaster risk. This currently has membership of 31 countries including India and US, and 8 international organisations.

The International Solar Alliance (ISA) is also a prime example of how positive and constructive global climate action can be taken forward through partnership. The ISA currently has 108 countries as signatory, the latest being the United States, Norway, Hungary and Panama that joined the Alliance.

India and Sweden are leading the industry (LeadIT) transition track to promote voluntary action for low carbon transition in hard to abate industry sectors, following the original invitation by the United Nations Secretary General.

As a climate-vulnerable country with a limited historical contribution to causing climate change, and low historical and current per-capita emissions, India has made significant progress towards global climate action by reducing the emissions intensity of its economic activities and enabling a clean energy transition. India's stated climate goals can be fully realized only if financial assistance, low-carbon technology transfer and capacity-building needs are met under the provisions of the UNFCCC and its Paris Agreement. Developed nations must take the lead not only in emissions reductions, but in developing international climate finance and technology arrangements that respond to gaps in available resources in the developing world.

India can neither afford to defer the unmet energy and human development requirements of its population, nor remain unresponsive to the threat that climate change poses to its development goals. Predictable, sustained and adequate climate finance would accelerate progress towards India's climate and development goals (MEA, 2018b; 2021d).

6.3.1 Improving Access to Climate Finance

In this context, there remain serious shortcomings in the scope, scale, and speed of the climate finance made available to developing countries from developed countries, multilateral development banks, and multilateral climate funds, including UNFCCC funds (MoEFCC, 2021). There are also shortcomings in defining, tracking, and reporting international climate finance flows in standardized ways (MoEFCC, 2021). In addition, the climate finance available to the developing world is inadequate to meet either mitigation or adaptation needs as set out in NDC, and existing financial resources tend to be skewed towards mitigation rather than adaptation, with adverse implications for developing countries facing climate-induced disasters (MoEFCC, 2021). In the past, India has repeatedly drawn attention to these issues (DEA, 2015; (MoEFCC, 2021)).

Raising India's climate ambitions will require new, additional, and climate-specific financial resources and support. Furthermore, India is committed to global cooperation on developing transparent climate finance processes and equitable market mechanisms to fill financing gaps. Initiatives aimed at scaling up sustainable investments, particularly in climate adaptation, will play an important role in financing long-term low-carbon development pathways. India will urge the global community to disseminate information on best practices related to climate finance, closely track international climate finance flows though standardized processes, and identify barriers and opportunities to scale up international climate finance in multilateral discussions with other countries. In the absence of a roadmap for climate finance, India and other developing countries will face serious constraints in achieving the climate goals in subsequent updates to NDC (MEA, 2018a). Therefore, it is India's view that the global climate regime should track progress not just on climate mitigation efforts, but on the delivery of international climate finance to developing countries (MEA, 2021e).

6.3.2 Facilitating Technology Transfer, and Support for Losses and Damages

India cannot deploy low-carbon climate technologies at a significant scale unless a facilitative global technology transfer regime is in place, and the incremental and associated costs of these technologies are met from international climate funds. A collaborative international mechanism needs to ensure that barriers such as intellectual property rights are lowered to facilitate technology transfer from developed to developing countries. Through engagement with multilateral platforms, India will seek to increase access to low-carbon technologies, including solar photovoltaics, offshore wind equipment, LED bulbs, efficient air conditioners, low-carbon iron and steel manufacturing technologies, biofuels and hydrogen technology (MoEFCC, 2021). India will aim to stimulate markets for clean energy technologies emerging in India, with investment pathways developed in accordance with international best practices for research, innovation, and manufacturing in this field. India also aims to support multilateral initiatives to create networks of research institutions working on clean energy technologies and their deployment-related best practices in India and in other countries (MoEFCC, 2021). Enabling low-carbon technologies and emerging scientific fields may require institutions to create global technological standards to encourage production and use. India will also contribute to, and support, such efforts (MEA, 2022).

As climate-induced heat waves, floods, cyclones, and irregular rainfall patterns increase in frequency and intensity over South Asia, India will experience infrastructural losses and damages due to climate change. India looks forward to furthering a productive global dialogue on a potential framework with which to address developing countries' responses to losses and damages, within the scope of the provisions and principles established under the UNFCCC (PIB, 2019a).

6.3.3 Building Cooperative rather than Exclusionary Global Processes

India is committed to advancing common sustainable development goals. It also believes that international cooperation is necessary to support developing economies through finance and technology and win-win strategies. Coordinated actions that advance technologies while expanding market access for goods from developing countries are important for a smooth transition, whereas exclusionary and discriminatory regulations such as border carbon taxes may raise barriers to the transition in developing countries (MEE, 2021). India is committed to the principles for cooperation under the United Nations Framework Convention on Climate Change, and the Paris Agreement negotiated under the Framework, and reiterates the importance of meeting the nationally determined contributions under the Agreement rather than building parallel tracks for pursuing climate progress (PIB, 2021d).

Apart from cooperation over climate finance, joint projects, inter-ministerial dialogues, channels for sharing knowledge and experience, joint development of global technology standards, building networks of research institutions, and strategic technology partnerships are some of the potential avenues for strengthening international cooperation that India believes can enable an equitable and sustainable transition (PIB, 2021e). Both non-market and market mechanisms such as agreed under Article 6 of the Paris Agreement will play an important role in India's engagement with the global community on climate change going forward (PIB, 2019b).

List of Abbreviations

AFR	Alternate Fuels and Raw Materials
AIPA	Apex Committee for the Implementation of the Paris Agreement
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
AUSC	Advanced Ultra Supercritical Coal Technology
BAU	Business as Usual
BEE	Bureau of Energy Efficiency
Bio-PNG	Bio Piped Natural Gas
BoM	Bill of Materials
BRSR	Business Responsibility and Sustainability Report
BURs	Biennial Update Reports
CAGR	Compound Annual Growth Rate
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
CAPEX	Capital Expenditure
CBDR-RC	Common But Differentiated Responsibilities and Respective Capabilities
CBG	compressed biogas
CCS	Carbon capture and storage
CCUS	Carbon Capture Utilisation and Storage
CDRI	Coalition for Disaster Resilient Infrastructure
CEA	Central Electricity Authority
CEEW	Council on Energy, Environment and Water
CEM	Climate Equity Monitor
CERC	Central Electricity Regulatory Commission
CII	Confederation of Indian Industry
COG	Coke Oven Gas
CORE	Central Organization for Railway Electrification
CPHEEO	Central Public Health & Environmental Engineering Organization
CSCAF	Climate Smart Cities Assessment Framework
c-Si	crystalline Silicon
CSIR	Council of Scientific and Industrial Research
DAE	Department of Atomic Energy
DCR	Development Control Regulations
DEA	Department of Economic Affairs
DISCOM	Distribution Company
DME	Dimethyl ether
DST	Department of Science & Technology
ECBC	Energy Conservation Building Code
ECCC	Executive Committee on Climate Change
EMU	Electric Multiple Unit

ESG	Environmental, Social and Governance
ESMF	Environmental and Social Management Framework
ESO	Energy Storage Obligations
EVs	Electric Vehicles
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FAO	Food and Agricultural Organisation
FDI	Foreign Direct Investment
FFPMS	Forest Fire Prevention and Management Scheme
FICCI	Federation of Indian Chambers of Commerce and Industry
FSI	Forest Survey of India
GA	Green Ammonia
GCF	Green Climate Fund
GDP	Gross domestic product
GGI-OSOWOG	Green Grids Initiative One Sun One World One Grid
GH	Green Hydrogen
GHG	Greenhouse Gas
GIM	Green India Mission
GIS	Geographic Information System
GRIHA	Green Rating for Integrated Habitat Assessment
GVA	Gross value added
HAPs	Heat Action Plans
HDI	Human Development Index
HFFA	Hydro Processed Esters and Fatty Acids
HKH	Hindu Kush Himalaya
HPC	High Performance Computing
ICAP	India Cooling Action Plan
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
IDSC	Inter Departmental Steering Committee
IEA	International Energy Agency
IGBC	Indian Green Building Council
IGCC	Integrated Gasification Combined Cycle
IIP	Indian Institute of Petroleum
ILO	International Labour Organization
INR	Indian Rupee
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IRIS	Infrastructure for Resilient Island States

ISA	International Solar Alliance
IT	Information Technology
IUCN	International Union for Conservation of Nature
IWMP	Integrated Watershed Management Programme
JI-VAN	Jaiv Indhan Vatavaran Anukool fasal awashesh Nivaran
LAPs	Local Area Plans
LeadIT	Leadership Group on Industry Transition
LED	Light emitting diode
LEED	Leadership in Energy and Environmental Design
Li -Br	Lithium bromide
LiFE	Lifestyle for Environment
LMV	Light Motor Vehicle
LNG	Liquified natural gas
LoCs	Lines of credit
LPG	Liquefied petroleum gas
LT-LEDS	Low-Term Low greenhouse gas Emission Development Strategies
LULUCF	Land Use and Land Use Change and Forestry
MEA	Ministry of External Affairs
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MNRE	Ministry of New and Renewable Energy
MoC	Ministry of Coal
MoEFCC	Ministry of Environment, Forest and Climate Change
MoF	Ministry of Finance
MoHUA	Ministry of Housing and Urban Affairs
MoP	Ministry of Power
MoR	Ministry of Railways
MoRTH	Ministry of Road Transport & Highways
MoS	Ministry of Steel
MSME	Micro Small and Medium Enterprises
MSW	Municipal Solid Waste
NAFCC	National Adaptation Fund for Climate Change
NAP	National Afforestation Programme
NAP	National Agroforestry Policy
NAPCC	National Action Plan on Climate Change
NBA	National Biodiversity Authority
NBAP	National Biodiversity Action Plan
NDC	Nationally Determined Contribution
NDMA	National Disaster Management Authority
NFP	National Forest Policy

NG	Natural Gas
NHAI	National Highways Authority of India
NICRA	National Innovations in Climate Resilient Agriculture
NITI Aayog	National Institution for Transforming India
NMSA	National Mission for Sustainable Agriculture
NRDC	National Research Development Corporation
NRF	National Research Foundation
NRLM	National Rural Livelihoods Mission
NTFP	Non Timber Forest Products
NUPF	National Urban Policy Framework
NVY	Nagar Van Yojana
OECD	Organisation for Economic Cooperation and Development
OMCs	Oil Marketing Companies
PA	Paris Agreement
PAT	Perform, Achieve and Trade
PIB	Press Information Bureau
PLI	Production Linked Incentive
PLI ACC	Production Linked Incentive Advanced Chemistry Cell
PMAY	Pradhan Mantri Awaas Yojana
PMUY	Pradhan Mantri Ujjwala Yojana
PV	Photovoltaic
R&D	Research & Development
RBI	Reserve Bank of India
RCP	Representative Concentration Pathway
RDF	Refuse derived fuel
RE	Renewable Energy
REDD+	Reducing Emissions from Deforestation and forest Degradation
ROSHANEE	Roadmap of a sustainable and holistic approach to National Energy Efficiency
RPO	Renewable Purchase Obligations
SAF	Sustainable Aviation Fuel
SATAT	Sustainable Alternative Towards Affordable Transportation
SBM	Swachh Bharat Mission
SCADA	Supervisory Control and Data Acquisition
SCM	Smart Cities Mission
SDGs	Sustainable Development Goals
SEBI	Securities and Exchange Board of India
SIDS	Small Island Developing States
SNY	School Nursery Yojana

SPM	Summary for Policy Makers
TACE	Technical Advisory Committee of Experts
TIFAC	Technology Information Forecasting and Assessment Council
TOF	Trees Outside Forests
TPPs	Thermal Power Plants
UJALA	Unnat Jyoti by Affordable LEDs for All
ULBs	Urban Local Bodies
UN	United Nations
UNEP	United Nations Environment Programme
UNEP-DTU	United Nations Environment Programme Danish Technical University
UNFCCC	United Nations Framework Convention on Climate Change
URDPFI	Urban and Regional Development Plans Formulation and Implementation
USD	United States Dollar
UTs	Union Territories
VAM	Vapour absorption/adsorption machines
VGF	Viability Gap Finance

References

Aggarwal, P., Goel, S., Laan, T., Mehta, T., Pant, A., Raizada, S., Viswanathan, B., Vishwamohan, A., Beaton, C. & Ganesan, K. 2022. Mapping India's Energy Policy 2022. International Institute for Sustainable Development. https://www.iisd.org/system/files/2022-05/mapping-india-energy-policy-2022.pdf

Agrawal, A. & Sonkusare, A. 2021. Transforming Innovative Research into a Profitable Technology.NITI Aayog.https://www.niti.gov.in/sites/default/files/2021-09/Transforming-Innovative-research-into-a-ProfitableTechnology.pdf

Ahuja, M. & Soi, U. 2020. The Case for Green Buildings in India. Observer Research Foundation. https://www.orfonline.org/expert-speak/case-green-buildings-india/.

Arthur, R. 2019. Shoring Up: Climate Change and the Indian Coasts and Islands. In India in a Warming World: Integrating Climate Change and Development, edited by Navroz K Dubash, 537–59. New Delhi: Oxford University Press India. https://academic.oup.com/book/35227/chapter/299755793.

Asia Pacific Energy. n.d. Perform, Achieve and Trade (PAT) Scheme. ESCAP Policy Documents Management. Accessed August 8, 2022. https://policy.asiapacificenergy.org/node/3654.

BEE. 2017. Energy Conservation Building Code. Bureau of Energy Efficiency, Ministry of Power, Government of India. https://beeindia.gov.in/sites/default/files/BEE_ECBC%202017.pdf

BEE. 2022. Elements of the Electrification Strategy for India. Bureau of Energy Efficiency, Ministry of Power, Government of India. https://beeindia.gov.in/sites/default/files/Elements%20of%20Electrification%20Strategy%20for%20India.pdf.

BERPD. 2018. Invigorating India's Infrastructural Capabilities: The Essential Element in India's Development Story. Bureau of Economic Research and Policy Development, New Delhi. https://doi.org/10.13140/RG.2.2.35675.41762

Bhagat, R. B. 2018. Urbanization in India: Trend, Pattern and Policy Issues. Working Paper No. 17. International Institute for Population Sciences, Mumbai. https://doi.org/10.13140/RG.2.2.27168.69124

Calice, P. 2021. Greening Public Credit Guarantee Schemes for Net Zero. October 21, 2021. https://blogs.worldbank.org/psd/greening-public-credit-guarantee-schemes-net-zero.

CBRE. 2019. Exploring the Future: India at 2030. https://www.cbre.com/insights/articles/exploring-the-future-india-at-2030.

CDRI. 2021. Launch of 'Infrastructure for Resilient Island States' (IRIS) at COP26. Coalition for Disaster Resilient Infrastructure. https://www.cdri.world/press-releases/launch-infrastructure-resilient-island-states-iris-cop26.

CDRI. 2022. Members of the Coalition for Disaster Resilient Infrastructure (CDRI). Coalition for Disaster Resilient Infrastructure. https://www.cdri.world/members.

CEA. 2022. Executive Summary on Power Sector. Central Electricity Authority. Ministry of Power, Government of India. https://cea.nic.in/wp-content/uploads/executive/2022/06/Executive_Summary_Jun_2022-1.pdf.

CEA. n.d. All India Power Supply Dashboard. Central Electricity Authority. Ministry of Power, Government of India. Accessed October 10, 2021. https://cea.nic.in/dashboard/?lang=en

CERC. 2020. Report on Short-Term Power Market in India: 2019-20. Economics Division, Central Electricity Regulatory Commission, Ministry of Power, Government of India.https://cercind.gov.in/2020/market_monitoring/Annual%20Report%202019-20.pdf.

CII. n.d. MSME: Growth Driver of Indian Economy 2019. Confederation of Indian Industry. https://www.resurgentindia.com/pdf/1145452775MSME%20Growth%20Driver%20of%20Indian%20Economy.pdf

Climate Equity Monitor. n.d. Online Dashboard. M.S. Swaminathan Research Foundation and National Institute for Advanced Studies. https://climateequitymonitor.in/index.html

CORE. n.d. Electrification of Indian Railways. Central Organisation for Railway Electrification. Ministry of Railways, Government of India. https://core.indianrailways.gov.in/

D'Souza, R., & Rana. T. 2020. The Role of Monetary Policy in Climate Change Mitigation, Observer Research Foundation, Issue no. 350. https://www.orfonline.org/wp-content/uploads/2020/04/ORF_IssueBrief_350_MonetaryPolicy-Climate_Change.pdf

Das, S. & Deb, S. 2020. Vehicle-Grid Integration – A New Frontier For Electric Mobility In India. Alliance for an Energy Efficient Economy, New Delhi. https://aeee.in/wp-content/uploads/2020/10/Full-Report-Vehicle-Grid-Integration-AEEE.pdf.

DEA. 2015. Climate Change Finance, Analysis of a Recent OECD Report: Some Credible Facts Needed. Discussion Paper. Ministry of Finance, Government of India. https://dea.gov.in/sites/default/files/ClimateChangeOEFDReport_0.pdf

DEA. 2018. Climate, Climate Change, and Agriculture. In Economic Survey 2017-18. New Delhi: OUP India. Department of Economic Affairs, Ministry of Finance, Government of India. https://mofapp.nic.in/economicsurvey/economicsurvey/pdf/082-101_Chapter_06_English_Vol_01_2017-18.pdf

DEA. 2020. Report of the Sub-Committee for the Assessment of the Financial Requirements for Implementing India's Nationally Determined Contribution (NDC). Department of Economic Affairs, Ministry of Finance, Government of India. https://dea.gov.in/sites/default/files/Sub%20Committee%20Report%20Final.pdf

DEA. 2021. Economic Survey 2020-21: Volume 2. Department of Economic Affairs, Ministry of Finance, Government of India. https://www.indiabudget.gov.in/budget2021-22/economicsurvey/doc/echapter_vol2.pdf

DEA. 2022. Economic Survey 2021-22. Department of Economic Affairs, Ministry of Finance, Government of India. https://www.indiabudget.gov.in/economicsurvey/

Dilip, A., & Kundu, S. 2020. Climate Change: Macroeconomic Impact and Policy Options for Mitigating Risks. Reserve Bank of India Bulletin. Government of India. https://rbidocs.rbi.org.in/rdocs/bulletin/pdfs/1climatechangef7c6ad14719e43daa7fa84c1f8f1cfed.pdf

DST. 2016. Climate Change & Human Health. Department of Science and Technology, Ministry of Science and Technology, Government of India. https://dst.gov.in/sites/default/files/Report_DST_CC_Health.pdf

FAO. 2020. Global Forest Resources Assessment 2020: Main Report. Food and Agriculture Organization. https://doi.org/10.4060/ca9825en.

FICCI. 2020. India Roadmap on Low Carbon and Sustainable Mobility (Decarbonisation of Indian Transport Sector). Federation of Indian Chambers of Commerce & Industry, New Delhi. https://shaktifoundation.in/wp-content/uploads/2020/08/India-Roadmap-on-LCST.pdf

FSI. 2021. India State of Forest Report 2021. Forest Survey of India, Ministry of Environment Forest and Climate Change. https://fsi.nic.in/forest-report-2021-details

Garg, A. 2020. Synchronizing Carbon Mitigation and the Sustainable Development Goals. Carbon Management. 11 (3): 203–4. https://doi.org/10.1080/17583004.2020.1757338.

Graver, B., Rutherford, D. & Zheng, S. 2020. CO Emissions from Commercial Aviation: 2013, 2018, and 2019. International Council on Clean Transportation, Washington, United States. https://theicct.org/wp-content/uploads/2021/06/CO2-commercial-aviation-oct2020.pdf

Hess, J. J., Sathish, L. M., Knowlton, K., Saha, S., Dutta, P., Ganguly, P., Tiwari, A., Jaiswal, A., Sheffield, P., Sarkar, J., Bhan, S. C., Begda, A., Shah, T., Solanki, B., & Mavalankar, D. 2018. Building Resilience to Climate Change: Pilot Evaluation of the Impact of India's First Heat Action Plan on All-Cause Mortality. Journal of Environmental and Public Health. https://doi.org/10.1155/2018/7973519.

IEA. 2021. India Energy Outlook 2021. International Energy Agency. Paris, France. https://www.iea.org/reports/india-energy-outlook-2021

IEA. n.d. Country wise Data & Statistics. International Energy Agency. Paris, France. Accessed August 8, 2022. https://www.iea.org/data-and-statistics/data-browser

ILO. 2018. Women and Men in the Informal Economy: A Statistical Picture. International Labour Organization. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_626831.pdf

IPCC. 2021. Climate Change 2021: The Physical Science Basis - Summary for Policymakers. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

IPCC. 2022. Climate Change 2022: Mitigation of Climate Change - Summary for Policymakers. Intergovernmental Panel on Climate Change https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

ISA. 2021. World's First Partnership For Interconnected Solar Grids, GGI-OSOWOG, launched at COP26 World Leaders Summit. International Solar Alliance. https://isolaralliance.org/uploads/docs/df8a70c6691b1a1462386893a08e8f.pdf.

ISA. 2022. Countries Who Have Signed and Ratified the ISA Framework Agreement. International Solar Alliance. https://isolaralliance.org/membership/countries.

IUCN. n.d. India's Bonn Challenge. International Union for Conservation of Nature. Accessed October 31, 2022. https://www.bonnchallenge.org/pledges/india

Jain, N., Sehgal, V. K., Singh, S., & Kaushik. N. 2018. Estimation of Surplus Crop Residue in India for Biofuel Production. Technology Information, Forecasting and Assessment Council (TIFAC), New Delhi.https://www.researchgate.net/publication/328686493_Estimation_of_Surplus_Crop_Residuein_India_for_Biofuel_Production

Kanitkar, T., Banerjee, R. & Jayaraman, T. 2015. Impact of economic structure on mitigation targets for developing countries. Energy for Sustainable Development, 56-61.https://www.sciencedirect.com/science/article/pii/S0973082615000277

Kanitkar, T., Thejesh, N. & Ranjan, U. 2021. Cost of avoided carbon: Optimizing power supply in southern India. Energy Policy, 149, 111988. https://www.sciencedirect.com/science/article/abs/pii/S0301421520306996

Kaza, S., Yao, L. C., Perinaz, B-T. and Frank, V. W. 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development; Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/30317

Khosla, R. & Janda, K. B. 2019. India's Building Stock: Towards Energy and Climate Change Solutions. Building Research & Information 47 (1): 1–7. https://doi.org/10.1080/09613218.2019.1522482

Krishnan, R., J. Sanjay, Gnanaseelan, C., Mujumdar, M., Kulkarni, A. and Chakraborty, S. 2020. Assessment of Climate Change over the Indian Region, A Report of the Ministry of Earth Sciences (MoES), Government of India. Springer Singapore. https://doi.org/10.1007/978-981-15-4327-2.

Krogstrup, S. and Oman, W. 2019. Macroeconomic and Financial Policies for Climate Change Mitigation: A Review of the Literature. September 4, 2019. https://www.imf.org/en/Publications/WP/Issues/2019/09/04/Macroeconomic-and-Financial-Policies-for-Climate-Change-Mitigation-A-Review-of-the-Literature-48612

Kumar, K. S. K. and Viswanathan, B. 2019. Mainstreaming Climate Change Adaptation: Agriculture. In India in a Warming World: Integrating Climate Change and Development, edited by Navroz K Dubash, 519–36. Oxford University Press India. https://academic.oup.com/book/35227/chapter/299755724.

LeadIT. 2022. Members of the Leadership Group for Industry Transition. https://www.industrytransition.org/members/

Lele, S. and Krishnaswamy, J. 2019. Climate Change and India's Forests. In India in a Warming World: Integrating Climate Change and Development, edited by Navroz K Dubash, 477–97. Oxford

University Press India. https://academic.oup.com/book/35227/chapter/299755542

McKinsey Global Institute. 2010. India's Urban Awakening: Building Inclusive Cities. Washington, DC: McKinsey & Company. https://www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/urban%20awakening%20in%20india/mgi_indias_urban_awakening_full_report.pdf

MEA. 2018a. Remarks by External Affairs Minister at the 'EU High Level Event on Climate Change'. Ministry of External Affairs, Government of India. https://mea.gov.in/Speeches-Statements.htm?dtl/29996/Remarks_by_External_Affairs_Minister_at_the_EU_High_Level_Event_on_Climate_Change

MEA. 2018b. Statement by EAM At UNSG's Climate Change Event. Ministry of External Affairs, Government of India. https://mea.gov.in/Speeches-Statements.htm?dtl/30429/Statement_by_EAM_At_UNSGs_Climate_Change_Event

MEA. 2019. PM's Remarks at Climate Action Summit 2019 during 74th Session of UNGA. Ministry of External Affairs, Government of India. https://mea.gov.in/Speeches-Statements.htm?dtl/31847/PMs_remarks_at_Climate_Action_Summit_2019_during_74th_session_of_UNGA

MEA. 2021a. Universalization of the Membership of the International Solar Alliance (ISA). Ministry of External Affairs, Government of India. https://www.mea.gov.in/press-releases.htm?dtl/33390/Universalization_of_the_Membership_of_the_International_Solar_Alliance_ISA

MEA. 2021b. Remarks by External Affairs Minister at World Sustainable Development Summit - High Level Round Table on Rebooting Green Growth (February 10, 2021). Ministry of External Affairs, Government of India. https://mea.gov.in/Speeches-Statements.htm?dtl/33516

MEA. 2021c. Address by Prime Minister at the Leaders' Summit on Climate 2021. Ministry of External Affairs, Government of India. https://mea.gov.in/Speeches-Statements.htm?dtl/33820/Address_by_Prime_Minister_at_the_Leaders_Summit_on_Climate_2021

MEA. 2021d. External Affairs Minister and Portuguese Foreign Minister on the Future of India-EU Relations (June 23, 2021). Ministry of External Affairs, Government of India. https://mea.gov.in/interviews.htm?dtl/33942/ORF_InConversation__External_Affairs_Minister_and_Portuguese_Foreign_Minister_on_the_Future_of_IndiaEU_relations_June_23_2021

MEA. 2021e. National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow. Ministry of External Affairs, Government of India. https://www.mea.gov.in/Speeches-Statements.htm?dtl/34466/National_Statement_by_Prime_Minister_Shri_Narendra_Modi_at_COP26_Summit_in_Glasgow

MEA. 2022. English Translation of Prime Minister's Remarks at the Session on 'Investing in a Better Future: Climate, Energy, Health' at G7 Summit in Germany. Ministry of External Affairs, Government of India. https://www.mea.gov.in/Speeches-Statements.htm?dtl/35447/English_Translation_of_Prime_Ministers_remarks_at_the_session_on_Investing_in_a_better_Future_Climate_Energy_Health_at_G7_Summit_in_Germany

MEE. 2021. Joint Statement issued at the conclusion of the 30th BASIC Ministerial Meeting on Climate Change. Ministry of Ecology and Environment. https://english.mee.gov.cn/News_service/news_release/202104/P020210420346484492808.pdf

MHI. n.d. Faster Adoption and Manufacturing of Electric Vehicles. Ministry of Heavy Industries. Government of India. https://fame2.heavyindustries.gov.in/.

MNRE. 2019. New Horizons Covered by MNRE: RE Round-Up for 2018-19. Ministry of New and Renewable Energy, Government of India. https://mnre.gov.in/img/documents/uploads/0449bedb6afc4867b5b65c8ef9a22522.pdf

MNRE. 2021. Ministry of New and Renewable Energy Press Release. Ministry of New and Renewable Energy, Government of India. December 28, 2021. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1785808

MNRE. 2022. Physical Progress: Programme/Scheme Wise Cumulative Physical Progress as on June, 2022. Ministry of New and Renewable Energy, Government of India. https://mnre.gov.in/the-ministry/physical-progress

MoC. n.d. Generation of Thermal Power from Raw Coal. https://coal.nic.in/en/major-statistics/generation-of-thermal-power-from-raw-coal

MoEFCC. 2015. India's Intended Nationally Determined Contribution. Ministry of Environment, Forests and Climate Change. Government of India. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/India%20First/INDIA%20INDC%20TO%20UNFCCC.pdf

MoEFCC. 2021. India: Third Biennial Update Report to The United Nations Framework Convention on Climate Change. Ministry of Environment, Forests and Climate Change, Government of India. https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf

MoEFCC. 2022. Annual Report 2021-22. Ministry of Environment, Forest and Climate Change, Government of India. https://moef.gov.in/wp-content/uploads/2022/03/Annual-report-2021-22-Final.pdf

MoF. 2018. 3 Essential 'S's of Climate Finance - Scope, Scale and Speed: A Reflection." Climate Change Finance Unit, Department of Economic Affairs, Ministry of Finance, Government of India. https://dea.gov.in/sites/default/files/3%20Essential%20S%20of%20Climate%20Finance.pdf

MoHUA. n.d. Metro Rail Sector. Ministry of Housing and Urban Affairs, Government of India. https://mohua.gov.in/upload/uploadfiles/files/Metro%20Rail%20_%20MoHUA.pdf

MoP. 2019. The Roadmap of Sustainable and Holistic Approach to National Energy Efficiency (ROSHANEE). Bureau of Energy Efficiency, Ministry of Power, Government of India. https://beeindia.gov.in/sites/default/files/Roshanee_print%20version%282%29.pdf

MoP. 2022. Green Hydrogen Policy. Ministry of Power, Government of India. https://powermin.gov.in/sites/default/files/Green_Hydrogen_Policy.pdf

MoP. 2022a. Annual Report 2021-2022. Ministry of Power, Government of India. https://powermin.gov.in/en/content/annual-reports-year-wise-ministry

MoP. 2022b. Power Sector at a Glance. Ministry of Power, Government of India. https://powermin.gov.in/en/content/power-sector-glance-all-india

MoR. 2018. Citizen Charter of Passenger Services. South Eastern Railway. Ministry of Railway, Government of India. https://ser.indianrailways.gov.in/view_section.jsp?fontColor=black&backgroundColor=LIGHTSTEELBLUE&lang=0&id=0,5,2062

MoR. 2021. Mission 100% Electrification Moving towards net Zero Carbon Emission. Ministry of Railways, Government of India. https://indianrailways.gov.in/railwayboard/uploads/directorate/secretary_branches/IR_Reforms/Mission%20100%25%20Railway%20Electrification%20-%20Moving%20towards%20Net%20Zero%20Carbon%20Emission.pdf

MoR. 2022. Indian Railways Yearbook 2020 - 21. Ministry of Railways. Government of India. https://irtpms.indianrailways.gov.in/site/wp-content/uploads/2022/03/Year-Book-2020-21-English.pdf

MoRTH. 2021. Road Transport Year Book (2017-2018 & 2018-2019). Ministry of Road Transport and Highways, Government of India. https://morth.nic.in/sites/default/files/RTYB-2017-18-2018-19.pdf

MoRTH. 2022. Voluntary Vehicle Fleet Modernization Program (V-VMP). Ministry of Road Transport & Highways, Government of India. https://morth.nic.in/sites/default/files/VVMP-Investor-Handbook.pdf

MoRTH. n.d. Ministry of Road Transport & Highways [Official Website]. Government of India. https://morth.nic.in/road-transport

MoS. 2019. Steel Scrap Recycling Policy. Ministry of Steel, Government of India. https://steel.gov.in/sites/default/files/Steel%20Scrap%20Recycling%20Policy%2006.11.2019.pdf

Nandi, J. 2022. Gujarat to Launch India's First Carbon Trading Market Among Large Polluters. EPIC (blog). May 24, 2022. https://epic.uchicago.edu/news/gujarat-to-launch-indias-first-carbon-trading-market-among-large-polluters/

NBA. 2018. Achievement of Aichi Biodiversity Targets 11 and 16: Success Stories from India. Celebration of the 25 Anniversary of the Convention on Biological Diversity. http://nbaindia.org/uploaded/pdf/Aichi%20target%20design%20low%2014-11-2018.pdf

NDMA. 2019. Annual Report 2018-19. National Disaster Management Authority. https://ndma.gov.in/sites/default/files/PDF/Reports/NDMA-Annual-Report-2018-19-English.pdf

NGFS. n.d. Network for Greening the Financial System. NGFS Secretariat. Accessed August 8, 2022. https://www.ngfs.net/en

NITI Aayog. 2022. Harnessing Green Hydrogen. Opportunities for Deep Decarbonisation in India. NITI Aayog, Government of India. https://www.niti.gov.in/sites/default/files/2022-06/Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf

NITI Aayog. 2022a. LiFE – Lifestyle for Environment. NITI Aayog. https://www.niti.gov.in/sites/default/files/2022-10/Brochure-10-pages-op-2-print-file-20102022.pdf

NRDC. 2022. Expanding Heat Resilience across India: Heat Action Plan Highlights 2022. Natural Resources Defense Council (NRDC) International, India. https://www.nrdc.org/sites/default/files/india-heat-resilience-20220406.pdf.

OECD. 2022. Aggregate Trends of Climate Finance Provided and Mobilised by Developed Countries in 2013-2020. Climate Finance and the USD 100 Billion Goal. Organisation for Economic Co-operation and Development https://doi.org/10.1787/d28f963c-en

OXFAM. 2022. Climate Finance Short-Changed: The Real Value of the $100 Billion Commitment in 2019–2020. https://www.oxfamamerica.org/explore/research-publications/climate-finance-short-changed-the-real-value-of-the-100-billion-commitment-in-20192020/

Patra, J. 2016. Review of Current and Planned Adaptation Action in India. CARIAA Working Paper no. 10. International Development Research Centre, Canada and UK Aid, United Kingdom. https://www.iisd.org/system/files/publications/idl-55866-india.pdf

PIB. 2017. Energy Conservation Building Code 2017. Press Information Bureau. Release ID: 165748. https://pib.gov.in/newsite/PrintRelease.aspx?relid=165748

PIB. 2019a. Loss and Damage Not Only an Issue for Small Island Developing Countries, but Also a Critical Issue in Large Countries like India. Press Information Bureau. Release ID: 1570790. https://pib.gov.in/PressReleasePage.aspx?PRID=1570790.

PIB. 2019b. Statement of Union Environment Minister at UNFCCC COP25. Press Information Bureau. Release ID: 1595787. https://pib.gov.in/PressReleseDetail.aspx?PRID=1595787.

PIB. 2019c. India Cooling Action Plan Launched. Press Information Bureau. Release ID: 1568328. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1568328

PIB. 2020. Union Power Minister Launches Green Term Ahead Market (GTAM) in Electricity. Press Information Bureau. Release ID: 1650384. https://pib.gov.in/PressReleasePage.aspx?PRID=1650384

PIB. 2021a. Cabinet Approves Production Linked Incentive Scheme 'National Programme on Advanced Chemistry Cell Battery Storage'. Press Information Bureau. Release ID: 1717938. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1717938

PIB. 2021b. National Research Foundation Outlay to Be Rs 50,000 Crore, over 5 Years. Press Information Bureau. Release ID: 1693887. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1693887

PIB. 2021c. Effect of Climate Change on Agriculture. Press Information Bureau. Release ID: 1696468. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1696468

PIB. 2021d. Important to Ensure That No Parallel Tracks for Climate Negotiations Are Created Brushing aside the Fundamentally Agreed Principles: India at UNSC. Press Information Bureau. Release ID: 1700305.https://pib.gov.in/PressReleseDetailm.aspx?PRID=1700305

PIB. 2021e. Prime Minister's Address at G20 Summit Session II: Climate Change and Environment. Press Information Bureau. Release ID: 1768638. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1768638

PIB. 2021f. Nuclear Power, Department of Atomic Energy. Press Information Bureau. Release ID: 1782229. https://pib.gov.in/PressReleasePage.aspx?PRID=1782229

PIB. 2022a. UJALA Completes 7 Years of Energy-Efficient and Affordable LED Distribution. Press Information Bureau. Release ID: 1787594.https://pib.gov.in/Pressreleaseshare.aspx?PRID=1787594

PIB. 2022b. Cabinet Approves India's Updated Nationally Determined Contribution to Be Communicated to the United Nations Framework Convention on Climate Change. Press Information Bureau. Release ID: 1847812. https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1847812

Rani, N. & Handoo, J. 2022. Indian Climate Policy and Decarbonized Indigenous Economic Transition. Financial Express. May 15, 2022. https://www.financialexpress.com/lifestyle/science/indian-climate-policy-and-decarbonized-indigenous-economic-transition/2525195/

Ravindranath, N. H. and Bala, G. 2019. Impact, Vulnerability and Adaptation to Climate Change in the Forest Sector in India. Report prepared as input to Third National Communication of Ministry of Environment, Forest and Climate Change. Indian Institute of Science, Bangalore.

RBI. 2021. Heed to Heal - Climate Change is the Emerging Financial Risk. Reserve Bank of India. https://www.rbi.org.in/Scripts/BS_SpeechesView.aspx?Id=1127

Reddy, C. S., Saranya, K. R. L., Pasha, S. V. Satish, K. V., Jha, C. S., Diwakar, P. G., Dadhwal, V. K., Rao, P. V. N. & Krishna Murthy, Y.V.N. 2018. Assessment and monitoring of deforestation and forest fragmentation in South Asia since the 1930s, Global and Planetary Change, Volume 161, Pages 132-148, ISSN 0921-8181. https://doi.org/10.1016/j.gloplacha.2017.10.007

Roxy, M. K., Modi, A., Murtugudde, R., Valsala, V., Panickal, S., Prasanna Kumar, S., Ravichandran, M., Vichi, M., and Lévy, M. 2016. A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean, Geophysical Research Letters, 43, 826– 833, https://doi:10.1002/2015GL066979

Sehgal, A. and Tongia, R. 2016. Coal Requirement in 2020: A Bottom-up Analysis. Brookings India Report. https://www.brookings.edu/wp-content/uploads/2016/09/2016_08_16_coal_future_2020_asrt.pdf

Singh, C., Gajjar, S. P. & Deshpande, T. 2014. Policies, Projects and People: Exploring the Adaptation-Development Spectrum in India. CARIAA-ASSAR Working Paper. CARIA-ASSAR Working Paper. Ottawa, Canada and London, United Kingdom: International Development Research Centre, Ottawa and UK Aid, London. http://www.assar.uct.ac.za/sites/default/files/image_tool/images/138/Working_Papers/CARIAA-ASSAR%20working%20paper%202%20-%20Policies%2C%20Projects%20and%20People.pdf

Singh, S. 2020. Solid Waste Management in Urban India: Imperatives for Improvement. ORF Occasional Paper No. 283, Observer Research Foundation. https://www.orfonline.org/research/solid-waste-management-in-urban-india-imperatives-for-improvement-77129/

Singh, V. P. and Sidhu, G. 2021. Investment Sizing India's 2070 Net-Zero Target. Council on Energy, Environment and Water. https://www.ceew.in/cef/solutions-factory/publications/investment-sizing-india-s-2070-net-zero-target

Srinivasan, V. 2019. Climate Adaptation in the Water Sector in India. In India in a Warming World: Integrating Climate Change and Development, edited by Navroz K Dubash, 498–518. Oxford University Press India. https://academic.oup.com/book/35227/chapter/299755629.

Standard Chartered. 2022. Just in Time: India Will Need USD12.4 Trillion to Transition to Meet Long Term Net Zero Goals. Press Release. https://av.sc.com/in/content/docs/in-transition-to-meet-long-term-net-zero-goals.pdf

Tongia, R. 2020. India's Energy Transition: Coal Is down but Not Out. Centre for Social and Economic Progress. September 7, 2020. https://csep.org/blog/indias-energy-transition-coal-is-down-but-not-out/

UN. 1992. United Nations Framework Convention on Climate Change. United Nations. https://unfccc.int/resource/docs/convkp/conveng.pdf

UNEP. 2005. Register of International Treaties and other Agreements in the Field of the Environment. https://www.unep.org/resources/report/register-international-treaties-and-other-agreements-field-environment

UNEP. 2021. UNEP Adaptation Gap Report 2021. United Nations Environment Programme. https://www.unep.org/resources/adaptation-gap-report-2021

UNEP-DTU. 2018. Adaptation Gap Report 2018. UN Environment DTU Partnership. https://www.unep.org/resources/adaptation-gap-report-2018

UNEP-IEA. 2017. Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector: Global Status Report. United Nations Environment Programme - International Energy Agency. https://worldgbc.org/wp-content/uploads/2022/03/UNEP-188_GABC_en-web.pdf

UNFCCC. 2022. India Updated First Nationally Determined Contribution Submission to UNFCCC. Government of India. https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf

Vishwanathan, S. S., & Garg, A. 2020. Energy System Transformation to Meet NDC, 2 °C, and Well below 2 °C Targets for India. Climatic Change 162 (4): 1877–91. https://doi.org/10.1007/s10584-019-02616-1

Vishwanathan, S. S., Panagiotis, F. and Garg. A. 2021. Assessing NDC and Climate Compatible Development Pathways for India. Climate Compatible Growth. https://climatecompatiblegrowth.com/wp-content/uploads/3B-COP26-Policy-Brief.pdf

World Bank. 2020. Poverty and Shared Prosperity 2020: Reversals of Fortune. The World Bank.https://doi.org/10.1596/978-1-4648-1602-4

Submission to the United Nations Framework Convention on Climate Change

Ministry of Environment, Forest and Climate Change

Indira Paryavaran Bhawan
Jorbagh Road New Delhi - 110 003
INDIA

www.moef.gov.in
www.cckpindia.nic.in

Instruction to the faculty members

1. Please make a whatsapp or email group and send the study material and syllabus with instruction sheet to students. You are free to provide additional data based on syllabus and instructs the students.

2. Give strict time period (maximum a week after sending study materials) for submission of project. Please mention your department and your time of availability.

3. Please arrange few classes online or offline mode.

4. Please evaluate the projects, and submit the marks (out of 10) accordingly to serial number of students supplied to you within 31st March, 2025 as hard copy as well as email. Please preserve the same also for upload portal when open.

For any query or suggestions, please consult with Convener or Dr. Goutam Ghosh

Dr. Parasuram Kamilya, Convener, Phone No.- 9831683998, email – pkamilya.in@gmail.com

Dr. Goutam Ghosh, Phone No.- 8282953633, email – goutambot@rediffmail.com

VERSION AS ON 23 Oct 2018

Approved Draft, VMKatoch, 23/10/2018

सत्यमेव जयते

NATIONAL ACTION PLAN FOR CLIMATE CHANGE & HUMAN HEALTH

Ministry of Health & Family Welfare

Government of India

Oct 2018

PREFACE

Climate sensitive illnesses are on increase due to climate change and extremes of weather either through direct or indirect impact. The United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol in 1997 refers to the legal framework for Climate change process internationally. The Conference of the Parties (COP) to the Convention meets annually to negotiate and discuss the international climate change agenda and related commitments from countries. The sustainable development Goal 13 (SDG 13) also emphasises to "take urgent action to combat climate change and its impacts."

India's first National Action Plan on Climate Change (NAPCC) was released by the then Prime Minister Manmohan Singh on June 30, 2008. It outlines existing and future policies and programs addressing climate mitigation and adaptation. The plan identifies eight core "national missions". After the 21st Conference of Parties (COP 21) under the United Nations Framework Convention on Climate Change (UNFCCC) concluded in Paris, Hon'ble Prime Minister Mr Narender Modi broadened India's response to climate change, by introducing four new missions including one for "Health" in 2014. The proposed 'Mission on Health' will address the health-related aspects of climate change through multi-pronged approach.

A National Expert Group on Climate Change & Health was constituted in July 2015 under the chairmanship of *Dr Vishwa Mohan Katoch, Former Secretary (Health Research), Government of India and DG (ICMR*) to prepare action plan, recommend strategies for adaptation, capacity building etc. The *National Centre for Disease Control (NCDC*) is the nodal agency for drafting of Action Plan under the Health Mission. The expert group (NEGCCH) had members' representation from Dte.GHS, MoHFW, MoEFCC, ICMR, DST, NDMA, CGWB, Min of Agriculture, CPCB, MoES, TERI, NEERI, which had drafted the National Action Plan on Climate Change and Human Health after detailed deliberation.

India is a diverse country in terms of geography, climatic conditions, resources and health care infrastructure etc. Owing to this diversity, each state and UT may have morbidity and mortality due to diseases which may occur as per the geographic-climatic conditions. Hence it was realised that country requires state/region specific action plan for climate change and human health (SAPCCHH). Four regional consultations for all the states and UTs were conducted by Centre for Environmental & Occupational Health, National Centre for Disease Control recently. The states and Union Territories were sensitised on effect of climate variability and change on 'occurrence and virulence of vectors' and recent change in pattern of different climate sensitive illnesses in their geographic area.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Climate change is occurring due to natural internal processes or external force and is defined as: "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*." It affects social and environmental determinants of health like –clean air, safe drinking water, sufficient food and secure shelter.

Climate change may negatively affect human health through a number of ways, but the commonly experienced are increased frequency and intensity of heat waves, rise in heat related illnesses and deaths, increased precipitation, floods and droughts, costing lives directly. High temperature is known to increase the level of 'ground level ozone' and other 'climate altering pollutants' other than carbon dioxide, which further exacerbate cardio-respiratory and allergic diseases and certain cancers. Beside these, there is increase in transmission and spread of infectious diseases, changes in the distribution of water-borne, food borne and vector-borne diseases and effects on the risk of disasters and malnutrition.

The *United Nations Framework Convention on Climate Change (UNFCCC)* came into force on 21st March 1994. Since then many steps were initiated to reduce the effect of climate change at meetings like "Rio Convention 1992", *Kyoto protocol 1997",* "Convention of Parties", "*Cancun Agreement 2010"," Durban Platform 2011","* Nationally Determined Contributions" (NDCs) at Conference of Parties 21",

Initiatives undertaken by India are: a) Identification of Ministry of Environment, Forest & Climate Change (MOEF&CC) as nodal ministry; b) Formulation of National Environmental Policy 2006; c) Formulation of Prime Minister's Council on Climate Change for matters related to Climate Change. MoEFCC has developed National Action Plan on Climate Change with eight missions. Later on four new missions (including Health Mission) were identified. As a follow-up action, MoHFW constituted a National Expert Group on Climate Change & Health (NEGCCH) under the chairmanship of *Dr Vishwa Mohan Katoch, Former Secretary (Health Research), Government of India and DG (ICMR*) to prepare action plan, recommend strategies for indicators, mitigation, capacity building etc.

The Health Mission aims to reduce climate sensitive illnesses through integration with other missions under NAPCC as well as through programmes run by various ministries, The vision of NAPCCHH is: To strengthen health of citizens of India against climate sensitive illness, especially among the vulnerable like children, women and marginalized population. With a goal to reduce morbidity, mortality, injuries and health vulnerability to climate variability and extreme weathers. The NAPCCHH objectives with some initially identified key actions are:

1. To create awareness among general population (vulnerable community), health-care providers and Policy makers regarding impacts of climate change on human health.
    a. Development of IEC material
    b. Advocacy
2. To strengthen capacity of healthcare system to reduce illnesses/ diseases due to variability in climate
    a. Strengthening of Healthcare system in context of climate change
    b. Capacity building (training) for vulnerability assessment.
3. To strengthen health preparedness and response by performing situational analysis at national/ state/ district/ below district levels.
    a. Develop/ strengthen the monitoring and surveillance systems for climate sensitive diseases
    b. Develop mechanisms for EWS/ alerts and responses at state, district and below district level
4. To develop partnerships and create synchrony/ synergy with other missions and ensure that health is adequately represented in the climate change agenda in the country
    a. Develop joint action plan with other deptt./ organizations In view of their capabilities and complementarities

   b. Integrate, adopt and implement environment friendly measures suggested in other missions on climate change
5. To strengthen research capacity to fill the evidence gap on climate change impact on human health
   a. Strengthening of healthcare services based on researches on climate variables and impact on human health

Initial Inputs desired (first 2 years)

1. Establish 'Environmental Health Cell' in State Health Department,
2. Identification of State Nodal Officer- Climate Change at State Health Department
3. Notification of Task Force with representation of other health programmes (vector-borne disease, infectious diseases, nutrition etc) multi-sectors/ departments such as Disaster Management Authority, Health Information System, district unit of departments of Meteorology, Pollution Control Board, Water and Sanitation, Public Works Departments and civil societies etc.
4. Vulnerability Assessment for baseline rate for Climate Sensitive Illnesses in terms of
   a. Geography (Plain/ Mountain/ Desert/ Coastal), identify worst affected areas (districts)
   b. Risk mapping with extreme events (heat/ cold/ drought/ flood/ cyclone/other),
   c. Affected *Population* (Total, density, Vulnerable, Occupation)
   d. Contributing/ exaggerating factors for these *Climate sensitive illnesses*
   e. Healthcare Infrastructure/ facilities like PHC, CHC, District hospital, Tertiary care hospitals- Government as well as Private.
   f. Identify areas for capacity building –human resource, technical and healthcare service delivery.
5. State health adaptation plan must be prepared for extreme events (heat related illness), Air Pollution and health related issues, Vector borne diseases and Water borne illnesses
6. State health department should identify and strengthen department/ institute/ organization/ health care facilities/ other stakeholders for providing assistance for management of cases and for monitoring and surveillance for climate sensitive illnesses
7. Coordinate with premiere institute/ organisation like Centre of Excellence for developing training module/ guidelines and Inclusion of mitigation and adaptation measures in Students' Curriculum.
8. Develop, integrate and Implement media communication plan for common CSDs involving health determining sectors and communities.

Process: 2 to 5 years

1. Formulate specific implementation framework for climate sensitive diseases.
2. Contingency plans for climate sensitive illnesses - appropriate and efficient health personnel, logistics & resource allocation.
3. Capacity building and training of health care personnel on guidelines and treatment modalities against climate sensitive illnesses at district level in each state.
4. Development of early detection tools for CSDs (rapid diagnostics, surveillance) or mathematical /prediction models for preparedness of population and health care system.
5. Periodic reviews for improvements or deterioration of indicators (vulnerability, response capacity, preparedness, and environmental determinants) identified for each CSD.
6. Awareness generation- integrate IEC, engage local leaders & community, yearly "Advocacy network meeting" and health talks, specific day celebration, health melas etc.
7. With projected climate risks, adapt new technologies, building design, energy, water and sanitation provisions for new constructions of healthcare facilities, but if already existing, modify as per permissible building norms.
8. Link data on data of Climate sensitive diseases, environmental factors determining health, meteorological information, and outcomes as morbidity and mortality.
9. Risk mapping and seasonal trend for CSDs: multi-sector management approach.
10. Research and epidemiological studies / surveys on vulnerable population for climate sensitive illnesses.

Expected Output:

1. Awareness & Behaviour modification of general population for impact, illnesses, prevention and adaptive measures for climate sensitive illnesses.

2. Increase in trained healthcare personnel and equipped institutes/ organization towards achievement of climate resilient healthcare services and infrastructure at district level in each state.
3. Integrated monitoring system for collection and analysis of health related data with meteorological parameters, environmental, socio-economic and occupational factors
4. Regulation on key environmental determinants of health: air quality, water quality, food, waste management, agriculture, transport.
5. Evidence–based support to policy makers, programme planners and related stakeholders

The Monitoring & Evaluation of the implementation of NAPCCH has been stipulated with a mix of internal and external approaches. MoHFW, State DoHFW, District Health Officers and the individual health facilities will be involved in regular internal monitoring. External Monitoring will be done by an independent agency.

To address the diversity and to target the specific health issues, four regional consultations with states and Union Territories were conducted in 2017-18 by *Centre for Environmental and Occupational Health*, National Centre for Disease Control, Delhi. The aim was to sensitise states/UTs' health personnel to reassess diseases' morbidity and mortality with respect to climate variability and extremes. The states and UTs were communicated to identify the '*Nodal Person for Climate Change* from *State Health Department',* Constitution of *"State Environment Health Cell"* at State Health Ministry level and Constitution of a team of experts with representation from Ministry for Environment, Forest & Climate Change, Ministry of Drinking Water and Sanitation, Ministry of Agriculture, Ministry of Earth Sciences, ICMR branch (if in state), Disaster Management Authority, State Pollution Control Board or other stakeholders identified by state.

These regional consultations had participations from health and non-health department of states and UTs, as well as from WHO as well as research institutions. The representatives were aware of the urgency and had serious concern for the agenda of these consultations. State health teams were expected to list and prioritize climate sensitive illnesses in their state and UTs, compilation of data on morbidity and mortality, statistics related to vulnerable population, geographical factors, health care infrastructure/ facilities, or any mitigation and adaptation measures adopted by state against impact of climate change on human health. The available data of states and UT need to be linked to climate/ weather data for which the assurance was given by the representative from Regional Centre Meteorological Departments. Many states have initiated actions by identifying State Nodal Officer (Climate Change), notified experts from non-health sectors for Task Force and few states have prepared their action plan for climate change as well as adaptation plan for heat related illnesses.

Now, India is signatory to "*Male' Declaration"* wherein health sector has to be strengthened so as to make it climate resilient. According to Male' Declaration, it is desired that health-care facilities should be prepared & climate-resilient, particularly in promoting to encourage that these are able to withstand any climatic event, and that essential services such as water, sanitation, waste management and electricity are functional during such events. Further, for climate resilient, the health department has to undertake measures to initiate the greening of the health sector by adopting environment-friendly technologies, and using energy-efficient services.

I. INTRODUCTION

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties (usually by models or statistical tests), and that persists for an extended period, typically decades or longer [1-2,6]. Climate change may be due to natural internal processes or external force such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. The Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods* [3]". The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes [4,5].

Climate change is perceived to be among the greatest health risks of the 21st Century[4,5]. It affects social and environmental determinants of health like –clean air, safe drinking water, sufficient food and secure shelter. Climate change, together with other natural and human-made health stressors, influences human health and disease in numerous ways (Fig:1).

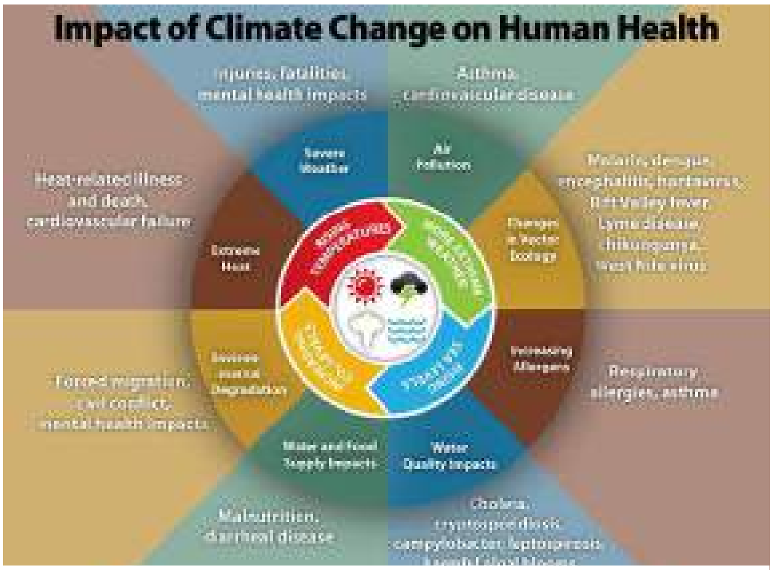


Fig:1. Likely Impacts of Climate Change on Human Health
Source: https://www.cdc.gov/climateandhealth/effects/default.htm

Climate change may have various impacts, but most commonly observed negative effects on human health are seen as rise in illnesses and deaths. The climatic variables costing lives directly are identified as increase in frequency and intensity of heat waves, increased precipitation, floods and droughts[17-18,26]. High temperature is known to increase the level of 'ground level ozone' and other 'climate altering pollutants' other than carbon dioxide, which further exacerbate cardio-respiratory and allergic diseases and certain cancers.

Beside these, there is increase in transmission and spread of infectious diseases, changes in the distribution of water-borne, food borne and vector-borne diseases and occurrence of disasters and increased probability of malnutrition. The marginalised populations among all are found to be more adversely affected due to variability and change in climatic conditions.

The World Health Organization (WHO) estimates that between 2030 and 2050, climate change is expected to cause approximately 2,50,000 additional deaths per year, resulting from malnutrition, malaria, diarrhea and heat stress. These deaths will further have financial implications which are estimated to be between US$ 2-4 billion/year by 2030[13,14,16]. Diseases such as malaria, yellow fever, dengue and cholera are all sensitive to climate change due to effect on the viability and the geographical distribution of the mosquitoes and micro-organisms, which prefer a wetter, warmer world.

India is a highly populous country, undergoing industrialisation, with large scale rural to urban migration, chaotic, unplanned urbanization, depletion of forest cover and requirement of high energy demand makes it more vulnerable to adverse impacts of climate change. As evident from various literature worldwide, the health effects may occur either due to direct or indirect causes of climate change or extremes of weather 21.

A) Direct Impacts of Change in Climate and Weather on Health:

Changes in temperature and precipitation and occurrence of heat waves, floods, droughts and fires directly impact health of people.

1. **Heat-Stress and Related Impacts**

   The IPCC Special Report on Extreme Events (SREX)[6] has a mention that there has been an overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and nights, at the global scale. If there has been an increase in daily maximum temperatures, resulting in increase in number of heat-related illnesses. As per the basic processes of human thermoregulation, the health effects are seen when body temperature rises above 38°C i.e. physical functions are impaired with experience of weakness (heat exhaustion), when body temperature rises further to 40.6°C, the risk of physical and cognitive functions get impaired (heat syncope), risks of organ damage, loss of consciousness, and death increase sharply at further rise in body temperature usually above 40.6°C (heat stroke). Various factors interplay in occurrence of these morbidity and mortality majorly affecting mainly the vulnerable population especially in the vulnerable regions[21-23].

The *vulnerable population* implies the demography (extremes of age, sex, population density, pregnant women and certain occupations), Health Status (like proportion of malnourishment, suffering with infectious and/ or chronic diseases, mental or physical disability), socio-economic status (poor/ marginalised- more vulnerable), type of occupation or socio-cultural practices. The *vulnerable regions* implies unplanned urban housing, proportion of slums, drought risk zones, water-stressed zones, food-insecure zones and remote rural areas

Numerous studies have reported increase in temperature-related morbidity (hospital admissions or emergency presentations), events due to cardiovascular, respiratory, and kidney diseases. These impacts have been related to the duration and intensity of heat. Health risks during heat extremes are greater in people who are physically active.

Eighteen heat-waves were reported in India between 1980 and 1998, with a heat-wave in 1988 affecting ten states and causing 1,300 deaths. Heat-waves in Odisha, India during 1998 to 2000 caused an estimated more than two thousand deaths and heat-waves in 2003 in Andhra Pradesh, India, caused more than 3000 deaths. The significant correlation between mortality and high temperature and high heat index has also been documented.

2. Drought, Storms and Floods

Climate change can result in more hot days, resulting in more periods of 'drought', 'dust storms', or 'heavy rains (precipitation)', and even 'flooding'. The health gets directly affected due to injuries, hypothermia, hyperthermia, drowning and indirectly through population dislocation, crowding, poor living conditions, faeco-oral transmission of gastro-intestinal pathogens causing water and food borne illnesses, respiratory illness and other infectious diseases (e.g., leptospirosis, vector-borne disease, cholera and also mental illnesses)[48-50]. The reason primarily is due to contamination of water and sewage disposal.

3. Ozone

Ozone is a secondary pollutant, formed via sunlight-driven photochemical reactions involving precursor hydrocarbons and oxides of nitrogen. Ozone pollution is projected to increase because warmer temperatures enhance these reactions. Ozone is a powerful oxidant that has been persistently associated with damage to structure of airway or lung tissue. It contributes to more severe symptom of asthma, increase in other respiratory illnesses and deaths. High concentration of ground-level ozone accompanied with Heat waves result in higher frequency and severity of cardio-pulmonary attacks [34-36]. Similarly, combination of high level of Ozone and dust storms or alteration of allergens or all, will result in outbreaks of asthma and allergic rhinitis.

4. **Air pollution**

Air pollution is a major environmental risk to health. The formation, transport and dispersion of many air pollutants is determined partly by climate and weather factors such as temperature, humidity, wind, storms, droughts, precipitation and partly by human activities known to produce various air pollutants. It is thus logical to assume that climate change will influence the dynamics of air pollution. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma [29,30].

Ambient (outdoor air pollution) in both cities and rural areas was estimated to cause 3.7 million premature deaths worldwide in 2012. Air pollution also affect health by causing acid rain; eutrophication due to nitrogen oxides emission in air from power plants, cars, trucks, and other sources; Haze; toxic effects on wildlife; Ozone depletion; Crop and forest damage etc. Over 4 million people die prematurely from illness attributable to the household air pollution from cooking with solid fuels. 3.8 million premature deaths annually from non-communicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer are attributed to exposure to household air pollution[41-43].

5. **Ultraviolet Radiation**

The IPCC AR5 mention few studies which states that ultraviolet radiation (UVR) are linked to higher incidence of few skin carcinoma for every 1°C increment in average temperatures[36]. However, exposure to the sun also has beneficial effects on synthesis of vitamin D, with important consequences for health. Accordingly the balance of gains and losses due to increased UV exposures vary with location, intensity of exposure, and other factors (such as diet) that influence vitamin D levels.

The excess of exposure to solar *ultraviolet radiation (UVR)* even within the ambient environmental range may results in sunburn, photo-ageing, cataracts, immune suppression and skin melanomas[37]. UVR induced immune-suppression may influence occurrence of various infectious diseases as well as affect vaccine efficacy. There is evidence to support a relationship between sunburn during childhood and adolescence and skin cancer in adulthood. The World Health Organization (WHO) has argued that school sun protection programmes should be emphasised, because a sizeable portion of lifetime sun exposure occurs during childhood and adolescence. Similarly, personal exposure studies among outdoor workers found that individuals engaged in road construction, horticulture, roofing and other outdoor occupations received ~20 - 26% of the total daily ambient solar UV radiation levels.

B) Indirect Impacts of Climate and Weather on Health:

Indirect impacts are due to ecological disruptions, rising sea level, changing temperatures and precipitation patterns which leads to crop failures, shifting patterns of disease' vectors, water-borne disease, vector-borne disease. Climate dependant diseases particularly affecting the vulnerable populations include the following:

1. **Air-Borne and Cardio-Respiratory Illnesses**: Climate change influences various illnesses including respiratory tract infections like asthma, rhino-sinusitis, chronic obstructive pulmonary diseases (COPD), respiratory viral diseases (Avian Influenza) & circulatory collapse posing danger to cardiac patients. The cited reasons are poor air quality, high ozone, dust storms, extreme heat, desertification, alteration of allergens, change in timing and duration of survival and transmission cycle of respiratory virus, alteration in bird migration. Further the other contributory factors are demographic factors (age, sex, immunity status, pregnant women, prevailing endemic illnesses etc) low socio-economic status, overcrowding, poor hygienic conditions, accessibilities to health care facilities, population with tuberculosis, immune-compromised level, or mentally or physically challenged people[37-39].

2. **Vector-borne diseases (VBD)**: Climate change and other weather parameters have significant impact on vector borne diseases such as Malaria, Dengue, Chikungunya, Japanese Encephalitis, kala-azar, and filariasis. The known parameters are temperature, humidity, wind, rainfall, flood and drought, affecting 'distribution of vector' and 'effectiveness of transmission of pathogen' through vectors. The temperature affects: vectors' survival, population growth, feeding behaviour, susceptibility to pathogen, incubation period, seasonality of vector activity as well as pathogen transmission. The roles of rainfall on vectors are: increase in breeding sites due to increase in surface water, increase vegetation and expansion of vertebrate hosts, flooding bring vertebrate host close to human population[41-43].

   Other factors affecting VBDs are population growth, population displacement, socio-economic status, changes in residential pattern, changes in land use, water projects, agricultural practices, housing projects, international travel, resistance of diseases vectors and pathogens, accessibility to health care and diagnostic facilities.

3. **Waterborne & Foodborne diseases** such as typhoid, hepatitis, dysentery, and others caused from micro- organisms such as Vibrio vulnificus and Vibrio cholera, E.Coli, Campylobacter, Salmonella, Cryptosporidium, Giardia, Yersinia, Legionella are some climate-dependant infectious diseases. The increase in temperature is seen to be associated with increased survival and abundance of micro-organisms[44,46]. The decreased precipitation and drought result in decrease availability of safe-water, reuse of wastewater, contamination of water sources, transmission from vertebrate to human or human to human etc. Flooding cause contamination of water source as well as disruption of sewage disposal system, further contributors are population displacement, overcrowding, poor sanitation and hygiene, subsequent faeco-oral contamination and spread of pathogens etc .

4. **Malnutrition** and consequent disorders, like retarded child growth and development have been identified as one of the health threat by the Working Group-II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Climate change result in food insecurity, namely, food availability, food accessibility, food utilization, and food system stability. Drought occurrence diminishes crop yield, dietary diversity, supply chain disrupted, increase in market prices, also reduction in animal and aquatic products are being experienced. These factors reduce overall food consumption, and may therefore lead to macro as well as micronutrient deficiencies.

   For India, a proactive approach is critical as nearly half of children (48%) aged less than five are chronically malnourished, more than half of women (55%) and almost one-quarter of men (24%) are anaemic (NFHS-3). The health of the vulnerable population is further threatened by the changing climate. For instance, in Gujarat, during a drought in the year 2000, diets were found to be deficient in energy and several vitamins. In this population, serious effects of drought on anthropometric indices may have been prevented by public-health measures[48,49].

There are certain **positive effects of climate change** too, like modest reductions in cold-related morbidity and mortality, geographical shifts in food production, and reduced capacity of disease-carrying vectors due to exceeding of thermal thresholds. These positive effects will however be increasingly outweighed, worldwide, by the magnitude and severity of the negative effects of climate change.

II. STEPS TO REDUCE IMPACTS OF CLIMATE CHANGE

The United Nations Framework Convention on Climate Change (UNFCCC) came into force on 21st March 1994. The “Rio Convention”, was adopted out of three conventions identified at “Rio Earth Summit” in 1992. Today, this convention known as “Convention of Parties” has 197 countries. Industrialized nations agree under the Convention to support climate change activities in developing countries by providing financial support for action on climate change. This was followed by first Conference of Parties (COP1) that took place in Berlin in 1995.

Another milestone was *Kyoto protocol, which* was adopted in Kyoto, Japan, on 11th December 1997. The Parties agreed-for were made bound for ‘targets’ for reducing emission. The Kyoto Protocol places a heavier burden on developed nations under the principle of "*common but differentiated responsibilities*", owing to high level of GHG emissions by developed nations by their industrial activity for approximately 150 years. The detailed rules for the implementation of the Protocol were adopted at COP-7 in Marrakesh, Morocco, in 2001, and are referred to as the "Marrakesh Accords." Its first commitment period started in 2008 and ended in 2012.

The *Cancun Agreement* came up in 2010 at COP-16 in Cancun, where Governments decided to establish a “*Green Climate Fund*”. The fund will support projects, programmes, policies and other activities in developing country using thematic funding windows. The objective was to enhance action on adaptation, international cooperation and coherent consideration of matters relating to adaptation under the Convention.

At COP17, *Durban Platform*, Enhanced Action drafted, where governments clearly recognized the need to draw up the blueprint for a fresh universal, legal agreement to deal with climate change beyond 2020, where all will play their part to the best of their ability and all will be able to reap the benefits of success together. The Durban outcome recognized, in its spirit and intention that smart government policy, smart business investment, and the demands of an informed citizenry, all motivated by an understanding of mutual self-interest, must go hand in hand in pursuit of the common goal.

At COP 21 in Paris, Parties to the UNFCCC reached a historic agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future. The Paris Agreement requires all Parties to put forward their best efforts through “Nationally Determined Contributions” (NDCs) and to strengthen these efforts in the years ahead.

India has undertaken many initiatives in pursuance to the obligation implied by UNFCCC like: a) Identification of Ministry of Environment, Forest & Climate Change (MOEF&CC) as nodal ministry for matters related to Climate Change; b) Formulation of National Environmental Policy 2006; c) Formulation of Prime Minister’s Council on Climate Change to advice proactive measures, facilitate inter-ministerial coordination and guide policy in relevant areas.

The hon’ble Prime Minister of India office had released a National Action Plan on Climate Change in June 2008. NAPCC addresses the urgent and critical concerns of the country through enhancement of the current and planned programmes presented in the Technology Document. It identifies measures that promote our development objectives along with yielding co-benefits for addressing climate change effectively. It outlines a number of steps to simultaneously advance India’s development and climate change related objectives of adaptation and mitigation. The NAPCC identified eight national missions initially:

1. National Mission on Sustainable habitat
2. National Mission for Sustaining the Himalayan Ecosystem
3. National Mission for Sustainable Agriculture
4. National Solar Mission
5. National Mission for Enhanced Energy Efficiency
6. National Water Mission
7. National Mission on Strategic Knowledge for Climate Change
8. National Mission for “Green India”

The reconstituted Prime Minister Council on Climate Change (PMCCC) reviewed the progress of eight national missions on 19th January 2015 and suggested formulation of four new missions on Climate Change viz.

1. Health Mission
2. National Mission on “Waste to Energy Generation”
3. National Mission on India’s Coastal areas
4. National Wind Mission

In this background, the proposed ‘Health Mission’ was undertaken by Ministry of Health & Family Welfare, Government of India under the umbrella of ‘National Action Plan on Climate Change’ by MoEFCC. As a follow-up action, MoHFW constituted a National Expert Group on Climate Change & Health (NEGCCH) under the chairmanship of *Dr Vishwa Mohan Katoch, Former Secretary (Health Research), Government of India and DG (ICMR*) to prepare action plan, recommend strategies for adaptation and response plan for diseases occurring due to climate variability and change.

National Centre for Diseases Control (NCDC) was identified as the nodal agency for ‘Health Mission’ by Ministry of Health & Family Welfare, Government of India. An expert group was constituted with members’ representation from DteGHS, MoHFW, MoEFCC, ICMR, DST, NDMA, CGWB, Min of Agriculture, CPCB, Ministry of Earth Sciences, TERI, NEERI etc.

III. INDIA's STRATEGIC FRAMEWORK FOR ADAPTATION OF HUMAN HEALTH AGAINST CLIMATE CHANAGE

India's Health and Family Welfare System derives strength from several institutes and infrastructures of the GOI, multi-lateral institutes, and NGOs including the National Institute of Malaria Research; Indian Institute of Tropical Meteorology, India Meteorological Department, Director General of Health Services, Indian Council of Medical Research, National Centre for Disease Control and many others.

Measures that would help address the imminent challenges would include *development of an integrated early health warning system*, *state specific emergency response plan*, along with increased capacity to provide health care to the most vulnerable and the marginalized populations.

Therefore a fundamental area of intervention would include strengthening of local monitoring of appropriate climate and disease variables. This would be directed at building temporally and spatially *disease specific database*. A strong surveillance would help develop effective prevention strategies, aid epidemiological understanding and predictive computations. Improvements in information infrastructure that are innovative and that promote interdisciplinary collaborations have been identified as areas that require strengthening in India (Bush et al. 2011).

The linkage of health with environmental and climate change determinants is well recognized. Consequently, coordination and synergies with other Ministries becomes crucial to yield health benefits. To facilitate joint action and Inter-Ministerial cooperation, it is imperative to develop feedback mechanisms of health trends to related Ministries and agencies to enable health statistics to leapfrog.

Health sector in preparedness for climate change needs urgent, serious, and multifaceted action, which should include:

1. Strengthen/ develop coordination for health related early warning and surveillance systems in specific areas (e.g. heat waves, floods, air pollution, ultraviolet radiation, vector borne, water-borne and infectious diseases) through an integrated disease surveillance system.

2. Feedback mechanisms to other ministries responsible for several ecological determinants of health particularly- air, water, food, fuel and human resource.

3. Development of risk maps for climate sensitive diseases for each geographical area.

4. Strengthening/ developing response action based on innovative or new strategies or technological approaches to increase access, early health care advice/ referral and health tracking system incorporating *Aadhaar* card number to assist surveillance and generate trends.

5. Undertake case studies and research and pilot test new approaches aimed at building health resilience in climatically sensitive locations.

The proposed 'Health Mission' will take a multi-pronged approach to address the health-related aspects of climate change through the strategies listed in the National Action Plan for Climate Change and Human Health (NAPCCHH). The Health Missions seeks coordination with other missions identified under the umbrella of National Action Plan for Climate change (NAPCC) listed earlier in this document. The targets achieved by other national missions launched under the NAPCC will also scale down the morbidity and mortality of various types of illnesses.

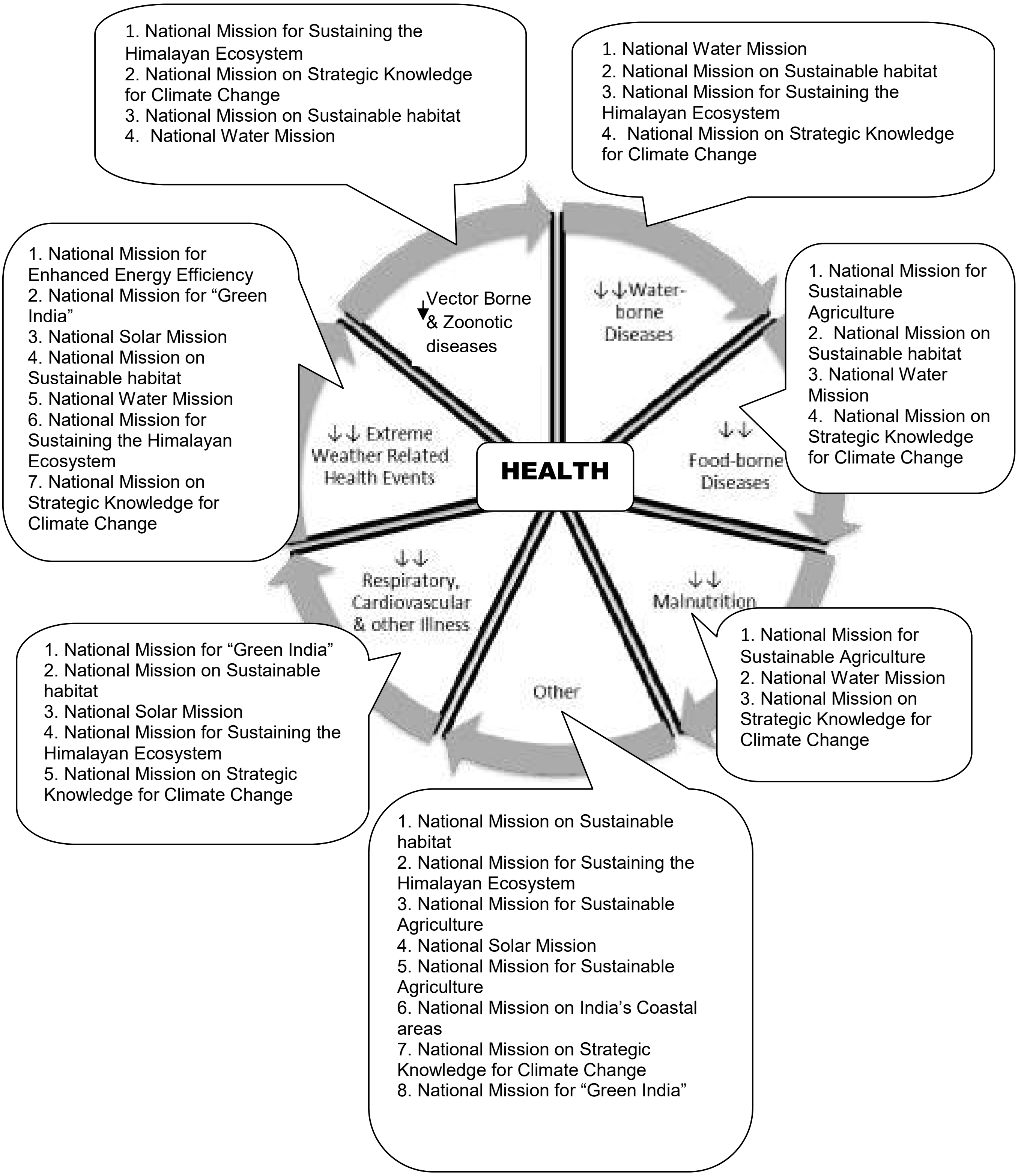
IV: INTEGRATION OF HEALTH MISSION WITH OTHER MINISTRIES AND MISSIONS ON CLIMATE CHANGE

The frequency and magnitude of occurrence of "morbidity and mortality", "acute and chronic" "communicable" or "Non-Communicable" illnesses depends on socioeconomic status, residence, occupation, level of nourishment, underlying illness, availability of safe drinking water, sanitation facilities, overcrowding, pollution, extreme weather, chemical exposures, agricultural practices, governance (local, state and national level), access to health facilities, trained/ skilled health manpower, laboratory support, and religious practices etc.

The strengthening of the National Programmes under various ministries will raise the level of health of people through direct or indirect impacts by reducing risk factors. To name the beneficial national programmes/ schemes are: Namami Gange Programme, Mid Day Meal Programme, Integrated Child Development Schemes, Indira Gandhi Matritva Sahyog Yojna, Deen Dayal Upadhyaya Gram Jyoti Yojna, Atal Mission for Rejuvenation and Urban Transformation, Gramin Bhandaran Yojna, Jawaharlal Nehru National Urban Renewal Mission, Livestock Insurance Scheme, National Urban Livelihood Mission, Smart Cities Mission, National Vector Borne Disease Control Programme, *National Programme for Prevention and Control of Diabetes, Cardiovascular diseases, Cancer and Stroke*, *National Mental Health Programme*, *National Iodine Deficiency Disorder Control Programme*, *Revised National TB Control Programme (RNTCP*), *National Programme for Control and Treatment of Occupational Disease*, *National Programme for the Health Care for the Elderly*, *National Programme for Prevention and Control of Deafness* and *Universal Immunization Programme*.

The MoHFW seeks to coordinate & collaborate with other Ministries, departments & NGOs/CBOs. These Ministries & Departments are: *Ministry of Environment, forest & Climate Change*, *Ministry of Information & Broadcasting*, *Ministry of Human Resource Development*, *Indian Council of Medical Research, Ministry of Agriculture*, *Medical Council of India*, *Ministry of Drinking Water and Sanitation, Min. of New & Renewable Energy, National Disaster Management Authority*, *Ministry of Women and Child Development, Indian Institute of Tropical Meteorology, Indian Institute of Tropical Meteorology, Department of Space*, *Department of Science & Technology*, *Council of Scientific & Industrial Research, Ministry of Home Affairs*, *Defence Research & Development Organization*, *Indian Council of Agricultural research*, *National Institute of Malaria Research*, *Food Safety and Standards Authority of India*, *Department of Health Research*, *National Environmental Engineering Research Institute*, *Community Based Organizations*, *Public Health Foundation of India* etc.

The possible health impacts of other missions under NAPCC are foreseen as follows:



V: NAPCCHH: VISION, GOAL & OBJECTIVES

Vision: Strengthening of healthcare services for all the citizens of India esp vulnerable like children, women and marginalized population against climate sensitive illnesses.

Goal: To reduce morbidity, mortality, injuries and health vulnerability due to climate variability and extreme weathers

Objective: To strengthen health care services against adverse impact of climate change on health.

Specific Objectives

Objective 1:

To create awareness among general population (vulnerable community), health-care providers and Policy makers regarding impacts of climate change on human health.

Objective 2:

To strengthen capacity of healthcare system to reduce illnesses/ diseases due to variability in climate.

Objective 3:

To strengthen health preparedness and response by performing situational analysis at national/ state/ district/ below district levels.

Objective 4:

To develop partnerships and create synchrony/ synergy with other missions and ensure that health is adequately represented in the climate change agenda in the country

Objective 5:

To strengthen research capacity to fill the evidence gap on climate change impact on human health

VI. NAPCCHH: ACTIVITY MATRIX

S. No.	Key Actions	Activity			Indicators
		Short term (First two years)	**Medium Term** (up to five years)	**Long Term** (up to fifteen years)	
1.	**To create awareness among general population (vulnerable community), health-care providers and Policy makers regarding impacts of climate change on human health**				
	Development of IEC material on health impacts of Climate variability & change	-Identify *nodal agency* to undertake communication needs assessment for the target groups - Develop *Communication Plan* & Tools -Develop *IEC materials* in Hindi, English and other vernacular languages. - Dissemination of IEC: mass media and inter-personal communication - Training & Sensitization of Health Care Providers	-Develop integrated IEC strategy -Explore inter-sectoral / inter-ministerial / civil society / NGOs for collaboration -Integrate health impacts of climate change into school and College curricula - Periodic Impact assessment of communication activities and monitor dissemination and utilization of IEC material -Explore additional sources of funding	-Determine whether the target population is covered/ informed timely -Commissioning of impact studies -Follow up 'Evaluation' of awareness activities -Actively pursue partnerships with other agencies	- Number of states and UTs developed & translated IEC on H*ealth impacts of* Extreme *weather event like 'Heat'* in local language - Number of states and UTs developed & translated IEC on H*ealth impacts of* Air Pollution in local language - Number of states and UTs developed & translated IEC on H*ealth impacts of* climate change on vector borne illnesses in local language - Number of states and UTs developed & translated IEC on H*ealth impacts of* climate change on water borne illnesses in local language - Number of states and UTs developed & translated IEC on H*ealth impacts of* climate change on food borne illnesses in local language - Number of states and UTs developed & translated IEC on H*ealth impacts* of climate change on zoonotic diseases in local language
	Advocacy on health impacts of Climate variability & change	- Advocacy forum to conduct and support workshops and meetings. - Evidence based Information to legislators and decision makers on issues of climate change and impact on health	Provide evidence/ information for decision-makers to assess existing policies, practices and systems Involve community-based organizations (CBOs) for dissemination of information.	Expand the span of coalitions to strengthen and support favourable legislatures/ policies	- Number of states/ UTs notified Advocacy forum. -Number of sensitisation workshops / meetings conducted with healthcare personnel on issue of climate change and impact on health. - Number of workshop/ campaign conducted on issue of climate change and impact on health with community-based organizations (CBOs)
	Nodal Department/ Ministry: MOHFW / Dte.GHS / NCDC Suggested Supportive Department/ Ministry: Min. I &B / CHEB/ DAVP / MoEF&CC / ICMR / DHR/ Min of Drinking Water and Sanitation / MHA/ Min of Agriculture/ ICAR & DARE NDMA/ MoWCD Min. of HRD FSSAI				

<table>
<tr><th rowspan="2">S. No.</th><th rowspan="2">Key Actions</th><th colspan="3">Activity</th><th rowspan="2">Indicators</th></tr>
<tr><th>Short term
(First two years)</th><th>Medium Term
(up to five years)</th><th>Long Term
(up to fifteen years)</th></tr>
<tr><td>2.</td><td colspan="5">To strengthen capacity of healthcare system to reduce illnesses/ diseases due to variability in climate</td></tr>
<tr><td></td><td>Strengthening of health care system in context of climate change</td><td>-Establish ‘Environment Health Cell’ at Health deptt.
- Depute State Nodal Officer – Climate change as focal point
- Notify Task Force with multiple stakeholders and review existing Indian Public Health Standards and appropriate suggestions
- State to form climate sensitive health Programme Implementation Plan (PIP)</td><td>Implement/ adapt/ modify Monitoring, Supervision and Evaluation tool for climate sensitive diseases
-Coordinate with other agencies (municipalities, PRIs) for efficient and effective implementation of proposed activities at state and below level.
- Phased Implementation of the recommendations of Task Force.</td><td>- Share appropriate technology like reduction in carbon footprint at healthcare facilities
- Continue Phased Implementation of recommendations of Task Force.</td><td>- Number of States/ UT with ‘Environment Health Cell’ at Health deptt
- Number of States/ UT deputed State Nodal Officer (CC) at Health Department
- Number of States/ UT which have notified Task Force
-Number of meetings conducted with other stakeholders like municipalities, other department PRI</td></tr>
<tr><td></td><td>Capacity building for vulnerability assessment at various levels and liaison with centre</td><td>-Identify agency/ institute/ Organizations/ Centers of Excellence for developing guidelines, capacity building, supporting implementation, monitoring, supervision.
- Enlist (customized as per states’ vulnerabilities)
i) Technical committees/ working groups to support the focal point,
ii) skilled staff,
(iii) logistics,
(iv) funds</td><td>- As per priority list, State to prepare guideline/ action plan and upload the same on its website for ready reference.
-Develop training modules, organize training
- Conduct meeting / Workshops/ Training on CC&HH for health care personnel
- Sensitize and orient private health care providers</td><td>- Extend and expand trainings to reach health care staff till village level.
- Conduct workshops/ structured training in new treatment/ management technologies at regional or local level
- Disseminate reports and good practices;</td><td>- Number of States/ UTs enlisted agency/ institute/ Organizations in their state for development of guidelines related to climate sensitive illnesses.
- Number of states/ UTs enlisted experts for Technical committees/ working groups to support Nodal Officer and Task Force for climate Change.
- Number of states/ UTs conducted vulnerability assessment for commonly occurring Climate sensitive illnesses in the state.
- Number of States/ UTs conducted Training Need assessment in view of climate sensitive illnesses.
- Number of States/ UTs made assessment in terms of required logistics and funds thereof.</td></tr>
<tr><td></td><td colspan="5">Nodal Department/ Ministry: MOHFW / Dte.GHS / NCDC
Suggested Supportive Department/ Ministry: ICMR /Min. of Drinking Water and Sanitation / MHA/ DHR/ ICMR/ Min. of Agriculture/ ICAR & DARE/ DRDO / NDMA/ MWCD/ MoEF&CC</td></tr>
</table>

<table>
<tr><th rowspan="2">S. No.</th><th rowspan="2">Key Actions</th><th colspan="3">Activity</th><th rowspan="2">Indicators</th></tr>
<tr><th>Short term
(First two years)</th><th>Medium Term
(up to five years)</th><th>Long Term
(up to fifteen years)</th></tr>
<tr><td>3.</td><td colspan="5">To strengthen health preparedness and response by performing situational analysis at national/ state/ district/ below district levels.</td></tr>
<tr><td></td><td>Develop/ strengthen the monitoring and surveillance systems for climate sensitive diseases</td><td>- Develop / strengthen surveillance for each CSD
-“Standardize information Prepare Guidelines, reporting forms for CSDs.
- Train all concerned personnel on surveillance system (data collection, collation and analysis)
- Integrate relevant non-health data in the health surveillance system
- Initiate Sentinel & real-time surveillance for illnesses due to Air Pollution, Heat etc</td><td>- Build an interdisciplinary platform i.e. link health databases with real-time monitoring of weather, climate, geospatial, and exposure data so as to accurately forecast health illness/ event
- Develop/ modify mechanism and indicators to monitor trend of CSDs.
- Conduct Joint Review Missions / Central Internal Evaluations and feedback mechanisms.</td><td>Update monitoring and surveillance system as per new evidences
Evaluate inter-disciplinary platform and upgrade as per evolving technologies.
Identify gaps for research</td><td>- Number of states and UT conducted training for Concerned personnel on surveillance system
- Number of states and UT integrated relevant meteorological data in the surveillance system of Climate sensitive illnesses.
- Number of states/ UT initiated Real Time surveillance for Climate sensitive illnesses (Illnesses due to Air Pollution, Heat Exposure, Vector borne and Water borne illnesses)
- Number of states/ UTs initiated Sentinel surveillance for illnesses due to Air Pollution, Heat etc</td></tr>
<tr><td></td><td>Develop mechanisms for EWS/ alerts and responses at state, district and below district level</td><td>Constitute multi-stakeholder working group for development of early warning system for each CSD
- Design and integrate public health response plan with Meteorology Dept, NDMA, EMR</td><td>-Review monitoring and surveillance system of CSDs
-Develop thresholds/ prediction models for health events or CSDs.
-States to develop communication plan and dissemination systems to warn people and communities</td><td>Evaluation and modifications for the appropriateness of the plans’ for
-Thresholds of action
-Interventions to maximize response effectiveness for the relevant community or region.</td><td>- Number of States and UTs constituted working group for development of mechanism for EWS/ alerts
-Number of states and UTs developed mechanism to integrate public health response plan with related stakeholders
- Number of states and UTs developed communication plan and dissemination systems to warn people and communities</td></tr>
<tr><td></td><td colspan="5">Nodal Department/ Ministry: MOHFW / Dte.GHS / NCDC
Suggested Supportive Department/ Ministry: MoEF&CC / ICMR / DHR/ Ministry of Drinking Water and Sanitation / MHA/ Ministry of Agriculture/ ICAR & DARE NDMA/ Min. of HRD/ ICMR / DRDO / NDMA/ MWCD</td></tr>
</table>

S. No.	Key Actions	Activity			Indicators
		Short term (First two years)	**Medium Term** (up to five years)	**Long Term** (up to fifteen years)	
4.	**To develop partnerships and create synchrony/ synergy with other missions and ensure that health is adequately represented in the climate change agenda in the country**				
	Develop joint action plan with other deptt./ organizations In view of their capabilities and complementarities	-Enlist, map and analyse services by all possible stakeholders in the state as per their role in Climate Resilient Health Services -Identify or assess aspects/ areas underserved in management of CSDs - Develop affordable and acceptable tools for risk reduction and Environmental Health Impact Assessment - Establish *Corporate Social Responsibility* / *Accountability* in terms of finances for implementing measures for prevention/ reduction/ treatment of CSDs	- Broaden Stakeholders' network and partnership and reassess service areas to be served for climate related health risk reduction and Environmental Health Impact Assessment. - Evaluate Corporate Social Responsibility (CSR) under laws for Health strategies, Policies and measures for promotion of health - Meeting/ Consultation with local governing body for reassessment of roles and services and appropriate resource allocation and for limiting duplication of actions	- Reassess tools for risk reduction and Environmental Health Impact assessment. - Share best management practices which are affordable and acceptable in social/ traditional context locally - Evidence based support to decision makers for addressing gaps in climate resilient healthcare services	- Number of states and UTs enlisted stakeholders for CRHS - Number of states and UTs conducted stakeholders' mapping -Number of states and UTs analysed stakeholders' services and identified underserved aspects/ areas related to CSDs - Number of states and UTs developed tool for Environmental Health Impact Assessment for commonly occurring CSDs. - Number of states and UTs which have Involved corporate sector in management of CSDs.
	Integrate, adopt and implement environment friendly measures suggested in other missions on climate change	- Increase plantation in and around building to make it 'Green' - Incorporate measures in building design for making it climate resilient - Use technologies which reduce harmful chemicals emission & carbon foot-print - Use of energy-efficient equipments and services	- Expand measures to make healthcare sector 'Green'. - Replicate the successful 'model of building design' for new healthcare facilities - Explore and support technologies, equipments and services which are energy efficient and reduce harmful chemicals emission & carbon foot-print	Assess and document reduction of climate risk in climate resilient building design for replication in other states and UTs	- Number of states and UTs initiated 'Greening Effort' in their healthcare sector -Number of states and UTs ensured use of energy efficient equipments and technologies in healthcare sector -Number of states and UTs which have successfully built the 'prototype of healthcare building' which has incorporated measures to make it withstand climate disasters
	Nodal Department/ Ministry: MOHFW / Dte.GHS / NCDC Suggested Supportive Department/ Ministry: ICMR /DHR/ ICAR/DARE/ DRDO / NDMA / MoEF&CC / IMD /Min of Space/ NGOs / CBOs / Min. of New & Renewable Energy				

S. No.	Key Actions	Activity			Indicators
		Short term (First two years)	**Medium Term** (up to five years)	**Long Term** (up to fifteen years)	
5.	**To strengthen research capacity to fill the evidence gap on climate change impact on human health.**				
	Strengthening of healthcare services based on researches on climate variables and impact on human health	- Create database of professionals, researchers and institutions engaged in studies of impact of weather and climate on health - Create a platform for 'data-repository' of various researches on climate and health effects - Scenario-building (initiation of study, data sources, mechanism used, apportionment of risk factor, methodology, assumptions, model used, confidence interval) for establishing relation of climate variables and health impacts. - Identify best practices in implementation of measures to combat the effect of climate change	- Development of models mathematical or other types for early warning alerts for CSDs. -Develop / adapt techniques for modelling or use other research advances by transitioning them into operational products and decision support tools - Reassess health data esp CSDs using modelling techniques - Inform Policy-makers about 'scenario' of health-related statistics with focus on CSDs. - Conduct seminars, workshops, conferences on best practices of measures to combat effect of climate change on human health.	- Develop and validate models, enhance research on the effectiveness of CSDs management. - Evaluate and improve the effectiveness of modelling technique. - Evidence based information to Policy-makers - Conduct seminars, workshops, conferences on best practices of measures to combat effect of climate change on human health.	-Number of states and UTs with database of professionals, researchers and institutions engaged in studies of impact of weather and climate on health - Number of states and UTs which have created a platform for 'data-repository' of various researches on climate and health effects - Number of states and UTs which have listed 'Best Practices' of measures to combat effect of climate change - Number of states and UTs conducted at least two seminars in a year on CSDs and related aspects including 'best practices'.
	Nodal Department/ Ministry: MOHFW / Dte.GHS / NCDC Suggested Supportive Department/ Ministry: NDMA / IMD/ DOS / Dept. of Science & Technology / ICMR/DHR / ICAR/DARE/ DRDO/ CSIR				

VI. CLIMATE CHANGE vs HEALTH RESILIENCE

As per the available evidences, it is known that change or variation in climate at any geographic location may affect the pattern of morbidity and mortality among the dwelling population. The commonly identified illnesses may be grouped as i) Extreme events (heat related illness), ii) Air Pollution and health related issues, iii) Vector borne diseases and iv) Water borne illnesses v) Malnutrition and vi) Various NCDs.

To protect health of people, it is necessary that health department of all states must consider the climate change as an emerging threat in causation of most of the illnesses and hence must undertake measures to adequately address this issue.

Initial Inputs/ activities desired (first 2 years)

1. Establish 'Environmental Health Cell' in State Health Department,
2. Identification of State Nodal Officer- Climate Change at State Health Department
3. Notification of Task Force with representation of other health programmes (vector-borne disease, infectious diseases, nutrition etc) multi-sectors/ departments such as Disaster Management Authority, Health Information System, district unit of departments of Meteorology, Pollution Control Board, Water and Sanitation, Public Works Departments and civil societies etc.
4. Vulnerability Assessment for baseline rate for Climate Sensitive Illnesses in terms of
    a. Geography (Plain/ Mountain/ Desert/ Coastal), identify worst affected areas (districts)
    b. Risk mapping with extreme events (heat/ cold/ drought/ flood/ cyclone/other),
    c. Affected *Population* (Total, density, Vulnerable, Occupation)
    d. Contributing/ exaggerating factors for these *Climate sensitive illnesses*
    e. Healthcare Infrastructure/ facilities like PHC, CHC, District hospital, Tertiary care hospitals- Government as well as Private.
    f. Identify areas for capacity building –human resource, technical and healthcare service delivery.
5. State health adaptation plan must be prepared for extreme events (heat related illness), Air Pollution and health related issues, Vector borne diseases and Water borne illnesses
6. State health department should identify and strengthen department/ institute/ organization/ health care facilities/ other stakeholders for providing assistance for management of cases and for monitoring and surveillance for climate sensitive illnesses
7. Coordinate with premiere institute/ organisation like Centre of Excellence for developing training module/ guidelines and Inclusion of mitigation and adaptation measures in Students' Curriculum.

8. Develop, integrate and Implement media communication plan for common CSDs involving health determining sectors and communities.

Process: 2 to 5 years

1. Formulate specific implementation framework for climate sensitive diseases.
2. Contingency plans for climate sensitive illnesses - appropriate and efficient health personnel, logistics & resource allocation.
3. Capacity building and training of health care personnel on guidelines and treatment modalities against climate sensitive illnesses at district level in each state.
4. Development of early detection tools for CSDs (rapid diagnostics, surveillance) or mathematical /prediction models for preparedness of population and health care system.
5. Periodic reviews for improvements or deterioration of indicators (vulnerability, response capacity, preparedness, and environmental determinants) identified for each CSD.
6. Awareness generation- integrate IEC, engage local leaders & community, yearly "Advocacy network meeting" and health talks, specific day celebration, health melas etc.
7. With projected climate risks, adapt new technologies, building design, energy, water and sanitation provisions for new constructions of healthcare facilities, but if already existing, modify as per permissible building norms.
8. Link data on data of Climate sensitive diseases, environmental factors determining health, meteorological information, and outcomes as morbidity and mortality.
9. Risk mapping and seasonal trend for CSDs: multi-sector management approach.
10. Research and epidemiological studies / surveys on vulnerable population for climate sensitive illnesses.

Expected Output:

1. Awareness & Behaviour modification of general population for impact, illnesses, prevention and adaptive measures for climate sensitive illnesses.
2. Increase in trained healthcare personnel and equipped institutes/ organization towards achievement of climate resilient healthcare services and infrastructure at district level in each state.
3. Integrated monitoring system for collection and analysis of health related data with meteorological parameters, environmental, socio-economic and occupational factors
4. Regulation on key environmental determinants of health: air quality, water quality, food, waste management, agriculture, transport.
5. Evidence–based support to policy makers, programme planners and related stakeholders

VIII. CLIMATE RESILIENT HEALTH SYSTEM: STAKEHOLDERS's INTERVENTION

India is signatory to "Male' Declaration" wherein health sector has to be strengthened so as to make it climate resilient. According to Male' Declaration, it is desired that health-care facilities should be prepared & climate-resilient, particularly in promoting to encourage that these are able to withstand any climatic event, and that essential services such as water, sanitation, waste management and electricity are functional during such events. Further, for climate resilient, the health department has to undertake measures to initiate the greening of the health sector by adopting environment-friendly technologies, and using energy-efficient services (Annexure-).

The existing efforts in public health preparedness, disaster risk reduction, and programs for communicable and non-communicable diseases may be inadequate, ineffective or unsustainable, if they are not climate resilient. It requires vulnerability re-assessment and should take into account both current climate variability and projected future impact of climate change on disease burden and hence management. The overview of roles and activities for health as well as non-health departments are listed below as guide for group of Climate Sensitive Diseases. States and UTs have to make micro-plan as per their vulnerabilities and geo-climatic conditions.

A. Human Health vs Extreme weather events

States and UTs may have recorded raised morbidity and mortality due to effect of extreme weather conditions viz frequent and severe episodes of heat waves, floods, droughts and fires as a direct impact of climate variability and affecting population at large.

Vulnerability factors: Demography especially people at extremes of age (>65yrs, children), Health status, Socioeconomic status, Occupation, working place and working conditions, unplanned urban housing, overcrowding, remote area, Drought/ flood prone area, water scarcity zone

Role of Health Sector **(State Nodal Officer and Task Force)**

1. Develop/ adapt health micro-plans for extreme weather events based on meteorology warnings and change in trend of illnesses in recent years.
2. Map vulnerable population based on demography, land cover, water bodies, potential exposure, available resources health insurance coverage, and burden of chronic illnesses in the community.

3. Develop or translate IEC in local language, and make a communication plan for dissemination of health related alerts/ education materials for target or general population.
4. Build capacity of health care personnel to detect and treat illnesses associated with extreme weather events
5. Issue health advisory to healthcare personnel based on IMD seasonal prediction or warning
6. Ensure health related Real-time Surveillance and Monitoring System in case of extreme event
7. Explore collaborative mechanisms (e.g. memoranda of understanding) with other departments, stakeholders, such as meteorological, pollution control board etc for sharing data and for coordinating efforts to manage health risks.
8. Ensure Inter-sectoral convergence and coordination for improving architecture, design, energy efficient cooling and heating system at health facility, increase in plantation i.e. Climate Resilient Green Building Design.
9. Reassess 'Occupational Health standards' for various types of Occupation.
10. Ensure strict implementation of legislative/ regulatory actions as per Occupational Health Standards.

Coordination with other sectors in reducing illnesses due to Extreme Weather Events

SNO-CC and the Task Force should explore collaborative mechanism (e.g. memoranda of understanding) for regular sharing data and for coordinating efforts to manage health risks. The suggested sectors are listed below, however the list may be expanded or modified as per the need of the state /UT.

Meteorological Department

- Accurate and timely forecast for extreme weather
- Communication of 'alert' to state health departments, vulnerable groups/ agencies

Water Board

- Management and supply of safe and adequate water to all in the state.
- support & promote water conservation methods like rain water harvesting.

Municipalities

- Develop and promote building design and other infrastructure codes supporting 'Green building' and use of energy efficient and natural ways of lighting and cooling
- Undertake actions like: planting trees, ensure non-burning of garbage, supply of safe water and maintaining sanitation.
- build cool shades at public places, cool corridors for pedestrians

Ministry of Environment, Forest Climate Change

- Develop/ encourage projects to decrease the '*Urban Heat Island effect'*.

- Ensure green coverage in the cities through checking deforestation, urban planning and increasing plantation.

Ministry of Education

- Sensitise students towards health impact of extreme events and disseminate health ministry approved prevention and first-aid measures.
- Train teachers on first aid measures for all possible extreme events (as per state's vulnerability)
- During extreme events: keep a check on outdoor activities and close teaching institutes in case of issue of alert from Government.

Ministry of Transport

- Provision of safe and improved Public transport like air conditioned buses, local trains and other transport at affordable rates.

Media & NGOs

-Disseminate success stories, methods and measures to promote community awareness on preventive measures and first aid to reduce health impacts of extreme weather.

B. Water borne & Food borne diseases

Illnesses due to contaminated water and food are usually seen following flood, drought, religious or other mass gatherings. SNO-CC and the related stakeholders must undertake suitable measures to keep a check on morbidity and mortality due to water and food borne illnesses.

Vulnerability: Availability of safe water supply to all, sanitation facilities in general and in urban slums and remote rural areas, personal hygiene, political willingness, Socio-economic status, cultural beliefs, natural disasters, demographic changes, accessibility to health care.

Role of Health Sector **(State Nodal Officer and Task Force)**

1. Develop/ adapt health micro-plan for water and food borne illnesses (case management, resources required like logistics, drugs, vaccines, laboratories' role)
2. Map vulnerabilities: population at risk, geo-climatic conditions, recent trend of climate variability (flood, drought), change in population demography (migration), available resources, healthcare infrastructure, laboratories, burden of chronic illnesses in the community etc
3. Build capacity of health care personnel to detect and treat water and food borne illnesses
4. Strengthen/ Develop real-time surveillance, evaluation and monitoring system for water and food borne illnesses, enhance this surveillance during high risk period
5. Issue advisory to healthcare personnel, laboratories and related stakeholders
6. Develop or translate IEC in local language, and make a communication plan for dissemination of health related alerts/ education materials.

7. Ensure adequate supplies (vaccines and medications) for cases management with other required logistic as identified to the affected region
8. Improve access to health care facilities by vulnerable population, especially those in remote areas.
9. Coordinate with related stakeholders like Municipalities to keep a check and strengthen surveillance of food handling units, local vendors, water supply etc.
10. Explore collaborative mechanisms (e.g. memoranda of understanding) with other departments, stakeholders for sharing of data and for coordinating efforts to manage health risks.

Coordination with other sectors in reducing water and Food borne illnesses

Department of Water & Sanitation

- Ensure minimum household safe water supply
- Reuse treated waste-water for non-household use
- Encourage water saving technologies like low-flow toilets & Showers, rain water harvesting etc

Municipalities and other Local regulating bodies

- Ensure safe water supply and good sanitation to check transmission of infective agents
- Regulate street vendors, food handling units for quality food

Ministry of Agriculture

- Develop/ encourage programs for efficient use of irrigation water.
- Promotion of climate resilient crops among farmers

FSSAI and other food regulatory body

- Check food items for various types of contamination or adulteration
- Disseminate appropriate information for reducing food borne illnesses

C. Air Borne, Cardio-pulmonary & Respiratory Allergic Diseases

Climate variability and frequent change in weather and extreme events affects have been linked to increase in illnesses of lungs and cardio-vascular system.

Vulnerability: Change in timing, survival, transmission & duration of certain microbes (like Influenza virus), Interaction of air pollution, pollen and weather, Proportion of population- malnourished, extremes of age, underlying illnesses, pregnant females, Commonest type of occupation, urban slums and remote rural areas, Socio-economic status, accessibility to health care

Role of Health Sector **(State Nodal Officer and Task Force)**

1. Develop/ adapt health micro-plan for 'Air borne, Cardio-pulmonary and Respiratory diseases (case management, resources required like logistics, drugs, vaccines, and laboratories' role).

2. Map vulnerabilities: population at risk, geo-climatic conditions, seasonal variation, exposure to pollens or allergens by change in types of crops or flower plants, change in population demography, migration (in & out), available resources, healthcare infrastructure, laboratories, burden of chronic illnesses in the community
3. Strengthen/ Initiate Sentinel surveillance, real-time surveillance, evaluation and monitoring system for respiratory and cardio-vascular illnesses, hospital admission as well as Outpatient attendance in relation to weather and air quality parameters.
4. Enhance vaccination programs and 'Vaccination Campaign' for vaccine-preventable air borne and respiratory diseases
5. Develop or translate IEC in local language, and make a communication plan for dissemination of health related alerts/ education materials.
6. Capacity building and increasing awareness for individuals, communities, health care workers through involvement of various media as well as campaigns and training workshops.
7. Develop Standard treatment guidelines for allergen management based on exposure forecasts – air quality, allergens, dust, etc.
8. Ensure adequate logistic support, including equipments and other treatment modalities and supplies for case management at all levels of health care and also under 'Emergency response Plan' in case of any disaster where air borne illnesses may occur as an outbreak
9. Inter-sectoral and stakeholders' coordination to monitor health outcomes with early warning system related to extreme weather events/ Air Quality Index/ ground level Ozone etc.

Coordination with other sectors for reducing respiratory and cardio-vascular illnesses

(Adapted from MoHFW's Steering Committee Report on Air Pollution & Health Related issues 2015)

Ministry of Environment, Forests and Climate Change

- Ensure that Central and State Pollution Control bodies set standards for industry-specific emission and effluent, monitor levels of pollutants and enforce penalties.
- Enforce strict air quality standards for pollution
- Strict implementation of Environment Impact Assessments (EIA) to minimize the adverse impact of industrial activities on the environment
- Effective implementation of 'National Green Tribunal' directives on trash burning/ waste disposal from different sources
- Take strict measures for unregulated sectors (such as brick kilns, trash burning, stone crushing) which contributes to ambient air pollution

Ministry of Human Resource Development

- Regular screening of school children for early detection of diseases, this can be attributed to the existing air pollution

- Inclusion of harmful health effects of environmental pollution (AAP and HAP) in the school curriculum, including current policies and mitigation practices that are designed to reduce air pollution
- Improve indoor air quality of educational institutions nationwide
- Improve walkability and access to educational institutions by non-motorised transport, thus minimizing the air pollution in the school surroundings
- Sensitize students and teachers on using the Air Quality Index in planning outdoor school activities

Ministry of Agriculture

- Policy in place to promote multiple uses of crop residues and prevent their on-farm burning.

Ministry of Rural Development

- Include health promotion (like clean air) guidelines as part of "Nirmal Gram Puraskar"/ Model Villages evaluation criteria/ create alternate awards with specific criteria based on air pollution.
- Under integrated rural development, develop and implement micro level planning policies/schemes with Panchayati Raj Institutions to address the social determinants of health for reducing the hazards of air pollution (lack of education, unemployment, poverty, poor housing conditions, etc.)

Ministry of Urban Development

- Formulate/revise urban transport policy which reduces vehicular pollution (Include Health Promoting city guidelines in the "100 Smart Cities")
- Develop and implement policies to reduce indoor air pollution (like disincentivizing diesel gensets and promoting clean cooking fuels thus 'making available clean and making clean available')
- Enforcement of ban on burning garbage or biomass (especially during winter months)
- Help cities develop air pollution alerts and emergency plans based on the Air Quality Index or CPCB continuous air monitoring data

Ministry of New & Renewable Energy

- Develop policies for truly clean cookstoves and support research and development.
- Research and development of other non-conventional/renewable sources of energy and programmes relating thereto, including locally generated power to supply cooking appliances;
- Support and strengthen Integrated Rural Energy Programme (IREP) with emphasis on indoor air pollution
- Develop National Policy on clean Biofuels (biogas, ethanol, etc) and set up National Biofuels Development Board for strengthening the existing institutional mechanism and overall coordination.
- Create a national consensus action plan for replacing biomass fuels with alternative clean fuels

Ministry of Petroleum & Natural Gas

- Expand new initiatives to increase the availability of LPG and other cleaner fuels to the rural & tribal areas
- Expand the piped natural gas network to reach out to a larger population
- Better target LPG subsidies to poorer households

Ministry of Power

- Promote the development of more efficient cooking devices
- Evaluate the potential for electric cooking appliances to substitute for biomass and LPG

Ministry of Road Transport and Highways

- Ensure effective implementation of New Motor Vehicles Act, once approved
- Ensure proper engine checks for vehicles to assess pollution levels

Ministry of Information and Broadcasting

- Develop hard hitting, high impact and cost effective media plans, strategies and conduct activities for awareness generation on harmful effects of air pollution and options for their mitigation.
- Ensure enforcement of relevant provisions in the Cable Television Networks Act to regulate advertisements of tobacco etc.
- Involvement of Songs & Drama division; Department of Field Publicity to promote health promotion activity for air pollution and its impact on respiratory and NCD risk factors
- Develop policies to ensure that media houses allocate free airtime for health promotion messages as a corporate social responsibility activity

Ministry of Communications & Information Technology

- Use of mobile phones to encourage healthy choices and warn people about air pollution (both AAP and HAP, using Air Quality Index)
- Establish Telemedicine linkages between different levels of health care

Ministry of Labour and Employment

- Regular health check- ups for early screening of pollution related diseases.
- Frame guidelines and conduct workshops for health promoting workplaces, (guidelines on indoor air quality),
- Strengthen the capacity of ESI Hospitals to cater to the growing burden of respiratory diseases and NCDs
- Showcase and support companies which employ workplace policies that can reduce vehicular travel such as telecommuting, or placing the workplace in sites that are accessible through public transportation (eg. Metro) or non-motorised transport.

Ministry of Women and Child Development

- Advocate through Self Help Groups and Mahila Mandals for protection of women and children from significant exposure to smoke from biomass while inside the house.

- Awareness raising can be done to improve household ventilation to reduce smoke inhalation from lighting (ex. kerosene) or cooking fuel

Ministry of Finance

- Analysis of the economic and financial implications of the health and other impacts of air pollution

Ministry of Law and Justice

- Support enforcement on bans of burning trash for heating or as a way of disposal

D. Vector-borne and Zoonotic diseases

Effect of variation in climate has been well established for illnesses which are spread through vectors or which are transmitted from animals to humans..

Vulnerability: Weather variables: temperature, rainfall, humidity, floods, drought, wind, daylight duration etc., Change in Vector / animal population due to change in growth, survival, feeding habits, seasonality, breeding sites, resistance etc, Change in interaction of vector/ animal & pathogen due to change in susceptibility, Incubation period, or transmission, Change in demography, migration, land-usage practices, water projects, agricultural practices and Public health infrastructure and access to it.

Role of Health Sector **(State Nodal Officer and Task Force)**

1. Programme Officer for National Programs for control of vector borne diseases (NVBDCP) & various zoonotic diseases must consider climate variability as an important factor for assessment of morbidity and mortality statistics and develop/ adapt health micro-plan based on recent VBD & Zoonotic diseases trend
2. Map vulnerabilities: population at risk, geo-climatic conditions, seasonal variation, change in population demography, migration (in & out), available resources, healthcare infrastructure, laboratories, etc.
3. Strengthen/ Develop active and passive surveillance and establish sentinel sites for vector borne & Zoonotic diseases.
4. Capacity building and increasing awareness for individuals, communities, health care workers through involvement of various media as well as campaigns and training workshops.
5. Develop or translate IEC on effects of climate change on VBDs & zoonotic diseases in local language, and make a communication plan for dissemination of health related alerts/ education materials.
6. Ensure adequate logistic support, including equipments and other treatment modalities and supplies for case management at all levels of health care and also under 'Emergency response Plan' in case of any disaster or an outbreak
7. Vaccination of animals and animal handlers for vaccine preventable diseases.

8. ‘Environmental Health Impact Assessment’ of new development projects
9. Early warning system for vector borne and zoonotic diseases.
10. Enforce legislation and regulations of vector borne and zoonotic diseases

<u>Coordination with other sectors for reducing VBDs & Zoonotic diseases</u>

(As per the suggested sectors in the NVBDCP)

- Inter-sectoral collaboration for vector control
- Providing equipments and other related logistics for control of vectors
- Elimination and reduction of vector breeding sites.
- Encourage research on new safe and effective control measures

Intervention by veterinary task force

- Prevention and control of animal diseases and zoonoses
- Vaccination of animals & control on population of stray animals
- Safe destruction of carcasses and other material of animal origin
- The care of ‘food animals’, including collection, feeding, sheltering, slaughtering etc

Intervention by Community & Individual

- Eliminate/ control small & manmade vector breeding sites
- Make barriers for human dwellings to keep stray animals away from human dwellings by fencing the residential areas especially if in approximation to forests etc.
- House protection by using screening windows, doors and fencing the garden etc.
- Use self protection measures like protective clothing etc,

E. Nutrition related diseases

Climate variability and extremes of weather events affect food quantity and quality through reducing production, poor storage, pathogen infestation, disrupted supply chain, hike in market price.

Vulnerability: Changes in food like availability, accessibility, utilization, system stability, crop failure/ yield decline. Indirect effects are due to reduction in animal/ aquatic population, agricultural yield

<u>Role of Health Sector</u> **(State Nodal Officer and Task Force)**

1. Develop/ adapt health micro-plan for reducing nutritional deficiency disorders
2. Map vulnerabilities based on seasonal nutritional screening (Vit A, Anaemia) in children, pregnant & lactating females high risk communities
3. Capacity building and increasing awareness for individuals, communities, health care workers through involvement of various media as well as campaigns and training workshops.
4. Strengthen/ Develop active and passive surveillance for nutritional deficiency diseases

5. Strengthening surveillance & control programs for diseases like malaria, schistosomiasis, parasitic infections
6. Scale up integrated food security, nutrition and health programmes in vulnerable zones for at risk populations
7. Strengthen maternal & child health services and promote implementation of IMNCI programme.
8. Expand & promote fortified food consumption in the vulnerable population
9. Develop or translate IEC, communication plan and mass media strategy for behaviour change of vulnerable population.
10. Capacity building and increasing awareness of the population through regular training workshops on health and nutrition education
11. Support and strengthen preventive programme on health nutrition (fortification and supplementation) and projects within public health divisions, with emphasis on community involvement projects.

Coordination with other sectors for reducing Nutrition related diseases

Ministry of Human Resource Development & Ministry of Women & Child Development

- Regular screening of school children for early detection of nutritional diseases.
- Inclusion of dietary guide in the school curriculum, with reference to Indian food habits.
- Sensitize students and teachers on nutritional deficiency, worm infestation and other Gastro-intestinal infections leading to malnutrition.

Ministry of Agriculture

- Promote agriculture practice addressing specific nutrition demand of general population and availability of same

F. Non-communicable Diseases (NCD) & Mental illnesses

Non-communicable diseases and mental disorders have been found to be closely associated with variation in climate, exposure to various types of pollutants and type of occupation

Vulnerability: Demography, Health status, Socio-economic status, type of occupation, accessibility to health care and diagnostic facilities, weather variables, exposure to pollution and Nutritional status

Role of Health Sector and related non-health sectors (State Nodal Officer and Task Force)

1. Establish & Integrate multisectoral mechanisms to plan, guide, monitor and evaluate and enactment of NCD through implementation of plans, policies and legislation

2. Adapt and implement WHO surveillance framework that monitors exposure (risk factors), outcome (morbidity and mortality), and health system response
3. Implement effectively the national health programmes aimed at reducing/ controlling NCD and mental illnesses.
4. Strengthen surveillance and monitoring for the high risk population and identify/ assess need in routine as well as in emergency situation (Emergency preparedness plans).
5. Ensure access to appropriate diagnostic facilities, related logistics and case management to the high risk population.
6. Define price regulatory mechanism for NCD drugs and basic diagnostic equipments and laboratory tests to increase affordability by the poor section of the society.
7. Risk communication, counselling and case management skills, should be available at all the levels including primary health-care level
8. Capacity building through training of human resource for addressing NCD related risk factors due to climate change.
9. Raise public and political awareness and understanding about NCDs including mental health, oral health, injuries and indoor air pollution through social marketing, mass-media and responsible media-reporting during extreme weather.
10. Assess the health impact of policies in non-health sectors e.g., agriculture, education, trade, environment, energy, labor, sports, transport, urban planning.
11. Strengthen supportive policies and legislations to promote healthy diet, reducing food with high transfat content, artificial colours and junk food
12. Strengthen capacity of the enforcement agencies (Police, Food Trade Inspectors and Road Safety Inspectors).
13. Provide adequate and sustained resources for NCDs by increasing domestic budgetary allocations, innovative financing mechanisms, and through other external donors

IX. NAPCCHH: ORGANISATIONAL FRAMEWORK FOR IMPLEMENTATION

Operational framework for implementation of National Action Plan for Climate Change and Human Health at National, States/UTs, District and Health-facility level is as follows:

National Level

A) National Level- Advisory Committee

This committee shall function under the Chairmanship of Secretary Health & Family Welfare. The proposed members of this committee are:

Secretary Health & Family Welfare	***Chairman***
Additional Secretary, Health, MoHFW, GOI	Member
Secretary Health Research cum Director General- ICMR, GOI.	Member
Director General Health Services, GOI	**Vice-Chairman**
Director, NCDC, Dte.GHS, MoHFW, GOI	**Member Secretary**
Director, NVBDCP, Dte.GHS, MoHFW, GOI	Member

Representation from other Ministries/ departments

Director General, National Disaster Management Authority	Member
Secretary, Ministry of Environment, Forest & Climate Change	Member
Secretary, Ministry of Earth Sciences	Member
Secretary, Ministry of Agriculture	Member
Secretary, Central Ground Water Board, Ministry of Water Resources, Rural Development and Ganga Rejuvenation	Member
Chairman, Central Pollution Control Board	Member
Representation from Department of Science & Technology	Member

Roles and Responsibilities of the National Level Advisory/ Steering Committee

- Nodal body to take decision regarding the policy making and implementation of the National Action Plan for Climate Change and Human Health (NAPCCHH) in the country.
- Nodal body to roll out the NAPCCHH in the country.

B) ***National Level- Centre for Environmental & Occupational Health Climate Change & Health (CEOH&CCH)*** *at National Centre for Diseases Control*. This centre is nodal agency for Climate Change & Human Health and will provide technical inputs and support to Environmental Health Cell at state and UTs regarding the capacity building, implementation, monitoring, supervision & evaluation of the NAPCCH program. Director, NCDC is the Nodal Person and Member-Secretary of Climate Change and human Health. The proposed manpower structure at this centre is as follows:

Additional Director & Head (Public Health)	1
Joint Director (Public Health)	3
Deputy Director (Public Health)	3
Assistant Director (Public Health)	6
Senior Consultant-Capacity building/ Training	2
Senior Consultant-Environmental Health Specialist	2
Senior Consultant-Monitoring & Evaluation	1
Senior Consultant- Public Health Informatics Specialist	1
Consultant- Finance & Admin	1
Consultant- Communication/ Advocacy	1
Technical Officer-Data Management	3
Secretarial Assistants cum Data Entry Operators	3

Roles and Responsibilities of the CEOHCCH Division, NCDC are:

- Technical inputs to be provided to all states and UTs for activities related to climate change and human health.
- Plan, Coordinate, Monitor and evaluate NAPCCHH related activities at National, State and below level
- Support states and UTs for development of health adaptation plan and operational guidelines for Climate Sensitive Diseases'.
- Review meetings, field observations regarding implementation of NAPCCHH.
- Strengthening of Surveillance of Climate Sensitive Diseases
- Strengthening of health care system by involving premiere institutes and organisation for disease management

- Development of prototype of IEC and advocacy material, training modules for healthcare personnel, revision of students' curriculum.
- Guiding state health department for providing list of required manpower, logistics, drugs and equipments for managing climate sensitive illnesses.
- Conduction of operational research and evaluation studies for the NAPCCHH

For coordination with other stakeholders, government departments at National and states/ UTs level in the country, the Environmental Health Cell at the Directorate General Health Services will support CEOHCCH division at NCDC. It will help assess the achievement of targets planned under the NAPCCHH programme.

State Level:

A) *State Level - Governing Body*

The state level governing body shall be working under Chairmanship of Honourable State Health Minister. The other members may be as follows:

Honourable State Health Minister	*Chairman*
Principal Secretary (Health*)*	*Vice Chairman*
Director Health Services/Head of Health System	Member Secretary
Mission Director-National Health Mission	Member
Director Medical Education	Member
Regional Director -Health & Family Welfare	Member

B) *State Level Task Force*

This task force shall be working under the guidance of Principal Secretary (Health) of the state. It shall be directly overseeing the implementation of the State Action Plan for Climate Change and Human Health (SAPCCHH) in their state/UT. It shall be working through Directorate of Health Services (DHS) of the state, which will be the implementing agency for SAPCCHH.

DHS will create an ***Environmental Health Cell*** within State Health Department, and will identify a ***Nodal Officer*** from Health department which preferably should be Public Health Expert of the rank of Joint/ Deputy Director. The State level task force shall have inter-ministerial members which are suggested as:

- *Public Health Expert* from State Health Department **Nodal Officer**
- Director, ICMR Institute/Centre (If any branch in the State/UT) Member

- Director, Meteorological department of State/UT Member
- Chairman, State Pollution Control Board Member
- Chairman, State Disaster Management Authority Member
- State Surveillance Officers Member
- Environmental Engineer/ Scientist from MOEFCC Member
- Secretary, State Agriculture Ministry Member
- Secretary, State Ground Water Board Member

The Task force of the State/ UT's Environmental Health Cell will coordinate with the Centre for execution of state/ UTs SAPCCHH. The proposed State Level Structure of Environmental Health Cell is as follows:

Structure at State/ UT Environment Health Cell:

Nodal Officer (State Health Department)	***1***
Consultant-Capacity building/ Training/ HR Management	***1***
Consultant-Environmental Health	***1***
Data Manager & Analyst	***1***
Secretarial Assistants cum Data entry Operator	***1***

Roles and Responsibilities of the State/ UT Environmental Health Cell

- Preparation and Implementation of State Action Plan for Climate Change and Human Health
- Conduct Vulnerability assessment and risk mapping for commonly occurring climate sensitive illnesses in the state/ UT.
- Assessment of needs for health care professionals (like training, capacity building) and organise training, workshop and meetings.
- Maintain State and District level data on physical, financial, epidemiological profile for climate sensitive illnesses.
- Ensure Convergence with NHM activities and other related programs in the State / District
- Monitor programme, Review meetings, Field observations.
- Timely issue of warning/ alerts to health professionals and related stakeholders as well as general public through campaign or using mass media (Electronic or printed),

- ➢ Social mobilization against preventive measures through involvement of women's self-help groups, community leaders, NGOs etc.
- ➢ Advocacy and public awareness through media (Street Plays, folk methods, wall paintings, hoardings etc.)
- ➢ Conduction of operational research and evaluation studies for the Climate change and its impact on human health.

District Level:

At District level, a District Environmental Health Cell shall be constituted; which shall be comprised of the following:

The proposed District Level Structure is as under:

• District Magistrate/ District Commissioner	Chairman
• Chief Medical Officer/ CDHO	Member Secretary
• Deputy CMO (Admin)	Member
• Senior Deputy CMO	Member
• DMO/DVBDOPO	Member
• District Health Education Information Officer	Member
• District Coordinator	Member

Structure at District Environment Health Cell:

District Coordinator	***1***
Data entry operator	***1***

Roles and Responsibilities of the District Environmental Health Cell

- ➢ Preparation and Implementation of District Action Plan for Climate Change and Human Health.
- ➢ Conduct Vulnerability assessment and risk mapping for commonly occurring climate sensitive illnesses in the district.
- ➢ Maintain and update district database of illnesses identified in the district.
- ➢ Assess needs for health care professionals and conduct sub-district/ CHC level training/ workshop and meetings for capacity building.
- ➢ Ensure appointment of contractual staff and engage them in the assigned task of data management under the NAPCCHH.
- ➢ Maintain District level data on physical, financial, epidemiological profile for these illnesses.

Community Health Centre Level

The proposed CHC Level Structure is as under:

- Medical Superintendent (CHC Hospital) :Chairman
- Health Education Officer :Member Secretary
- Block Development Officer :Member
- Health Supervisor :Member

Health Facility Level:

At the health facility, the responsibility for implementation will lie with the Medical Officer (In-charge) of the facility. The existing machinery of NHM will be utilised for the related activities. The Rogi Kalyan Samiti (RKS) would be reviewing and monitoring implementation at the health facility level. The ANM, ASHA and Anganwadi worker will assist in activities related to implementation of action plan at local level.

X. NAPCCHH: CAPACITY BUILDING AND SYSTEM AWARENESS

Capacity building will be based on the baseline and follow-up situation which should be assessed periodically. Communication and training are crucial in adaptation to variability or changes in the climate. Communication programmes based on a thorough needs assessment must aim to enable and empower people, in particular, the illiterate, poor and other vulnerable people such as women, children, the elderly, people suffering from debilitating medical problems and those living in coastal areas, highlands and urban slums. Such programmes should have adequate and appropriately designed communication tools that are locally suitable, popular and comprehensible.

- ✓ Effective communication and public awareness activities/advocacy: sensitize, orient and take support of leaders/ opinion makers / stakeholders/ celebrities/ civil societies.
- ✓ Communication intervention for target audience: Appropriate, efficient and cost-effective measures include clear and timely information covering who is involved; what happened; when it happened; where it happened; and why or how it happened or what may happen – how, why, where, among whom and how to face it.
- ✓ National and Regional level capacity building institutions needs to be identified for capacity building of health staff: include training and imparting technical skills for case management, risk assessment skills, entomology, epidemiology, climate models, disaster management, meteorology, monitoring and evaluation, and research.
- ✓ Conducive institutional and management arrangements to ensure involvement of private sector by forming public private partnerships.
- ✓ Hospital and all other health-care systems must be strengthened. Involve community in the process of strengthening and in managing and maintaining the system.
- ✓ Inventory management: standardized list of adequate and appropriate logistics medicines, kits, equipment and machines along with efficient storage systems.
- ✓ Specific strategies and standard operating procedures for managing climate sensitive diseases need to be developed in light of the future impacts of climate change with prevention in mind.
- ✓ Communication interventions in schools are effective approaches for which teachers would need materials and training to educate the children.

XI. NAPCCHH: REPORTING, MONITORING AND EVALUATION

The Monitoring & Evaluation of the implementation of NAPCCHH has been stipulated with a mix of internal and external approaches. MoHFW, State DoHFW, District Health Officers and the individual health facilities will be involved in regular internal monitoring. External Monitoring will be done by an independent agency.

a) **Internal:** Monthly / quarterly progress monitoring for climate sensitive illnesses has to be done at all levels, i.e. District to State to MoHFW. These Monthly / Quarterly Progress Reports should include a collation / aggregation of the data / information compiled in each health care facility. The District Cell will have the responsibility of collation / aggregations of the data / information compiled in each health care facility and submit to the State Cell which will validate and forward the data to the National Cell. A set of indicators for NAPCCHH implementation should be merged with the overall HMIS that has been established under the NHM.

b) **External:** Each state should commission an independent evaluation every 2 years. At the minimum, the audit should cover one well performing district and one slack performing district. The agency to conduct the NAPCCHH Implementation Audit should be chosen based on the background, experience in the State's health sector, environmental auditing and reputation of reliability. The recommendations of the audit should be developed into an action plan to strengthen the existing system.

XII. FRAMEWORK FOR STATE SPECIFIC ACTION PLAN FOR CLIMATE CHNAGE AND HUMAN HEALTH

India is a diverse country in terms of geography, climatic conditions, resources and health related infrastructure. Also, it is a highly populous country, undergoing rapid industrialisation, unplanned urbanization, increasing malnutrition and having triple burden of diseases comprising of communicable, non-communicable, emerging and re-emerging diseases. All these factors have cumulative effect resulting in risk of ill- health of citizens of India.

States have developed Action Plan on Climate Change (available at MoEFCC's website), but, 'health related component' is missing in it. Hence all states and Union Territories are being encouraged to develop their State-specific Action Plan on Climate Change and Human Health (SAPCCHH). The broad suggested framework for the same is as follows:

1. Background

(Following Data has to be compiled district wise)

Geo-physical & Climate variables: Type of area (Plain/ Mountain/ Desert/ Coastal), type of Climatic or extreme events (heat/ cold/ drought/ flood/ cyclone/other) usually occurring in the state/ UT with potential to affect health status of the population. Approximate green cover and recent change in green cover/ forest, if any.

Statistics of state/ UT: Population (Total, Population density), Vulnerable Population (Under five Children, Adolescents, Elderly, migrants and Occupation (Primarily for major population and others).

Health care Infrastructure: Enlist the number of Health care Infrastructure/ facilities like PHC, CHC, District hospital, Tertiary care hospitals- Government as well as Private in State/UTs (preferably District wise).

Enlist and identify roles and responsibilities of operational district level bodies relevant to climate change and their constitution, such as Distt. Disaster Management Authority, Disease Surveillance Programmes, Distt. Health Information System, district unit of Departments of Meteorology, Pollution Control Board, Water and Sanitation, Public Works Departments and civil societies etc.

2. Operational Framework at State Level

Governing Body

The state level governing body for policy level decision may be constituted under Chairmanship of Honourable State Health Minister or any other Senior Officer. The suggested body is as below:

• Honourable State Health Minister	Chairman
• Principal Secretary (Health)	Vice Chairman
• Director Health Services/Head of Health System	Member Secretary
• Director Medical Education	Member
• Mission Director-National Health Mission	Member
• Regional Director -Health & Family Welfare	Member

(*However, State may take its own decision*).

Task Force: The task force under the guidance of Principal Secretary (Health) with Directorate of Health Services (DHS) of the state, and will ensure implementation of the State Action Plan for Climate Change and Human Health (SAPCCHH) in their state/UT.

Environmental Health Cell within State Health Department, DHS may identify a Nodal Officer from Health department, preferably should be Senior Public Health Expert. The State level task force shall have inter-ministerial members which are suggested as:

• Public Health Expert from State Health Department	Nodal Officer
• Director, ICMR or other Research Institute	Member
• Director, Meteorological department of State/UT	Member
• Chairman, State Pollution Control Board	Member
• Chairman, State Disaster Management Authority	Member
• Environmental Engineer/ Scientist from MOEFCC	Member
• Secretary, State Agriculture Ministry	Member
• Secretary, State Ground Water Board	Member
• State Surveillance Officers	Member

The details of Nodal Officer and experts in Task Force like name, designation, contact details (Phone number, postal address and email) should be listed in the SAPCCHH.

3. Current status of Climate Sensitive Illnesses

- Identify, assess, and document potential risks of climate sensitive diseases (as applicable to the state) like
  - Extreme weather events affecting health
  - Vector Borne diseases
  - Water & Food Borne disease
  - Cardio-respiratory illnesses
  - Zoonotic diseases
  - Others like renal diseases, nutritional deficiency disease etc

- Document Morbidity, Mortality and related statistics of these Climate Sensitive diseases with reference to change in recent years.
- Risk Mapping to identify the 'Hot spots' for vulnerable population with respect to health infrastructure and other resources.

4. Adaptation strategy and action plan for each of the illnesses/ diseases sensitive to Climate variability (as listed in point 3 above)

- List the stakeholders with defined roles and responsibilities (Govt. & non-Govt)
- Identify and list the resources available
- Identify actions for risk reduction that are agreed upon by stakeholders and the public
- Operational Coordination (Stakeholders' role and involvement): Building partnerships by involving citizens, organizations, and businesses.
- Make a detailed action plan with checklist for each identified climate sensitive illness:
    - Logistics required at health care facilities
    - Preparedness of health system and personnel
    - List activities for prevention of illnesses (IEC, pamphlets, advisories, training, workshop etc).
    - Operational communication channel
    - Mechanism to ensure data maintenance, surveillance, timely sharing with concerned departments and stakeholders.

5. List Actions undertaken and further proposed to reduce the burden of Climate sensitive illnesses at State/UT

- Activities conducted and planned for awareness generation on the health impacts of climate change
- Activities conducted and proposed to integrate climate-sensitive health concerns in respective health programmes or policy.
- Activities undertaken if any and further proposed to train health workforce on climate change.
- Actions undertaken if any and further proposed to ensure unaffected water supply, sanitation, waste management and electricity.
- Activities undertaken and further proposed related to greening of health sector i.e. health facilities use energy-efficient services and technologies.
- Activities undertaken and further proposed related to integration with State Disaster Management Authority for emergency risk reduction and early response.

- Activities undertaken and further proposed related to data collection and analysis, strengthening of surveillance related to climate variable and climate change sensitive illnesses.

6. Miscellaneous

- Diseases Specific Action plan/ Advisory/ IEC prepared if any, please enumerate and may kindly share with NCDC at email: ncdc.env@gmail.com.
- Other factors (if any) contributing to increase/ decrease of climate sensitive illnesses in your state
- How effective are current health and other sector policies and programmes to manage the climate sensitive illnesses in your state/UT.
- Success Stories if any, of the State/ UT health sector for adaptation or mitigation of climate sensitive illnesses.
- Research studies, reports, innovative actions etc related to climate change and human health if taken in the state must be shared with CEOHCCH division at NCDC for sharing it further with our states and UTs.

(Note: The indicators related to input process, output and outcome shall be added in the State Action Plan during subsequent meetings at time of firming up the State Action Plan for Climate Change and Human Health).

Regional Consultations

The *Centre for Environmental and Occupational Health Climate Change & Health*, National Centre for Disease Control, Delhi, conducted four regional consultations in 2017-18 involving all the states and Union Territories' of the country. Officials from Health department and related stakeholders were invited in these consultations.

Regional consultations aimed at sensitising states and Union Territories on reassessment of diseases' morbidity and mortality with respect to climate variability and extremes have been conducted. Prior to these regional consultations, the states and UTs were requested for:

1. Identification of *Nodal Person for Climate Change* from *State Health Department.*
2. Constitution of *"State Environment Health Cell"* at State Health Ministry level.
3. Notification of a Task Force with experts from other departments/ organisation or other stakeholders identified by state.

These regional consultations had participations from ministries and department of states and UTs including Senior Regional Directors, Regional Directors from Regional Office of Health & Family Welfare, State Nodal Officers, State Surveillance Officers, National Vector Borne Diseases Control Programme, Officers from Integrated Diseases Surveillance Programme, representatives from identified Centre of Excellence, representatives from Regional Centre of Meteorological Departments, Ministry of Environment Forest and Climate Change and Central Ground Water Board. The states and UTs' representatives were aware of the urgency and serious concern for the agenda of the consultation.

State health teams were expected to list and prioritize climate sensitive illnesses in their state and UTs, compilation of data on morbidity and mortality, statistics related to vulnerable population, geographical factors, health care infrastructure/ facilities, or any mitigation and adaptation measures adopted by state against impact of climate change on human health. The salient points of recommendations of regional consultations are as follows:

- Representative from Regional Centre, Indian Meteorological Department suggested to use the term '*Climate Variability'* to study the health consequence as Climate Change is more vast and generic term.
- The geographical distribution, mapping and epidemiology of the diseases like vector borne, water borne etc should be done at the earliest in each state/ UT.
- "*Personal Cooling Garment*" or equivalent devices developed by other agencies may be advocated for use if it is (these are) found appropriate.
- Existing surveillance system like IDSP should be used for disease related data capture, through expanding of reporting units and regularly conducting review meetings may be weekly.
- As population is indirectly related and resulting to climate change, population policy may be revised.
- Vector survival and breeding are known to be affected by the climate variability hence programme on vector borne diseases control should be revised to check diseases occurrence in new areas.
- For dealing with the extreme heat events, reconsider the following for issue of health related advisories:
    - OPD timings in healthcare settings
    - Drugs and vaccine storage
    - Norms for Working hours at workplace
    - School timings etc

- Detailed plan for each climate sensitive illnesses should be laid down by each state/ UT considering planning for present illnesses and also with scope to include new/ emerging or re-emerging climate sensitive illnesses.
- The state while drafting their state health action plan for climate change should also refer the Joint Monitoring Meeting report of IDSP.
- Rapid Response Teams may be trained at state level using infrastructure of CSU, IDSP and medical colleges.
- Participants proposed rules and regulations formulation should be in place for the factors which are directly or indirectly affecting weather and climate and hence the human health.
- Actionable points/ good initiatives/ practices should be shared so as the same can be adopted by other states/ UTs.
- Chairman proposed a 'Climate Change Health Forum' to include all experts as informal members. This forum will help in sharing of experience, meeting outputs and further it will bring all together to contribute in terms of feedback, suggestions,

XIII. NAPCCHH: BUDGET

The proposed activities under NAPCCHH focus primarily on awareness generation, sensitisation for effect of climate on occurrence of CSD, making of health system climate resilient, capacity building of states and UTs for preparing their specific action plan for climate change, promotion of partnership with multiple stakeholders and strengthening of monitoring, surveillance of CSDs in a geographic area and encouraging research for identifying linkages between weather parameters and diseases in a geographic area and supporting evidence based building capacity of health personnel.

To undertake proposed activities, it requires establishment of an 'Environment Health cell', hiring of experts and other human resources on the subject, arrangement of logistics/ equipments, carrying out capacity building activities like training and meetings, development of IEC material and advisories (*Dissemination cost of IEC material cost is not included in the first year of proposed budget*), development of Health Adaptation Plan and prediction model for developing early warning system for climate sensitive diseases.

The tentative budget proposal of NAPCCHH has been proposed under the NHM through EPC. The proposed sub-heads are as a) Human Resource (Contractual), b) Logistics/ Equipments, c) Trainings/ Meetings/ Workshops, d) Centre of Excellence (initially six in first year), e) Development of pilot models like Integration, Green hospitals etc, f) Development of prototype of IEC/ Advisory for impact of Climate Change on Human health (do not include dissemination cost) and g) Air pollution and Human health (do not include dissemination cost).

The budget for states and UTs: As the states and UTs are in the initial phase of establishment of 'Environment Health cell', identification of State Nodal Officer (CC) and notification of Taskforce involving multiple stakeholders. Hence it is proposed that once the initial phase is complete, state should propose their budget through State PIP and the same will be released only after the establishment of Environment Health Cell in the Health department of State/UT. The tentative annual budget is at Annexure-E

XIV. REFERENCES

1. IPCC. Summary for policymakers. In: Stocker TF, Qin D, Plattner,GK, Tignor M, Allen SK, Boschung J, et al., editors. Climate Change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press; 2013 (https://www.ipcc.ch/report/ar5/wg1/citation/WGIAR5_Citations_FinalRev1.pdf).
2. IPCC. Summary for Policymakers. In: Edenhofer O, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B., Kriemann JS, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx editors. Climate Change 2014, Mitigation of Climate Change Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA.: Cambridge Univ Press; 2014.
3. IPCC. Glossary. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, et al., editors. Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press; 2014.
4. Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.). 2007. Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK; and New York: Cambridge Univ Press.
5. Chapter 11, Human Health: Impacts, Adaptation, and Co-Benefits http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap11_FINAL.pdf & https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/drafts/fd/WGIIAR5-Chap11_FGDall.pdf
6. http://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf
7. Human Health; https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter8.pdf &
8. http://unfccc.int/essential_background/convention/items/6036.php.
9. http://unfccc.int/meetings/cancun_nov_2010/items/6005.php
10. http://unfccc.int/key_steps/durban_outcomes/items/6825.php
11. http://unfccc.int/paris_agreement/items/9485.php
12. http://www.moef.gov.in/sites/default/files/introduction-nep2006e.pdf
13. http://www.who.int/mediacentre/news/releases/2016/deaths-attributable-to-unhealthy-environments/en/
14. http://www.cdc.gov/climateandhealth/effects/
15. http://www.who.int/globalchange/publications/WMO_WHO_Heat_Health_Guidance_2015.pdf?ua=1
16. Rooney, C., A.J. McMichael, R.S. Kovats and M.P. Coleman, 1998: Excess mortality in England and Wales, and in Greater London, during the 1995 heat wave. J. Epidemiol. Comm Health, 52(8): 482–486.
17. Monika Nitschke, Graeme R Tucker , Alana L Hansen , Susan Williams , Ying Zhang and Peng Bi; Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis; http://www.biomedcentral.com/content/pdf/1476-069X-10-42.pdf%5D.
18. De, U.S. and Mukhopadhyay, R.K. (1998). Severe heat wave over Indian subcontinent in 1998 in a perspective of global Climate. Current Science, 75, 12: 1308-1311.
19. Mohanty, P. and Panda, U. (2003). Heat wave in Orissa: A study based on heat indices and synoptic features. Regional Research Laboratory, Institute of Mathematics and Applications, Bhubaneswar, 15.
20. Joon V, Jaiswal V: Impact of climate change on human health in india: an overview; Health and Population - Perspectives and Issues 35(1), 11-22, 2012
21. Vikas K Desai, Urvi Patel, Suresh K Rathi, Shailesh Wagle, Hemant S Desai: Temperature and Humidity Variability for Surat (coastal) city, India; International Journal of Environmental Sciences Volume 5, No 5, 2015.
22. J. Schnitzler, J. Benzler, D. Altmann, I. Mucke, G. Krause; Survey on the population's needs and the public health response during floods in Germany 2002; J Public Health Manag Pract, 13 (2007), pp. 461–464.
23. T. Jakubicka, F. Vos, R. Phalkey, M. Marx; Health impacts of floods in Europe: Data gaps and information needs from a spatial perspective MICRODIS report, Centre for Research on the Epidemiology of Disasters — CRED, Brussels, Belgium (2010) http://www.cred.be/download/download.php?file=sites/default/files/Health_impacts_of_floods_in_Europe.pdf
24. Paranjothy, J. Gallacher, R. Amlot, G.J. Rubin, L. Page, T. Baxter, J. Wight, D. Kirrage, R. Mcnaught, S.R. Palmer; Psychosocial impact of the summer 2007 floods in England; BMC Public Health, 11 (2011), p. 145.

25. Health Protection Agency: Annual report and Accounts 2012/13; https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/246760/0174.pdf
26. Pope, C.A. III, and D.W. Dockery. 2006. Health Effects of Fine Particulate Air Pollution: Lines That Connect. Journal of the Air & Waste Management Association 56(6): 709–42.
27. World Health Organization. 2006. Air Quality Guidelines: Global Update 2005-Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Copenhagen, Denmark: World Health Organization.
28. Rajarathnam U, Sehgal M, Nairy S, Patnayak RC, Chhabra SK. , Kilnani, et al. 2011. Part 2. Time-series study on air pollution and mortality in Delhi. Res Rep Health Eff Inst 157:47–74.
29. NSS; 68th round; http://mospi.nic.in/mospi_new/upload/nss_report_567.pdf
30. Norval M, Lucas RM, Cullen AP, et al. The human health effects of ozone depletion and interactions with climate change. Photochem Photobiol Sci 2011;10(2):199-225.
31. Armstrong BK. Stratospheric ozone and health. Int J Epidemiol 1994;23(5):873- 885.
32. Armstrong BK, Kricker A. The epidemiology of UV induced skin cancer. Photochem Photobiol B 2001;63:8-18.
33. Stern RS, Weinstein MC, Baker SG. Risk reduction for non-melanoma skin cancer with childhood sunscreen use. Arch Dermatol 1986;122:537-545.
34. World Health Organization. Sun Protection and Schools: How to Make a Difference. Geneva: WHO, 2003.
35. Hammond V, Reeder AI, Gray A. Patterns of real-time occupational ultraviolet radiation exposure among a sample of outdoor workers in New Zealand. Public Health 2009;123:182-187.
36. Gies HP, Roy C, Toomey S, MacLennan R, Watson M. Solar UVR exposures of three groups of outdoor workers on the Sunshine Coast, Queensland. Photochem Photobiol 1995;62:1015-1021.
37. World Health Organisation; Ambient (outdoor) air quality and health: http://www.who.int/mediacentre/factsheets/fs313/en/
38. Health & Environmental Effects of Air Pollution; http://www.mass.gov/eea/docs/dep/air/aq/health-and-env-effects-air-pollutions.pdf
39. World Health Organisation; Household air pollution and health; http://www.who.int/mediacentre/factsheets/fs292/en/
40. Singh PK, Dhiman RC: Climate change and human health: Indian context. http://www.ncbi.nlm.nih.gov/pubmed/22898475
41. Bhattacharya P, Sarkar S; Cerebral malaria caused by Plasmodium vivax in adult subjects; http://www.ijccm.org/article.asp?issn=0972-5229;year=2008;volume=12; issue=4;spage=204;epage=205;aulast=Sarkar.
42. Akhtar R, Seth RK, Sharma C, Chaudhary A et al: Assessing the relationship between climatic factors and diarrhoeal and vector-borne disease – a retrospective study Generic Research Protocol: A World health Organisation- SEARO report
43. Dhiman RC, Pahwa S, Dhillon GPS, Dash A: Climate change and threat of vector-borne diseases in India: Are we prepared? https://www.researchgate.net/publication/41429754_Climate_change_and_threat_of_vector-borne_diseases_in_India_Are_we_prepared.
44. Panic M, Ford JD: A Review of National-Level Adaptation Planning with Regards to the Risks Posed by Climate Change on Infectious Diseases in 14 OECD Nations. Int J Environ Res Public Health. 2013 Dec; 10(12): 7083–7109. Published online 2013 Dec 12. doi: 10.3390/ijerph10127083 PMCID: PMC3881155.
45. Morgan O, Ahern M, Cairncross S. Revisiting the Tsunami: Health consequences of flooding. PLoS Med. 2005;2:491–3.
46. Mandal S;Cholera Epidemic in and Around Kolkata, India: Endemicity and Management Oman Med J. 2011 Jul; 26(4): 288–289. PMCID: PMC3191718 doi:10.5001/omj.2011.71. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3191718/
47. Rudolph L; Towards sustainable groundwater management in the agricultural landscape, University of Waterloo; Published April 2015; http://www.cwn-rce.ca/assets/End-User-Reports/Agri-Food/Rudolph/CWN-EN-Rudolph-2015-5Pager-Web.pdf
48. NFHS-3 2005-06,; http://rchiips.org/nfhs/nutrition_report_for_website_18sep09.pdf
49. Kumar H, Venkaiah S, Kumar S, Vijayraghavan K; Diet and Nutritional Situation of the Population in the Severely Drought Affected Areas of Gujarat; https://www.researchgate.net/publication/237522677_Diet_and_Nutritional_Situation_of_the_Population_in_the_Severely_Drought_Affected_Areas_of_Gujarat

LIST OF ABBREVIATIONS

WHO	World Health Organisation
IPCC	Intergovernmental Panel on Climate Change
IPCC SREX	Intergovernmental Panel on Climate Change -Special Report on Extreme Events
UV	Ultraviolet
GOI	Government of India
NGO	Non-Governmental Organisation
NIMR	National Institute of Malaria Research
IITM	Indian Institute of Tropical Meteorology
IMD	India Meteorological Department
DGHS	Director General of Health Services
ICMR	Indian Council of Medical Research
MOHFW	Ministry of Health & Family Welfare
MOEF&CC	Ministry of Environment, Forest and Climate Change
NCDC	National Centre for Diseases Control
NDMA	National Disaster Management Authority
MHRD	Ministry of Human Resource Development
NEERI	National Environmental Engineering Research Institute
TERI	The Energy and Resources Institute
PHFI	Public Health Foundation of India
UNICEF	United Nations International Children's Emergency Fund
IEC (ICT)	Information Education Communication (Information and communications technology)
EWS	Early Warning System
PHC,	Primary Health Care
CHC	Community Health Centres
V&A	Vulnerability and Adaptation Assessments for Climate Change assessments
FSSAI	Food Safety and Standards Authority of India
MHA	Ministry of Home Affairs
DHR	Department of Health Research
DST	Department of Science & Technology
DOS	Department of Space
GIS	Geospatial Information System
ENSO	El Niño-Southern Oscillation

PRECIS	Providing Regional Climates for Intervention Studies
HADCM3	Hadley Centre Coupled Model, version 3
Ministry of I&B	Ministry of Information & Broadcasting
MCI	Medical Council of India
Dy.DG	Deputy Director General
DoHF&W	Department of Health & Family Welfare
NAPCCH	National Action Plan on Climate Change & Health
RKS	Rogi Kalyan Samiti
NHM	National Health Mission
PIP	Programme Implementation Plan

Constitution of NEGCCH: Office Order

साधारण
ORDINARY

T-25013/03/2015-NCD
Government of India
Ministry of Health and Family Welfare

Nirman Bhawan, New Delhi
Dated 2[?] July, 2015

ISSUED
MINISTRY OF HEALTH & F.W.

OFFICE ORDER

Subject: - Constitution of National Expert Group on Climate Change and Health

Pursuant to the decision to establish a Health Mission on Climate Change, the Government hereby constitutes an Expert Group comprising representatives from different Ministries, Institutions, State Governments and Special Invitees as under:

Composition of the Expert Group

Sl.No	Name and Designation	
1	Dr Vishwa Mohan Katoch, Former Secretary (Health Research), Government of India & Former DG ICMR	**Chairperson**
2	Joint Secretary (PH), Ministry of Health & Family Welfare, GOI	**Members**
	Joint Secretary (NCDs), Ministry of Health & Family Welfare, GOI	
	Joint Secretary (VBDs), Ministry of Health & Family Welfare, GOI	
3	Director (NVBDCP), Dte.GHS, MOH&FW, GOI	
	Dy. Director General (PH), Dte.GHS, MOH&FW, GOI	
	Dy. Director General (NCD), Dte.GHS, MOH&FW, GOI	
4	Representative of National Disaster Management Authority*	
5	Representative of Ministry of Environment Forest & Climate Change*	
6	Representative of Ministry of Earth Sciences*	
7	Representative of Central Ground Water Board, Ministry of Water Resources, River Development & Ganga Rejuvenation*	
8	Representative of Ministry of Agriculture*	
9	Representative of ICMR, New Delhi*	
10	Chairman, Central Pollution Control Board, New Delhi or his representative*	
11	Director / Director General Health Services from the State Governments**	
14	Director, National Centre for Disease Control, Delhi	**Member Secretary**

*Joint Secretary level representative from Ministries / Departments / Institutions.
** Representative from the State Governments of Maharashtra, Uttarakhand and Odhisa at present.

Special Invitees:

Sr.no	Name and Designation
1	WHO India Country Representative, New Delhi
2	Dr K Srinath Reddy, President, Public Health Foundation of India, New Delhi
3	Director, Calcutta School of Tropical Medicine, Kolkotta
4	Director, Centre for Environment and Occupational Health, MAMC, New Delhi
5	Director, National Environmental Engineering Research Institute (NEERI), Nagpur
6	Director, The Energy and Resources Institute (TERI)
7	Dr (Ms) H Achyuthan, Dept. of Geology, Anna University, Chennai
8	Dr R Nigam, Scientist F, Dy. Director, Geological Oceanography Division, National Inst. Of Oceanography, Goa

The MoH&FW, Govt. of India, may add members / experts to the said expert group as per requirement.

Terms of Reference

(1) Prepare an Action Plan for climate change, environment and human health
(2) Recommend strategies for mitigating adverse effects of climate change on human health
(3) Review epidemiological data on environment health and climate change
(4) Recommend strategies including indicators for monitoring and evaluation of health impact of climate change
(5) Recommend coordination mechanism with various stakeholders
(6) Recommend means of financial assistance to States and other Agencies working in the field of health and environment / climate change
(7) Suggest ways for building capacity in different areas of health including human resources, infrastructure and research for addressing the issues emanating from climate change
(8) Recommend National Environment Health Policy and Strategy
(9) Any other matter as requested by MoH&FW, Govt. of India

Meetings and Report

The "Expert Group" will meet as required with the objective to submit an interim report by the end of 3 months and a final report by the end of 6 months from the date of this office order.

All financial expenditure towards organizing meetings of the "Expert Group", including TA/DA, etc. will be borne under the NCDC Budget as per Govt. of India norms. TA/DA of government officials will be borne by their respective organizations as per Govt. of India norms. TA/DA of non-official members (including Special Invitees) will be provided by NCDC as per eligibility and as per Govt. of India norms. The outstation non-official members shall be entitled to economy class to & fro airfare as per applicable rules.

(A.K. Arora)
Deputy Secretary to the Government of India
Tele: 23061975

Distribution:

Chairperson and all Members / Special Invitees of the "Expert Group" on Climate Change and Health

Copy with request to nominate appropriate level officer as indicated in the OM for "Inter Ministerial Expert Group" to:-

1. Secretary, MOEF&CC / Secretary, Ministry of Earth Sciences / Chairman, NDMA Secretary, Ministry of Water Resources, RD &GR / Secretary, Ministry of Agriculture / DG, ICMR / Director, TERI / Health Secretaries of the State Govt. of Uttarakhand, Odhisa & Maharashtra

Copy for information to:

1. Secretary (H&FW)
2. DGHS
3. AS & MD, NHM, MOH&FW / AS (Health), MOH&FW / AS (SK), MoEF&CC
4. JS (PH)
5. Director (IFD)

2/7/2015
@ 4:45pm

Annexure-B

National Expert Group for Climate Change & Health (NEGCCH)

S.No.	Name & Designation	
1	**Dr Vishwa Mohan Katoch,** Former Secretary (Health Research), Government of India and Former DG, ICMR	**Chairman**
2.	**Shri Anshu Prakash**, Joint Secretary (PH & NCD), Ministry of Health and Family Welfare, Nirman Bhawan, New Delhi – 110011	Member
3.	**Shri Ravi S. Prasad**, Joint Secretary, Ministry of Environment, Forests and Climate Change, Indira Paryavaran Bhawan,JorBagh, Aliganj, New Delhi – 03.	Member
4.	**Dr N. S. Dharmshaktu**, Additional Director General, Directorate General of Health Services, Nirman Bhawan, New Delhi – 110011	Member
5.	**Dr A.C. Dhariwal**, Director, National Vector Borne Disease Control Programme, Block Number -III, Ground Floor, Delhi IT Park Shastri Park, Delhi- 110053	Member
6.	**Dr Inder Parkash**, DDG(PH), Dte General of Health Services, Nirman Bhawan, New Delhi –110011	Member
7	**Dr Mohammed Shaukat**, DDG(NCD), Directorate General of Health Services, Nirman Bhawan, New Delhi – 11	Member
8	**Dr A.K. Sinha**, Senior Research Officer, National Disaster Management Authority, No. 1, Safdarjung Enclave, NDMA Bhawan, New Delhi-110029	Member
9	**Dr Ajay Raghav**, Scientist F, Climate Change Division, Ministry of Environment, Forests and Climate Change, Indira Paryavaran Bhawan, Jor Bagh, Aliganj, New Delhi – 03	Member
10.	**Dr S. K. Peshin**, Scientist F, India Meteorological Department, Prithvi Bhawan, Opposite India Habitat Centre, Lodhi Road, New Delhi-110003	Member
11	**Dr B. C. Joshi**, Scientist D, Central Ground Water Board, Bhujal Bhawan, NH-IV, Faridabad – 121001	Member
12.	**Dr Dushyent Gehlot**, Soil Conservation Officer (Climate Change), Climate Change Cell (Room No. 22), Department of Agriculture and Cooperation, Ministry of Agriculture, Krishi Bhawan, New Delhi	Member
13.	**Dr D. K. Shukla**, Scientist G, Indian Council of Medical Research (ICMR), ICMR HQ, New Delhi	Member
14.	**Dr R.M. Bhardwaj**, Scientist E, In-charge, Pollution Assessment Monitoring Survey, Central Pollution Control Board, Parivesh Bhawan, East Arjun Nagar, Delhi – 110096	Member
15.	**Dr S. Venkatesh**, Director, National Centre for Diseases Control, 22-Shamnath Marg, Delhi-110054	Member Secretary

Special Invitees

S.No.	Name & Designation
1	**Dr Sadhna Bhagwat**, National Professional Officer (NCD), WHO Country Office For India, First Floor, RK Khanna Stadium, Safdarjung Enclave, Africa Avenue, New Delhi-110029.
2	**Dr V. Rao Aiyagari**, Senior Advisor, Research and Scientific Operations, Public Health Foundation of India (PHFI), Plot No. 47, Sector 44, Gurgaon 122002.
3	**Prof Nandita Basu**, Director, School of Tropical Medicine, 108, C. R. Avenue, Kolkata 700073
4	**Dr T. K. Joshi**, Director, Centre for Occupational and Environment Health, Maulana Azad Medical College, New Delhi 110002.
5	**Dr Pravin Naoghare**, Scientist, Environmental Health Division, National Environment Engineering Research Institute (NEERI), CSIR Lab, Nehru Marg, Nagpur-440020.
6	**Dr Suruchi Bhadwal**, Associate Director, Earth Science and Climate Change Division, The Energy and Resources Institute (TERI), Darbari Seth Block, India Habitat Centre, Lodhi Road, New Delh-110003.
7	**Dr Hema Achyuthan**, Department of Geology, Anna University, Chennai

Invitees

S.No.	Name & Designation
1	**Dr Jyoti Misri**, Principal Scientist (AH), Indian Council of Agriculture Research (ICAR), Room No. 410-A, Krishi Bhawan, New Delhi 110001
2	**Dr Tanvir Kaur**, Scientist E, Indian Council of Medical Research (ICMR), ICMR HQ,New Delhi
3	**Dr Anjali Srivastava**, Chief Scientist and Head, NEERI Zonal Centre, LohaMandiMarg, Naraina Industrial Area Phase I, Naraina, New Delhi, Delhi 110028.
4	**Ms Meena Sehgal**, Fellow, The Energy and Resources Institute (TERI), Darbari Seth Block, India Habitat Centre, Lodhi Road, New Delh-110003.
5	**Dr D.R.Sikka**, Former Director, Indian Institute of Tropical Meteorology (IITM), Dr. Homi Bhabha Road, Pashan, Panchawati, Pune, Maharashtra 411008.
6	**Dr Akhilesh Gupta**, Head, Climate Change Programme & Strategic Programme, Large Initiatives and coordinated Action Enabler (SPLICE), Department of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi-110016.
7	**Dr Nisha Mendiretta**, Scientist F and Director, Climate Change Programme, Department of Science & Technology(DST), Ministry of Science & Technology, Government of India

8 **Dr D. Behera**, Professor and Head, Pulmonary Medicine, PGIMER, Kairon Block, Sector-12, Chandigarh – 160012.

9 **Prof. Manju Mohan**, Professor, Centre for Atmospheric Sciences, Indian Institute of Technology, Delhi –16

10 **Dr Sagnik Dey**, Assistant Professor, Centre for Atmospheric Sciences, Indian Institute of Technology, New Delhi – 110016.

11 **Dr Vidhya Venugopal**, Professor, Department of Environmental Health Engineering, Sri Ramachandra University, Porur, Chennai – 600116.

12 **Dr P.K. Sen**, Additional Director, National Vector Borne Disease Control Programme, Block Number -III, Ground Floor, Delhi IT Park, Shastri Park, Delhi- 110053.

13 **Dr. Sher Singh**, Assistant Director (PH), National Vector Borne Disease Control Programme, Block Number -III, Ground Floor, Delhi IT Park, Shastri Park, Delhi- 110053.

OFFICERS FROM NCDC (Nodal Agency for Climate Change & Human Health)

S.No. Name & Designation

1 **Dr CS Aggarwal**, Additional Director, Centre for Environment, Occupational Health, and Climate Change, National Centre for Disease Control (NCDC), Delhi 110054

2 **Dr Shikha Vardhan**, Deputy Director, Centre for Environment and Occupational Health, National Centre for Disease Control (NCDC), Delhi 110054

3 **Dr Pranil M Kamble**, Assistant Director, Centre for Environment and Occupational Health, National Centre for Disease Control (NCDC), Delhi 110054

Annexure: C

NAPCCHH: Proposed Annual Budget

Proposed Annual Budget for supporting Activities at CEOHCCH Division at NCDC			
S.No	**Expenditure Category**	**Estimated Budget**	**Recurring/ Non-Recurring**
1	Human Resource (Contractual)	Rs 1,67,40,000/-	Recurring
2.	Logistics/ Equipments	Rs 12,60,000/-	Non-Recurring
3.	Trainings/ Meetings/ Workshops	Rs 55,37,500/-	Recurring
4.	Centre of Excellence (Initially six in first year)	Rs 15,00,000/-	
5.	Development of 'Pilot Models' like Green hospitals, Integration Platform	Rs 70,00,000/-	
6.	Development of 'Prototype' of IEC/ Advisory for impact of climate change on human health (Dissemination cost is not included)	Rs 2,00,000/-	
7.	Development of 'Prototype' of IEC/ Advisory for impact of Air Pollution (AAP, IAP & HAP) on human health (Dissemination cost is not included)	Rs 2,00,000/-	
	Subtotal at CEOHCCH, NCDC	**Rs 6,35,37,500/-**	
Proposed Annual Budget for Environment Health Cell at State Health Deptt#			
1	Human Resource (Contractual)	Rs 26,40,000/-	Recurring
2.	Logistics/ Equipments	Rs 4,00,000/-	Non-Recurring
	Subtotal at Env Health Cell at State	**Rs 30,40,000/-**	
# The budget has to be proposed through State PIP and the same will be released only after the establishment of Environment Health Cell in the Health department of State			
Proposed Annual Budget for supporting Activities at Environment Health Cell at District level			
1	Human Resource (Contractual)	Rs 7,80,000/-	Recurring
2.	Logistics/ Equipments	Rs 75,000/-	Non-Recurring
	Subtotal at Env Health Cell at District	**Rs 8,55,000/-**	

REGIONAL METEOROLOGICAL OFFICES: Address

Regional Meteorological office	Address
India Meteorological Department, Regional Meteorological Centre, Chennai	New 6, Old 50, College Road, Chennai, Tamil Nadu- 600006
India Meteorological Department, Regional Meteorological Centre, Guwahati	LGBI Airport, Guwahati, Assam- 781015
India Meteorological Department, Regional Meteorological Centre, Kolkata	4, Duel Avenue, Alipore, Kolkata, West Bengal – 700027
India Meteorological Department, Regional Meteorological Centre, Mumbai	Regional Meteorological Centre, Mumbai, Colaba, Mumbai, Maharashtra- 400089
India Meteorological Department, Regional Meteorological Centre, Nagpur	Regional Meteorological Centre, IMD DBAI Airport, Sonegaon, Nagpur, Maharashtra- 440005
India Meteorological Department, Regional Meteorological Centre, New Delhi	RMC Building, Lodi Road, New Delhi- 110003

Annexure-E

STATE POLLUTION CONTROL BOARD: Address

State Pollution Control Board	Address
Andhra Pradesh Pollution Control Board	Paryarana Bhawan, A-3, Industrial Area , Sanathnagar, Hyderbabad-500 018, Andhra Pradesh
Arunachal State Pollution Control Board	Government of Arunachal Pradesh Office of the Principal Chief and Secretary (E&F) Conservator of Forests, Itanagar 791111, Arunachal Pradesh
Assam Pollution Control Board	Control Board Bamunimaidam, Guwahati - 781021 Assam
A & N Islands Pollution Control Committee	Van Sadan, Port Blair-744 102
Bihar State Pollution Control Board	IInd Floor, Beltron Bhavan, Jawaharlal Nehru Marg, Shastri Nagar, Patna 800023, Bihar.
Chattisgarh State Environment Conservation Board	Nanak Nivas, Civil Lines Raipur - 492001 Chattisgarh
Chandigarh Pollution Control Committee	Chandigarh Administration, Additional Town Hall Building, IInd Floor, Sector 17-C, Chandigarh 160 017.
Delhi Pollution Control Committee	4th Floor, I.S.B.T. Building, Kashmere Gate, Delhi-110006
Daman Diu & Nagar Haveli Pollution Control Committee	Office of the Dy. Conservator of Forests, Moti Daman-396220, Daman
Goa State Pollution Control Board	Dempo Tower, Ist Floor Patto Plaza Goa 403110
Gujarat State Pollution Control Board	Sector 10-A, Gandhi Nagar 382043 Gujarat
Haryana State Pollution Control Board	S.C.O.No.11 A-12, Sector 7-C Madhya Marg, Chandigarh – 160019
H.P. State Environment Protection & Pollution Control Board	Paryavaran Bhawan, Phase III New Shimla -171 009 Himachal Pradesh
Jammu & Kashmir State Pollution Control Board	Sheikhul Alam Campus, Behind Govt. Silk Factory, Rajbagh , Srinagar (April - Oct.) Parivesh Bhawan Forest Complex, Gandhi Transport Nagar (Nawal), Jammu (Nov. - March)
Jharkhand State Pollution Control Board	T.A. Building, HEC P.O. Dhurwa Ranchi - 834004 Jharkhand
Karnataka State Pollution Control Board	6th-9th floors Public Utility Building NSB Building, Mahatama Gandhi Marg Bangalore 560001 Karnataka

Kerala State Pollution Control Board	Plamoodu Junction Pattom Palace Trivandrum 695004 Kerala
Meghalaya Pollution Control Board	“ARDEN”, Lumpyngngad, Shillong – 793 014, Meghalaya.
Madhya Pradesh Pollution Control Board	E-5, Arera Clony, Paryavaran Parisar, Bhopal - 463016 Madhya Pradesh.
Maharashtra Pollution Control Board	Kalpataru Points, 3rd & 4thfloor, Opp. Cine Planet, Sion Circle, Sion (E) Mumbai-400 022.
Mizoram State Pollution Control Board	M.G. Road, Khatna, Aizwal-796 012, Mizoram
Manipur Pollution Control Board	Langol Housing Complex, Imphal-795 004, Manipur.
Nagaland Pollution Control Board	Office of the Chairman, Forests Colony, Dimapur, Nagaland
Orissa State Pollution Control Board	A-118, Nilakantha Nagar, Unit-VIII, Bhubaneswar 751012. Orissa
Punjab Pollution Control Board	Vatavaran Bhawan, Nabha Road, Patiala-147 001 Punjab.
Pondichery Pollution Control Committee	Department of Science, Technology & Env. Housing Board Complex, IIIrd Floor Pondicherry-600 005
Rajasthan Pollution Control Board	A-4, Institutional Area, Jalana Dungri, Jaipur-302 004, Rajasthan.
Sikkim Pollution Control Board	State Land Use and Environment Cell Govt. of Sikkim, Deorali,- 737101
Tamil Nadu Pollution Control Board	No. 76, Mount Salai, Guindy, Chennai- 600 032, Tamil Nadu.
Tripura State Pollution Control Board	Vigyan Bhawan, Pandit Nehru Complex, Gorkhabasti,PO-Kunjaban, Agartala (W)-799 006 (Tripura) .
Uttar Pradesh Pollution Control Board	IIIrd floor PICUP Bhavan, Vibhuti Khand, Gomti Nagar, Lucknow - 226020, UP.
West Bengal Pollution Control Board	Paribesh Bhavan, 10-A, Block LA, Sector III, Salt Lake City, Kolkata-700 091.

RU-49-03-0004-011221/FAQ

PRESS INFORMATION BUREAU
(Research Unit)
Ministry of Information and Broadcasting
Government of India

(Frequently Asked Questions (FAQs)

National Action Plan on Climate Change (NAPCC)

(Ministry of Environment, Forest and Climate Change)

December 01, 2021

Context

Climate change[1] is one of the most critical global challenges of our times. Recent events have emphatically demonstrated our growing vulnerability to climate change. Climate change impacts will range from affecting agriculture – further endangering food security – to sea-level rise and the accelerated erosion of coastal zones, increasing intensity of natural disasters, species extinction, and the spread of vector-borne diseases.

Introduction

The vulnerability assessment and adaptation studies of climate change were made in various areas such as water resources, agriculture, forests, natural eco-systems, coastal zones, health energy and infrastructure as a part of the Initial National Communication of India[2] to the United Nations Framework Convention on Climate Change (UNFCCC).

Further, the Expert Committee on Impact of Climate Change set up by the Ministry of Environment & Forests in June 2007 assessed the impact of climate change on six areas, namely water resources, agriculture, Natural Ecosystem, Health, Coastal Zone Management and Climate modelling. Reports of the Expert Committee were then prepared and a range of policies and programmes were initiated to address the problem of climate change in the context of sustainable development.

1. **What is the National Action Plan on Climate Change (NAPCC)?**

   The National Action Plan on Climate Change (NAPCC) was released by the Prime Minister on 30th June 2008.[3] It outlines a national strategy that aims to enable the country to adapt to climate change and enhance the ecological sustainability of India's development path. It stresses that maintaining a high growth rate is essential for increasing living standards of the vast majority of people of India and reducing their vulnerability to the impacts of climate change.

   There are eight "National Missions" which form the core of the National Action Plan. They focus on promoting understanding of climate change, adaptation and mitigation, energy efficiency and natural resource conservation."[4]

[1] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2822162/
[2] https://unfccc.int/resource/docs/natc/indnc1.pdf
[3] https://pib.gov.in/newsite/erelcontent.aspx?relid=44098
[4] https://vikaspedia.in/energy/policy-support/environment-1/climate-change

2. What are the missions that come under the National Action Plan for Climate Change?

There are eight National Missions[5] on climate change:

1. National Solar Mission
2. National Mission for Enhanced Energy Efficiency
3. National Mission on Sustainable Habitat
4. National Water Mission
5. National Mission for Sustaining the Himalayan Eco-system
6. National Mission for a Green India
7. National Mission for Sustainable Agriculture
8. National Mission on Strategic Knowledge for Climate Change

3. What are the principles of this plan?

The Principles of NAPCC[6] are:

- Protecting the poor through an inclusive and sustainable development strategy, sensitive to climate change
- Achieving national growth and poverty alleviation objectives while ensuring ecological sustainability
- Efficient and cost-effective strategies for end-use demand-side management
- Extensive and accelerated deployment of appropriate technologies for adaptation and mitigation
- New and innovative market, regulatory, and voluntary mechanisms for sustainable development
- Effective implementation through unique linkages – with civil society, LGUs, and public-private partnerships

4. What is the National Solar Mission (NSM)?

The NSM was launched in January 2010[7], with the objective of establishing India as a global leader in solar energy, by creating the policy conditions for solar technology diffusion across the country as quickly as possible.

The initial target of NSM was to install 20 GW solar power by 2022. This was upscaled to 100 GW in early 2015. Numerous facilitative programmes and schemes under the Mission have driven the grid connected solar power installed capacity from 25 MW in the year 2010-11 to about 36.32 GW as on 31st October 2020. An additional 58.31 GW solar power capacity is currently under installation/ tendering process.

[5] https://dst.gov.in/climate-change-programme
[6] http://moef.gov.in/wp-content/uploads/2018/07/CC_ghosh.pdf
[7] https://www.pib.gov.in/PressReleseDetailm.aspx?PRID=1685046

5.What is the objective of the National Solar Mission?

The objective of the National Solar Mission[8] is to establish India as a global leader in solar energy, by creating the policy conditions for its diffusion across the country as quickly as possible. The Mission adopts a three-phase approach, Phase 1 (up to 2012 - 13), Phase 2 (2013 - 17) and Phase 3 (2017 - 22). The immediate aim of the Mission is to focus on setting up an enabling environment for solar technology penetration in the country both at a centralized and decentralized level.

6. What is the National Mission for Enhanced Energy Efficiency (NMEEE)?

NMEEE aims to strengthen the market for energy efficiency by creating conducive regulatory and policy regime and has envisaged fostering innovative and sustainable business models to the energy efficiency sector. The Mission is implemented since 2011.[9]

NMEEE consists of four initiatives to enhance energy efficiency in energy intensive industries[10]:

- Perform, Achieve and Trade (PAT)
- Market Transformation for Energy Efficiency (MTEE)
- Energy Efficiency Financing Platform (EEFP)
- Framework for Energy Efficient Economic Development (FEEED)

7. What is the National Mission on Sustainable Habitat?

The National Mission on Sustainable Habitat was approved by the Prime Minister's Council for Climate Change in June 2010.[11]

The key deliverables of the Mission include:

- Development of sustainable habitat standards that lead to robust development strategies while simultaneously addressing climate change related concerns
- Preparation of city development plans that comprehensively address adaptation and mitigation concerns
- Preparation of comprehensive mobility plans that enable cities to undertake long-term, energy efficient and cost effective transport planning
- Capacity building for undertaking activities relevant to the Mission

8. Whatis the National Water Mission?

A National Water Mission[12] will ensure integrated water resource management helping to conserve water, minimize wastage and ensure more equitable distribution both across and within states. The Mission will take into account the provisions of the National Water Policy and develop a framework to optimize water use by increasing water use efficiency by 20 per cent through regulatory mechanisms with differential

---

[8] Jawaharlal Nehru National Solar Mission — Vikaspedia
[9] https://vikaspedia.in/energy/policy-support/energy-efficiency/national-mission-for-enhanced-energy-efficiency
[10] https://www.pib.gov.in/PressReleasePage.aspx?PRID=1744431
[11] http://cpheeo.gov.in/cms/national-mission-on-sustainable-habitat.php
[12] http://nwm.gov.in/

entitlements and pricing. It will seek to ensure that a considerable share of the water needs of urban areas are met through recycling of waste water, and ensuring that the water requirements of coastal cities with inadequate alternative sources of water are met through adoption of new and appropriate technologies such as low temperature desalination technologies that allow for the use of ocean water.

NWM[13]has identified five goals which are mentioned below:

- Comprehensive water data base in public domain and assessment of the impact of climate change on water resource
- Promotion of citizen and state actions for water conservation, augmentation and preservation
- Focused attention to vulnerable areas including over-exploited areas
- Increasing water use efficiency by 20 per cent
- Promotion of basin level integrated water resources management

9. What is the National Mission for sustaining the Himalayan Eco-system?

This particular mission sets the goal to prevent melting of the Himalayan glaciers and to protect biodiversity in the Himalayan region.[14]

The Himalayan ecosystem as a national mission will focus on the rapid generation of four types of national capacities, which deal with:

- Human and knowledge capacities
- Institutional capacities
- Capacities for evidence based policy building and governance
- Continuous self-learning for balancing between forces of Nature and actions of mankind

The mission attempts to address some important issues concerning

- Himalayan Glaciers and the associated hydrological consequences
- Biodiversity conservation and protection
- Wildlife conservation and protection
- Traditional knowledge societies and their livelihood and
- Planning for sustaining the Himalayan Ecosystem

10. What is the National Mission for a Green India?

The Cabinet Committee on Economic Affairs approved a proposal of the Ministry of Environment and Forests for a National Mission for a Green India[15](GIM) as a Centrally Sponsored Scheme.

GIM puts “greening”[16] in the context of climate change adaptation and mitigation. Greening is meant to enhance ecosystem services such as carbon sequestration and storage (in forests and other ecosystems), hydrological services and biodiversity; as well as other provisioning services such as fuel, fodder, small timber and non- timber forest products (NTFPs).

The Mission aims at responding to climate change by a combination of adaptation and mitigation measures, which would help:

---

[13]http://nwm.gov.in/
[14]http://dst.gov.in/sites/default/files/NMSHE_June_2010.pdf
[15]https://pib.gov.in/newsite/PrintRelease.aspx?relid=103978
[16]http://www.jkforest.gov.in/pdf/gim/GIM_Mission-Document-1.pdf

- Enhancing carbon sinks in sustainably managed forests and other ecosystems
- Adaptation of vulnerable species/ecosystems to the changing climate
- Adaptation of forest-dependent communities

The objectives of the Mission are:

- Increased forest/tree cover on 5 m ha of forest/non-forest lands and improved quality of forest cover on another 5 m ha (a total of 10 m ha)
- Improved ecosystem services including biodiversity, hydrological services and carbon sequestration as a result of treatment of 10 m ha
- Increased forest-based livelihood income of about 3 million households living in and around the forests
- Enhanced annual CO_2 sequestration by 50 to 60 million tonnes in the year 2020

11. What is the National Mission for Sustainable Agriculture?

National Mission for Sustainable Agriculture[17](NMSA) has been made operational from the year 2014-15, it aims at making agriculture more productive, sustainable, remunerative and climate resilient by promoting location specific integrated /composite farming systems; soil and moisture conservation measures; comprehensive soil health management; efficient water management practices and mainstreaming rain-fed technologies.

Farm Water Management (FWM) was implemented as one of the components of NMSA during 2014-15 with the objective of enhancing water use efficiency by promoting technological interventions like drip & sprinkler technologies, efficient water application & distribution system, secondary storage etc. Thereafter, these activities have been subsumed under the '**Per Drop More Crop (PDMC)**' component of **Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)** during 2015-16.

Soil Health Management (SHM) is one of the components under the National Mission for Sustainable Agriculture (NMSA). SHM aims at promoting Integrated Nutrient Management (INM) through judicious use of chemical fertilizers including secondary and micro nutrients in conjunction with organic manures and bio-fertilizers for improving soil health and its productivity, strengthening of soil and fertilizer testing facilities to improve soil test based recommendations to farmers for improving soil fertility.

"Soil Health Card" Scheme has been under implementation in the country since February, 2015 to provide Soil Health Cards to all farmers in the country. Soil Health Card will provide information to farmers on soil nutrients status of their soil and recommendation on appropriate dosage of nutrients to be applied for improving soil health and its fertility.

12. What is the National Mission on Strategic Knowledge for Climate Change?

The **National Mission on Strategic Knowledge for Climate Change (NMSKCC)** seeks to build a vibrant and dynamic knowledge system that would inform and support national action for responding effectively to the objective of ecologically sustainable development.

[17]https://pib.gov.in/PressReleasePage.aspx?PRID=1556469

Mission Deliverables[18]:

- At least 10 thematic knowledge networks with critical mass and strength in the areas of climate science, S&T Capacity building, Regional-climate modelling, Adaptation strategies in agriculture, water resources, and other socio-economic sectors, global technology foresight and regional emission inventories, optimal mix of energy related technologies, agro biotechnologies for different agro climatic zones relevant to Indian sub-continent
- Total number of 10-12 technical reports as a part of implementation of Sub- missions on the key areas of climate change adaptation, mitigation and impact areas such as agriculture, water resources, human health, energy etc,. Technical reports on climate change linkages with extreme atmospheric and ocean events like, Monsoon, tropical cyclones and other storms, floods, droughts, glaciers, etc. will also be brought out.
- Regional and disaggregated climate models taking into account of tropical physics and Indian monsoon-Himalayas interactions
- 50 Chair professorships in climate change science and technology
- About 200 specially trained climate change research professionals with specialization in different areas of knowledge domain and expertise
- At least three viable Public-Private Partnerships in the areas on adaptation and mitigation technologies
- Technologywatchgroupsintheareasofclimatechangescience,renewableenergy, clean coal technology, carbon sequestration and storage, watershed management, precision agriculture, convergent technology options for housing and construction, transport, solar energy materials and devices, waste management and S&T policy for climate change research will be developed and positioned with a critical mass of expertise base.
- Mission deliverables would include enunciated technical goals of the NAPCC document enshrined within the strategic knowledge mission objectives
- Thematic report on Technology-policy interfaces in the areas of energy, per-capita emissions at various GDP growth rates, agro biotechnology directives
- Development of S&T collaborations with countries like USA, China, Japan and multilateral groups like EU on specific areas identified through internal prioritization

References

- Assessment of Climate Change over Indian Region
- Impact of Climate Change on Farmers
- National Mission for Sustainable Agriculture

[18] https://dst.gov.in/sites/default/files/NMSKCC_mission%20document%201.pdf

Policies for Low Carbon Growth

27 November 2009

Karen Ellis, Bryn Baker and Alberto Lemma

Overseas Development Institute
111 Westminster Bridge Road
London SE1 7JD
UK

Tel: +44 (0)20 7922 0300 Fax: +44 (0)20 7922 0399
www.odi.org.uk

Acknowledgements

This research was financed by the UK Department for International Development (DFID). However, the views presented in this paper are those of the authors and do not necessarily represent the views of DFID. The authors wish to thank DFID and other stakeholders who were consulted in the preparation of this report for their comments, suggestions and insights. The authors take full responsibility for any errors or omissions contained in this report.

Contents

List of acronyms

ADB	Asian Development Bank
AIDS	Acquired Immunodeficiency Syndrome
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BERR	UK Department for Business, Enterprise and Regulatory Reform
BPO	Business Process Outsourcing
CAIT	Climate Analysis Indicators Tool (WRI)
CAT	Cap and Trade
CC	Climate Change
CCA	Climate Change Agreement (UK)
CCFP	Conversion of Cropland to Forest Program (China)
CCL	Climate Change Levy (UK)
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CFC	Chlorofluorocarbon
CFL	Compact Fluorescent Lamp
CHP	Combined Heat and Power
CIM	Inter-ministerial Committee on Climate Change (Brazil)
CN Net	Climate Neutral Network
CNCCP	Chinese National Climate Change Programme
CNG	Compressed Natural Gas
CONUEE	National Commission for the Efficient Use of Energy
COP	Conference of the Parties
CSO	Civil Society Organisation
DECC	UK Department for Energy and Climate Change
DEFRA	UK Department for Environment, Food and Rural Affairs
DFID	UK Department for International Development
DIUS	UK Department for Innovation, Universities and Skills
DOE	Department of Environment (Bangladesh)
ECA	Enhanced Capital Allowance (UK)
EE	Energy Efficiency
ESMAP	Energy Sector Management Assistance Program
EU	European Union
EVN	Economic Value to the Nation
EVW	Economic Value to the World
FBMC	Brazilian Forum on Climate Change
FAO	Food and Agricultural Organization
FIDE	Trust Law for Electric Energy Savings (Mexico)
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLCFA	Guyana Low Carbon Finance Authority
GNI	Gross National Income
GNVA	Gross National Value Added
GoUK	Government of the UK
GVA	Gross Value Added
HCFC	Hydrochlorofluorocarbon
HDR	Human Development Report
HIC	High-income Country
HVDC	High-voltage Direct Current
LC	Low Carbon
LCDS	Low Carbon Development Strategy
LIC	Low-income Country

MCP	Malaria Containment Programme
MELCA	Movement for Ecological Learning and Community Action (Ethiopia)
MIC	Middle-income Country
MoEF	Ministry of Environment and Forests (Bangladesh)
NAMA	Nationally Appropriate Mitigation Action
NAPA	National Adaptation Programme of Action
NAPCC	National Action Plan on Climate Change (India)
NDRC	National Development and Reform Commission (China)
NEAP	National Environment Action Plan (Malawi)
NFFP	Natural Forest Protection Program (China)
NGO	Non-governmental Organisation
NPCC	National Plan on Climate Change (Brazil)
NSCCC	National Steering Committee on Climate Change (Bangladesh)
NSREP	National Sustainable and Renewable Energy Programme (Malawi)
ODI	Overseas Development Institute
OECD	Organisation for Economic Co-operation and Development
PASDEP	Plan for Accelerated and Sustained Development to End Poverty (Ethiopia)
PAT	Perform, Achieve, Trade
PROINFA	Programme of Incentives for Alternative Sources of Electric Energy (Brazil)
PRSP	Poverty Reduction Strategy Paper
PSI	Pollution Standards Index
PV	Photovoltaic
R&D	Research and Development
REDD	Reduced Emissions from Deforestation and Degradation
SME	Small and Medium Enterprise
TWG	Technical Working Group
UK	United Kingdom
UN	United Nations
UNCTAD	UN Conference on Trade and Development
UNDP	UN Development Program
UNEP	UN Environment Programme
UNFCCC	UN Framework Convention on Climate Change
WDI	World Development Indicator
WRI	World Resources Institute
WTO	World Trade Organization
WWF	Worldwide Fund for Nature

Executive summary

The Overseas Development Institute (ODI) has reviewed the low carbon growth and climate change response strategies of a range of countries with differing economic characteristics to draw out the policy implications for developing countries at different stages of development (Ellis et al., 2009).

The study, financed by the UK Department for International Development (DFID), selected a cross-section of high-, middle- and low-income countries to conduct a balanced review of low carbon growth policies. High-income countries (HICs) included Germany and the United Kingdom. Middle-income countries (MICs) included China, Brazil, Guyana, Mexico and Nigeria.

Low-income countries included Bangladesh, and Ethiopia. Shorter 'snapshots' were also provided for South Korea, India, Malawi, Rwanda and South Africa. These countries were chosen because they indicate the range of activities being carried out. All have published official documents outlining their climate change policies, such as national strategy documents, National Adaptation Programme of Action (NAPA) reports to the UN Framework Convention on Climate Change (UNFCCC), and national communications to the UNFCCC.

Growth has been, historically, highly correlated with carbon emissions. In light of the impact that this has had on climate change, new, low carbon growth strategies are being sought, i.e. policymakers are now seeking to achieve growth pathways that are associated with relatively low increases in carbon emissions.

Many developing countries have struggled to achieve any kind of sustained growth however, and have contributed little to the problem of climate change. The question for them will be how to achieve growth at all, particularly in light of climate change and international mitigation policies and the impact these are having on their economies.

These countries will need to find climate resilient growth strategies (i.e. growth strategies which are achievable despite the impact of climate change), and identify and manage opportunities (such as new markets) and risks (such as trade barriers) that arise from international mitigation efforts, in order to achieve growth in future.

Having an appropriate policy framework in place (such as a NAPA or Nationally Appropriate Mitigation Actions (NAMA)), is likely to help countries secure public and private funding for adaptation and mitigation. Identification of future mitigation opportunities and low carbon growth trajectories could thus be important, even for countries that have achieved only low growth rates to date. This will allow such countries to position themselves to take maximum advantage of new opportunities that may arise. For this reason we have considered both low carbon and climate resilient growth strategies in this report, as well as strategies to maximise growth potential arising from international mitigation efforts going forward.

The report draws on the case studies and other relevant literature to identify possible policy lessons and discuss the extent to which low carbon growth challenges traditional growth theory and policies.

Achieving low carbon growth clearly has major implications for policy, and implies considerable adjustment of the traditional growth agenda. However, low carbon growth does not present a major challenge to traditional growth theory, it simply requires the internalisation of the environmental costs of growth through the appropriate pricing of goods and services. This can be achieved through a range of mitigation policies, such as taxes on the production or consumption of carbon intensive goods.

The potential impact of mitigation policies on growth is unclear. Constraints on emissions raise the cost of energy which, in turn, reduces the output that can be achieved with a given set of inputs. No consensus exists on the costs of mitigation however, which will depend on the efficiency and nature of the policies adopted, and the extent of technological innovation achieved. And mitigation could also generate new growth opportunities, which would offset those costs.

This could be the case if, for example, there is fast growth in demand for environmental goods and services. Significant co-benefits associated with mitigation could also occur if there are strong synergies between green technology change and industrial technological progress, which is a key source of growth. Policies designed to promote green technological innovation and technology transfer could thus also potentially increase growth. In addition, some mitigation policies generate revenues (e.g. carbon taxes) and provide opportunities to stimulate growth through the judicious use of the revenues raised.

Thus the design of national mitigation policies and the way incentive mechanisms for low carbon growth are created will determine overall growth effects. The literature on this is mixed however, and modelling results depend enormously on the particular assumptions that are used. While much of the literature on mitigation suggests an overall negative impact on growth, a recent report by The Climate Group finds that a global climate agreement could lead to an increase in global GDP of 0.8% by 2020 relative to projected GDP with no climate action.

In addition to the overall impact of mitigation on global growth, the distribution of mitigation efforts will be important in determining the growth impacts in different parts of the world. Rich countries may need to accept lower rates of growth in future, if developing countries are to have the necessary space to grow their way out of poverty. The way that revenues from international mitigation efforts are used will also be important. For example, if auction revenue raised from permit sales in carbon cap-and-trade schemes is then used to finance mitigation or adaptation in developing countries, this could generate significant gains for recipient countries.

Mitigation policies will affect different sectors in different ways and are likely to imply adjustments to the sectoral sources of growth enjoyed previously by some countries. For example, mitigation policies which drive down the price of oil will generate a net loss for oil exporting countries and net gain for oil importers.

Air transport taxes might reduce demand for tourism or for air freighted exports such as fruit and vegetables. Carbon taxes may generate carbon leakage (i.e. the shift of dirty industry to pollution havens) and reduce income associated with carbon intensive products. The impact of these policies will vary significantly by country, depending on their sectoral composition. The analysis of the potential impact of different kinds of mitigation policies is fairly limited to date and the subject of a forthcoming ODI study.

A key determinant of the impact of international efforts to mitigate climate change on developing countries' growth paths will be the policies adopted by developing countries to adapt, mitigate and strategically position themselves in order to benefit from these international mitigation responses. This is likely to include the pursuit of a low carbon growth path as a prerequisite for receiving finance either for mitigation or adaptation. Appropriate policies can help to position countries to take advantage of new economic opportunities that may arise and can also help protect countries from threats to their growth arising from climate change or its mitigation.

Identifying policy implications

To aid comparison across countries, and with conventional growth policies, the review has been structured around the following six key pillars:

1. Finance for mitigation and adaptation;
2. Human capital;
3. Technological progress in energy, infrastructure and transportation;
4. Investment in agriculture and forestry;
5. Trade and private investment opportunities;
6. Incentives and regulation for low carbon growth.

We have reviewed case studies and literature under each of these pillars and identified the following possible policy lessons. (A more detailed discussion of policy implications drawn from the country policy reviews is contained in the full version of this report.)

Finance for mitigation and adaptation

- For the international policy community, the achievement of an international agreement on emissions reductions is a priority to help unlock private finance for mitigation.
- Countries can be strategic in how they position themselves to attract finance for mitigation and adaptation. For example, the development of a 'Climate Change Fund'/multi-donor trust fund, and an appropriate policy framework e.g. a NAPA, NAMA, and/or a low carbon growth strategy, can help to convince donors that climate change is taken seriously in that country, and that any funding will be spent transparently and effectively.
- Developing countries need to continue to lobby for financial support for mitigation and adaptation, and for reform that will help them benefit more from carbon markets, including the Clean Development Mechanism (CDM).
- For countries with carbon assets, strategic positioning, policy development, and lobbying for financial support for mitigation and adaptation, may help to both influence the international agenda, and the development of international mitigation mechanisms, such as Reduced Emissions from Deforestation and Forest Degradation (REDD) and CDM, in their favour, both in terms of scope and scale.
- Widening the scope of carbon markets to enable more LICs to benefit, and improving the investment climate in developing countries may also help them to maximise financial inflows of private finance for mitigation.
- Not all developing countries will be able to obtain private finance for mitigation and adaptation. Increasing the availability of public finance will also be important in supporting developing countries' low carbon growth efforts.

Human capital

- Broad awareness-raising may help increase public understanding of climate change and its effects, and the implications for people's livelihoods and welfare going forward. This can be implemented formally, for example through schools, or informally, through public awareness campaigns.
- Training in skills relating to green technologies and industries can help position countries to take advantage of any new low carbon growth opportunities and markets.
- Targeted investments in health, water and sanitation may help increase climate resilience by protecting human capital from the potential negative health impacts of climate change.

Technological progress in energy, infrastructure and transportation

- Infrastructure improvements and the development of clean energy options should be made as soon as possible to reduce emissions as well as adapt to potential impacts. This will avoid locking in high-carbon technologies and processes as demand for energy rises. The development of decentralised grids may offer co-benefits between greener energy production, and increased access to energy.
- Strategic thinking and strong policy management of patterns of urbanisation may be required to increase climate resilience and facilitate low carbon growth.

- Government can play an important role in clarifying the future direction of policy and the key decisions that will be made on energy production and infrastructure development, to give business the confidence it needs to undertake low carbon investments.
- It is critical for low-income countries to receive international support and technology transfer to facilitate their transition to a low carbon economy. Greater efforts to promote international cooperation on research and development may help to promote technological diffusion. A re-examination of intellectual property provisions in the World Trade Organization (WTO) may also be needed.
- Countries should identify renewable resources that provide the greatest advantage in view of local conditions, resources, and state of development.
- The future development, demonstration and transfer of technology for carbon capture and storage will be very important for countries that continue to develop their large coal reserves.
- Governments in all countries can benefit from working with the private sector and civil society to scale up renewable technologies, from improved cook-stoves to large-scale wind and solar to hydropower.
- Transport is best approached holistically and should include public transport, clean, sustainable fuels, and efficient vehicles.
- Biofuels offer a potentially important new export opportunity for some developing countries, although major developed countries still impose protection on biofuel imports.

Investment in agriculture and forestry

- Greater understanding and awareness of the impact of climate change on agricultural productivity, and shifts in demand for agricultural produce will help developing countries to improve climate resilience and take advantage of possible new growth opportunities. Education of farmers will be an important component in this.
- Comprehensive approaches that include improved agronomic practices; climate-resistant crop varieties; water, soil and fertiliser management, and better livestock management are needed.
- Adaptation efforts in agriculture may be most important in poor countries that rely disproportionately on agriculture and are likely to be most affected by climate change.
- Forestry payments present a significant potential financing opportunity for some countries, if international mechanisms such as REDD can be successfully developed.
- Countries that develop a rigorous, comprehensive, transparent and inclusive process around sustainable forest management may be more likely to secure international investments and future CDM benefits and turn them into successful alternative growth strategies and conservation of forests.
- Agriculture offers considerable potential sequestration benefits though there are significant barriers to attracting carbon finance for this sector.

Trade and private investment opportunities

- Countries that identify, target and secure new green investment and growth opportunities stand to benefit more from the transition to a low carbon economy.
- There is a role for government leadership to identify low carbon growth sectors which may provide competitive advantage and employment growth.
- The development of new opportunities must be backed by sufficient support and funding from government and the international community. This includes the creation of an appropriate policy environment; provision of the necessary training/education; investment promotion and awareness raising; and collaborative partnerships between the public, private and NGO sectors.

Incentives and regulation for low carbon growth

- Internationally coordinated action to mitigate climate change can help reduce the risk of a 'race to the bottom' in relation to the taxation and regulation needed to stimulate low carbon growth.
- Donor support for low carbon regulation and taxation could help build developing countries' capacity to implement such policies effectively.
- An ongoing review of the efficacy and cost-effectiveness of measures by different countries to incentivise the necessary changes in behaviour and stimulate low carbon growth, could help improve policy-making in this area.
- Many of the barriers to low carbon growth, mitigation financing and technological transfer in developing countries are the same as the barriers to growth and investment generally i.e. a poor investment climate and uncompetitive markets. Policies to tackle these remain important.

Policy processes

In our review, we also looked at the policy processes adopted in each country. Possible lessons include:

- Policy statements should go beyond 'statements of intent' to provide a roadmap for specific measures and an implementation plan.
- Policy is strengthened by underpinning studies.
- Consultations help to obtain ideas and include various stakeholder viewpoints; promote coordination and collaboration, and enhance transparency and trust in the process.
- The inclusion of civil society helps build support for policies and thus aids in implementation. Consulting and partnering with the private sector can help increase the feasibility and market-friendliness of policies that are proposed. This can facilitate greater private sector engagement in achieving low carbon growth and improve the sustainability and scale-up of green investments.
- Training and education can help with coordinating different government departments and policies.
- Providing strong policy guidance is crucial to implementation.

Progress to date and lessons learned

The countries we have reviewed have already taken steps to develop a climate change or low carbon development strategy, and thus are, to a greater or lesser degree, ahead of other countries, within their income category at least. However, there are still a number of issues that most countries either did not address or could not resolve in their policy documents. These include:

- Specification of a (potential) funding source for climate mitigation and adaptation activities;
- An implementation roadmap with specific measures;
- Anti-corruption and pro-transparency measures governing the use of mitigation/adaptation funds;
- A framework for macro management and measures to combat Dutch Disease;
- Identification of new green growth opportunities and the policies needed to achieve them;
- A rigorous consultation process;
- The need for policy alignment and intra-governmental cooperation.

So, although many of these countries are, to some extent, ahead of the game in terms of policies to promote low carbon growth and climate resilience, it is clear that improvements can still be made.

Nonetheless, the policies they have set out and the processes they have pursued can provide valuable lessons for other countries only now beginning to think about how they will respond to climate change.

While it is too early to judge the efficacy of many of these policies (and indeed many of them are still only being planned), ongoing monitoring of their impact will be important in ensuring that lesson are learned globally, thus speeding up the effective response to this most pressing of problems.

1. Introduction

Developing countries as a group have contributed much less to the problem of climate change than developed countries, yet they are the most vulnerable to its negative impacts. Developing countries must have the opportunity to grow their way out of poverty, and the threats posed by climate change increase the urgency of promoting sustainable growth and development, which will help to increase the capacity of developing countries to manage a changing climate.

However, growth and development are usually associated with increases in carbon emissions, so are likely themselves to contribute to climate change. International pressure to control carbon emissions is growing, although the extent to which developing countries should bear the burden for mitigation remains highly controversial. The contribution to tackling climate change expected of large emitters like China and India is likely to be very different from that of low-income countries (LICs), as will be the policy requirements to achieve the necessary change.

Many developing countries have struggled to achieve sustained growth at all, and have thus contributed little to the problem of climate change. For them, the first question is how to achieve growth at all, particularly in light of the impact of climate change and international mitigation policies on their economies. They will need to find climate-resilient growth strategies (i.e. growth strategies which are achievable despite the impact of climate change), and to identify and manage opportunities (such as new markets) and risks (such as trade barriers) arising from international mitigation efforts, in order to achieve growth going forward. Having an appropriate policy framework in place (such as a NAMA (Nationally Appropriate Mitigation Action) or a NAPA (National Adaptation Programmes of Action)), is likely to help them secure public and private funding for adaptation and mitigation. Thus, identification of future low carbon growth trajectories will be important even for these countries, in order that they may position themselves to take maximum advantage of new opportunities that may arise. For this reason, we consider both low carbon and climate-resilient growth strategies in this report, as well as strategies to maximise growth potential arising from international mitigation efforts going forward.

At the same time, international mitigation efforts, and steps taken by developed countries to 'green' their gross domestic product (GDP), could have a significant impact on developing countries' economic prospects, generating both opportunities and threats, which developing countries need to factor into their own growth strategies and policy responses to climate change.

The objective of achieving low carbon growth – although increasingly a focus for policy debate – poses considerable challenges. As yet there is only a limited understanding of what low carbon growth will look like in a developing country context, the incentives for developing countries to pursue low carbon growth paths, the costs and benefits and the funding available. Of course, achieving any kind of sustained growth has by itself proved challenging for many developing countries.

Governments in both the developed and the developing world are only just beginning to think about how to develop a low carbon growth strategy. To date, most of the focus has been on policies for adaptation (to the effects of climate change), and mitigation (to constrain emissions and hence reduce climate change). But policymakers are now beginning to think also about what economic *opportunities* might arise in a new, carbon-constrained, global economy.

Thus, low carbon growth policies consist of two broad elements:

- Mitigation, to allow economic growth to continue while constraining any associated growth in carbon emissions. This includes policies designed to encourage greener energy sources, greater energy efficiency and reduced emissions from agriculture and forestry, and includes strategic thinking about other issues, such as management of infrastructure development to support greener forms of the urbanisation that is likely to accompany economic growth.

- Adaptation, to both climate change itself and to international mitigation policies, to ensure that domestic growth strategies are consistent with the changing global environment and policy context. This includes both taking account of threats to the future growth of certain high carbon industries and trying to capitalise on new opportunities arising, perhaps from growing demand in certain markets (e.g. for environmental goods and services), changing patterns of international trade and investment or new sources of finance being made available through carbon markets (e.g. the Clean Development Mechanism (CDM)), for example.

The specific country context will determine both the threats and opportunities faced, the capacity to either address or capitalise on them and the policies they will imply.

In this report, we review low carbon development strategies (LCDSs) and other policy responses to climate change that have been produced, across a spectrum of high-income, middle-income and low-income countries (HICs, MICs and LICs) with differing economic characteristics, with a view to drawing out implications for policy which can be considered by developing countries, depending on their context and stage of development.

The objective of the study is to review the official policy response in the case study countries, and so we have focused only on documents produced by or for governments in those countries; we have not reviewed commentaries or proposals made by other organisations seeking to influence government.

The countries reviewed are: Bangladesh, Brazil, China, Ethiopia, Germany, Guyana, Mexico, Nigeria and the UK. (Shorter snapshots of climate change/low carbon policy developments have also been produced for a number of other countries: India, Malawi, Rwanda, South Africa and South Korea).

In each case, subject to the information available, we have endeavoured to describe:

- The country context (e.g. main industries, level and source of carbon emissions, etc);
- The policy context and process (e.g. nature of ministerial involvement, degree of consultation, timeframe for implementation, etc);
- Stated motivations for the climate change response/low carbon growth strategy;
- The policies that have been proposed or implemented as part of this strategy;
- The policy/strategy documents reviewed.

The review of policies has been based on the following six key pillars:

1. Finance for mitigation and adaptation;
2. Human capital;
3. Technological progress in energy, infrastructure and transportation;
4. Investment in agriculture and forestry;
5. Trade and private investment opportunities;
6. Incentives and regulation for low carbon growth.

Not all of the country policies tackle all of these six issues, and the degree of emphasis on different policies, and also on the balance between adaptation and mitigation, varies considerably between countries depending on their level of income and economic structure.

In the final section, we discuss how low carbon growth challenges traditional growth theory, and traditional growth policies, drawing on the case studies and other relevant literature to identify possible policy lessons.

2. Low carbon growth case studies

2.1 High-income countries

2.1.1 Germany

Country context

Services accounted for 29% of German GDP in 2008 (including financial services, retail and real estate), followed by the industrial sector at 26% of GDP (including energy production and manufacturing) and by trade, transport and communications (18%). Of lesser importance to the German economy are the construction and agriculture sectors (at 4% and 1% of GDP, respectively). The German economy is also one of the world's leading exporters of goods, worth an estimated €56 billion a year in exports and accounting for 16% of global trade.

Energy in Germany is produced mainly by the use of mineral oils (35%), coal (24%) and natural gas (23%), while renewable forms of energy production account for only 7% of all energy consumed. In terms of electricity consumption, the manufacturing sector accounts for the greatest share of electricity used (with 43% of total electricity consumption), followed by the service sector (27%), the residential sector (27%) and the transport sector (3%).

CO_2 emissions by sector in Germany (compiled from the 2009 Worldwide Fund for Nature (WWF)/Allianz G8 Climate Change Scorecard) show that the energy sector is the greatest source of CO_2 emissions in Germany, accounting for 42% of all CO_2 emissions, followed by the industrial sector (22%), transport (16%), households and services (14%) and agriculture (5%).

Policy motivations for low carbon growth

Energy security, secure job creation and reductions in greenhouse emissions are the main stimuli for low carbon growth in Germany. To this end, the German government has launched a series of initiatives (leading up to 2020) to move towards more sustainable energy production as well as to enhance the German economy through the use and production of green growth technologies.

In terms of energy security, the German government explains that the country needs to move forward towards a greater use of renewable energy in order to mitigate changes in fossil fuel prices and move away from nuclear-based energy. Investments in renewable energy and energy security would also allow the German economy to save €20 billion a year (by 2020) on energy imports alone. Nuclear power will be eliminated from the national grid by 2022, as stated in the 2002 Atomic Energy Act, as the German government believes the risks associated with the use of nuclear power are not offset by its benefits.

The 'green growth sector' in Germany is estimated already to provide employment for around 1.8 million people and to have earned the German economy €56 billion in exports in 2006, while the renewable energy sector is estimated to employ 250,000 people and to be worth around €26 billion a year. Germany is one of the top exporters globally for green growth technologies, accounting for 5% of total German exports in 2007, while nearly a quarter of all new green technology patents in the European Union (EU) in 2007 originated from Germany. Green growth is also important for the services sector in Germany, as in 2008 revenues of €123 billion were generated within the 'green services' sector, with growth estimates of around 8% per annum.

The German government estimates that the green growth sector is currently worth €1500 billion a year (globally) and predicts that this figure will double to €3000 billion by 2020. In order to take a greater share of this market as well as to provide economic stimuli in a period of financial crisis, the German government wishes to enhance Germany's role in the production of green growth technologies, through further investments in research and development. According to the government, this would allow Germany to become a world leading exporter in the field and allow between 500,000 and 1 million new jobs to be created within the field by 2020.

In addition to the creation of new jobs and energy security, the German government aims to move Germany towards the achievement of the following key targets:

- Cut greenhouse emissions by 40% of 1990 levels by 2020;
- Increase energy efficiency by 3% per annum;
- Increase the share of renewable energy to:
    - 50% of primary energy consumption by 2020;
    - 30% of gross power consumption by 2020;
- Increased usage of biofuels in order to reduce greenhouse gas emissions by 7% by 2020;
- Double the contribution of combined heat and power (CHP) technologies to 25% of power generation in 2020.

The low carbon growth pillars

Finance for mitigation and adaptation
An Efficiency Fund, which will be used to pay for electricity saving projects in both the private and public sector, will be set up through revenues generated through the Emissions Trading Scheme from 2013; the fund is estimated to be able to generate around €1 billion per year.

The use of electrical vehicles will be encouraged through the National Development Plan for Electromobility. The plan involves a government investment of €115 million per year in order to encourage the use of electrical vehicles, both for personal transport and for freight.

A €500 million fund has been set up in order to implement the Renewable Energies Heat Act, which was implemented in January 2009. The act stipulates that a percentage of all energy used in all new buildings will come from renewable sources. The fund has been set up to ensure that all new buildings will be able to meet the requirements of the act.

Human capital
The reviewed policy documents call for improvements in education and qualifications to meet the demands of a rising ‘green’ sector; however, there are no specific strategies mentioned on how education levels (especially technical skills) can be improved within the German market.

Technological progress in energy/infrastructure/transportation
In terms of renewable energy, the German government introduced the Energy Sources Act in 2000, which was amended in 2009 to include new developments in renewables such as wind, photovoltaic and bioenergy, with the aim of further incentivising investment in these energy sources, with particular emphasis on the expansion of wind-powered energy sources and the replacement of old wind turbines with newer and more energy-efficient models.

The use of biomass as a source of energy has been promoted by the government; however, the roadmap acknowledges that there are certain associated problems, such as in land used to grow agricultural food products being converted into biomass production areas.

The German government wants to hasten the energy grid expansion, as it sees this as a long overdue project. The expansion falls under the Grid Expansion Act, which will allow new technologies to be introduced within the grid such as high-voltage direct current (HVDC) transmission cables, underground cabling and interconnections with neighbouring EU countries in order to trade energy between countries.

In 2009, the Combined Heat and Power Act[1] will be introduced in order to promote the investment and construction of new CHP power plants (which are far more efficient in the production of both heat and energy than traditional plants), as well as to increase CHP power and heat generation by 25% by 2020. The German government is also investing in further research into carbon capture and storage (CCS) facilities in order to increase its ability to further mitigate carbon emissions.

The roadmap highlights the need for an overhaul of the energy infrastructure within Germany, through an expansion of the electrical grid, the construction of new energy-efficient power stations, investment in HVDC electrical cables (which allow for far more efficient electrical distribution than conventional electrical cables) as well as investments in better energy storage facilities, renewable sources and better electrical load management.

Trade and private investment opportunities

The German government estimates that the green growth sector is currently worth €1500 billion a year (globally) and predicts that this figure will double to €3000 billion by 2020. In order to take a greater share of this market as well as to provide economic stimuli in a period of financial crisis, the German government wishes to enhance Germany's role in the production of green growth technologies, through further investments in research and development. According to the government, this would allow Germany to become a world leading exporter in the field and allow between 500,000 and 1 million new jobs to be created within the field by 2020.

Investment in agriculture and forestry

None of the reviewed documents calls for changes in the agriculture sector in terms of energy efficiency or resource management. As agriculture accounts for only 1% of GDP and 5% of CO_2 emissions, the German government may not regard it as strategically important in its green growth strategy.

Incentives and regulation for low carbon growth

The German government has already implemented the Integrated Energy and Climate Programme[2] in 2007, focused mainly on the promotion of renewables and CHP. The German government will continue to focus on the use of renewables as well as introducing the Efficiency Standards Act, aimed at increasing energy efficiency within the country.

The Energy Policy roadmap states that, by 2020, 40% of electricity generated will be produced in high energy efficiency coal power plants. The roadmap explains that the Emissions Trading Scheme set up in 2005 by the EU, by setting strict caps on CO_2 emissions by power plant, has already incentivised utility companies to move towards more energy-efficient power plants with lower carbon emissions. Current Emissions Trading Scheme caps will be decreased by 1.74% per annum from 2013, which should ensure a reduction in emissions by 21% as compared with 2005.

German electricity consumption will be reduced by 11% (based on 2005 levels) by 2020. The German government sees this as an important strategy towards carbon emission reductions, as electrical consumption accounts for nearly 50% of energy-related carbon emissions. The Integrated Energy and Climate Programme[3] (fully implemented in May 2008) is an important step towards the reduction in electricity usage, as within the programme (among other reforms, including vehicle tax reforms that take into account carbon emissions per vehicle, clean power plants and increases in the use of biofuels) there are provisions for improvements in energy efficiency and reductions in electricity usage by domestic appliances.

According to the roadmap, more information about electricity consumption and electricity prices needs to be provided to consumers, especially for low-income households, which the roadmap

1 http://www.dena.de/en/topics/energy-systems/projects/projekt/combined-heat-and-power-generation/.
2 http://www.erneuerbare-energien.de/inhalt/39945/42719/.
3 http://www.bmu.de/english/climate/downloads/doc/40589.php.

identifies as particularly vulnerable to price fluctuations. Energy-efficient electrical appliances need to become more widespread through the economy through a proposed system of labelling which would exclude from German markets any appliances that do not meet the minimum energy efficiency requirements. An Efficiency Act should be introduced in order to promote energy efficiency by businesses and individual consumers. Efficiency will also be promoted through government investments aimed at incentivising the private sector towards investments in energy-efficient companies.

The German government envisions a much greater role for CHP and renewables for heat generation in Germany, as a large proportion of heat is currently generated through fossil fuels. The roadmap also plans to reduce greatly the amount of fossil fuels used in heating as well as increasing the efficiency of current heating systems, such as through improved building heat insulations. The German government implemented the Renewable Energies Heat Act[4] in 2009. The act promotes the use of renewable energy sources (which meet approved standards) for new buildings.

A 20% reduction in carbon emissions generated by transport is also included in Germany's green growth strategy, as currently 20% of all carbon emissions generated in Germany have their source in the transport system. Road tax has been reformed in order to account for carbon emissions rather than engine size, as an incentive for consumers to purchase low carbon vehicles. In addition to the road tax, the EU will implement a CO_2 cap for vehicle emissions in 2012, which will be further reduced from 2020. The German government has introduced the Biofuel Quota Act, intended to reduce carbon emissions through the use of biofuels as well as regulating what biofuels are used.

Further action is also considered in order to reduce carbon emissions in the transport system, through increased taxes for luxury company cars, reduced taxes on the public transport system and decreased road speed limits in order to encourage fuel efficiency.

2.1.2 United Kingdom

Country context

The UK's economy is based largely on services. There has been significant growth in the financial sector, which went from 27% of the gross national value added (GNVA) in 2000 to 31.9% in 2007.[5] In contrast, the manufacturing sector has seen a significant decline, from 17% of GNVA in 2000 to 12.4% in 2007. Other significant areas of the economy are the education and health sector (13% of GNVA in 2007) and the transport and communication sector (7% of GNVA in 2007).

The latest figures from the UK Climate Change Programme: Annual Report to Parliament 2008 (UK DEFRA, 2008) show that total greenhouse gas (GHG) emissions fell from 655.5 million tonnes in 2005 to 652.3 million tonnes in 2006, with an estimated fall to 639.5 million tonnes in 2007; CO_2 emissions in 2007 had fallen to 543.7 million tonnes, from 554.5 million tonnes in 2006.

2006 figures from the UK Climate Change Programme show that the business sector is the main source of greenhouse gas emissions in the UK, accounting for 32% of all emissions, followed by the transport sector (25%), the residential sector (24%) and the agriculture sector (8%). Industry and exports account for a much lower share of GHG emissions, at 2.8% and 1.8%, respectively. In terms of electricity generation, 2009 figures from the UK Low Carbon Transition Plan (GoUK, 2009) show that the majority of electricity used in the UK comes from gas (45%), followed by coal (32%) and nuclear energy (13%); renewables account for only 6% of electricity used.

4 http://www.bmu.de/english/renewable_energy/downloads/doc/42351.php.
5 http://www.statistics.gov.uk/statbase/Product.asp?vlnk=1143.

Policy motivations for low carbon growth

The government of the UK has pledged to move towards low carbon growth and sees it as a growing market in which the UK is already competitively placed. The policy motivation is thus twofold: first of all to reduce GHG emissions and mitigate carbon emissions, hence reducing the impact of the UK on climate change, but also to take advantage of this growing market and allow British firms to profit from high global demand for low carbon technologies.

In terms of its pledge to reduce GHG emissions, the government of the UK initially launched Climate Change: The UK Programme 2006 (DEFRA, 2006), as well as subsequent annual reports to Parliament on the state of progress as well as new initiatives to be introduced.[6] The programme pledged a reduction of 20% in carbon emissions (based on 1990 levels) by 2010. Further to the 2006 programme, the UK government launched the UK Low Carbon Transition Plan in July 2009 (GoUK, 2009); the plan set out reviewed targets pledging a reduction of 18% in carbon emissions by 2020 on 2008 levels. In addition, the UK government is bound to meet Kyoto Protocol requirements (a 12.5% reduction in carbon emissions on 1990 levels in the 2008-2012 period) and a reduction of 60% (again on 1990 levels) by 2050.

The 2006 programme identifies a number of key areas (such as energy, the transportation system, business, public sector, residential, agriculture, etc) in which changes can be made in order to reduce carbon emissions, as well as looking into what actions the UK will take internationally in order to reduce global carbon emissions. The 2008 annual update specifies that the UK Climate Change Programme is based on three principles: 1) carbon pricing; 2) technology policy; and 3) removing barriers to behavioural change on energy efficiency.

The 2008 annual report to the government discusses the introduction of the Climate Change Act. The bill was made law in November 2008.[7] The bill provides a framework and legally binding targets for carbon reduction and energy efficiency up to the year 2050; by statute a 60% reduction in carbon emissions (based on the 1990 level) must be achieved. The bill also introduces five-year carbon budgets, setting strict targets for carbon emissions for each five-year period. In addition, the Committee on Climate Change will be introduced. The committee will advise the government on the carbon budgets to be set for each five-year period as well as providing annual reports to Parliament on progress made. The bill will also allow the government to introduce further carbon trading schemes, should they be required, in order to meet carbon reduction targets.

In order to gain access to the low carbon growth market, the Investing in a Low Carbon Britain paper of April 2009 highlights the key areas in which the UK economy can compete effectively: CCS technologies, offshore wind farms, marine energy, nuclear power and low carbon vehicles (DECC et al., 2009).

Within the UK the low carbon growth stimulus is supported throughout the government. The UK's Departments for Energy and Climate Change (DECC), Business, Enterprise and Regulatory Reform (BERR), Innovation, Universities and Skills (DIUS) and Environment, Food and Rural Affairs (DEFRA) have been the most active in promoting low carbon growth within the UK.

The low carbon growth pillars

Finance for mitigation and adaptation

The UK government has set up a Low Carbon Investment Fund, which acts as an incentive for low carbon companies to set up or relocate to the UK. The fund will offer support for the research and development of low carbon technologies which can be applied to the market in general. The Environmental Transformation Fund has also been set up, with the aim of supporting the

6 http://www.defra.gov.uk/environment/climatechange/uk/ukccp/.
7 http://www.defra.gov.uk/environment/climatechange/uk/legislation/.

commercialisation of low carbon technologies and allowing their rapid introduction within the market.

Enhanced Capital Allowances (ECAs) have been introduced; these allow business to claim 100% capital allowances on qualifying energy-efficient investments and act as an incentive for businesses to invest in eco-friendly technology across a variety of sectors.[8] To further help small and medium enterprises (SMEs), the Carbon Trust Scheme will include a loan package for around 3000 SMEs to purchase energy-efficient equipment, in order to allow firms to save on energy bills and at the same time reduce carbon emissions.

In addition to ECAs, the Climate Change Agreements (CCAs) were introduced in 2000, with two-year moving targets up to 2012.[9] The CCAs are 12-year agreements between DEFRA and industry organisations. Industries that agree to the CCAs are given an 80% discount on the Climate Change Levy (CCL) in return for achieved (and agreed) additional cuts in carbon emissions. The CCAs have been joined by 10 major industries (including food and drink, chemicals, cement, paper and steel) and over 30 minor industries.

The UK government has also initiated the Low Carbon Building Programme, implemented in April 2006. The programme provides funds to support the reduction in carbon emissions from buildings by combining energy efficiency measures and micro-generation technologies together.[10]

Provisions are also being made to reduce carbon emissions within the public sector. A package of funding will be made available to the public sector in order to improve energy efficiency as well as incentivise local authorities (councils) to pay more attention and improve their commitment towards the environment.

Part of the low carbon development growth plan revolves around the automotive industry including planned government incentives for consumers to purchase electric vehicles as well as an investment package for vehicle manufacturers to research and produce low carbon vehicles (part of a wider stimulus plan for British automotive manufacturers). British households will also receive financial aid through a 'cash back' incentive set up by the UK government, which will give fiscal incentives through monetary payments to households that use renewable electricity.

The British government is also implementing carbon budgets for different government departments. The size of these will depend on both the emissions generated by these departments (including subordinate institutions such as schools and the National Health Service) as well as the ability of said departments to influence carbon mitigation in different economic sectors. These budgets will be used both to offset carbon produced by the departments and to allow departments to set up carbon mitigation programmes for the industries and economic sectors for which they are responsible.

Human capital

The UK government will set up a Skill Funding Agency with the aim of ensuring that the UK labour market will have the right skill sets to meet the high demand for low carbon technologies. The agency will collaborate with training organisations, universities, qualification schemes and apprenticeship schemes.

Technological progress in energy/infrastructure/transportation

The government will invest in the research and development of better carbon abatement technologies as well as investigating and reducing the barriers to the mass implementation of CCS technologies within Britain. CCS is a key area into which the UK government wishes to invest,

8 http://www.eca.gov.uk/.
9 http://www.carbontrust.co.uk/climatechange/policy/cc_agreements.htm.
10 http://www.lowcarbonbuildings.org.uk/about/.

predicting savings of up to £1-2 billion a year by 2020 for UK businesses (including energy generation) if CCS were to be used to its full potential within the UK market. To this end, the UK government will invest in CCS research and development, as well as building four CCS demonstrations plants within the UK.

Investments have also been put in place to research low carbon electricity micro-generation technologies, in order to allow individual buildings (such as schools, public buildings, council houses, etc) to install their own electricity generators. In addition, the government established in 2007 the Energy Technologies Institute as a public–private initiative. This researches low carbon technologies, where private funding is matched by public funding.

Investment and support of renewable energy will be continued under the Renewables Obligation Act, which ensures that licensed energy providers within the UK generate a certain amount of energy through sustainable and renewable energy production[11] (from 5.5% in 2005/06 to 15.4% in 2015/16). It was introduced in April 2002, running until 2027. In order also to promote the growth of wind-powered energy and offshore wind farms, the government will ensure that wind farms receive better support from the Renewables Obligation Act through increased subsidisation of energy production.

The government will also invest in research on the use of wave and tidal stream technologies as a source of renewable energy for the UK. Further investment will also be undertaken in order to improve the infrastructure for the provision of renewable energy, such as better cabling to areas where proposed wind farms would be installed. Investments and support schemes to improve the provision of heat from biomass (wood stoves, etc) will also be undertaken. Further efforts will be made to allow the use of waste and hydrogen for heat and electricity generation as well as to increase national fuel security.

Investments will be undertaken in the research of advanced biofuel production techniques in order to further reduce carbon emissions. In addition to biofuels, the government will also engage in the research of other fuel sources, such as hydrogen cells. Grants will also be given towards a programme for the construction of an alternative refuelling infrastructure for fossil fuel alternatives. Overall government funds for all low carbon growth and carbon abatement research and development will total £405 million.

Investment in agriculture and forestry

The government will undertake a feasibility study of a carbon emission trading scheme for agriculture to assess the scope to extend the scheme to the sector. The government also aims to improve the management of agricultural activities in order to make them more energy efficient and reduce their impact on the environment.

Trade and private investment opportunities

In order to capitalise on opportunities in the new low carbon growth market, the Investing in a Low Carbon Britain paper of April 2009 (DECC et al., 2009) highlights the key areas in which the UK economy can compete effectively: CCS technologies, offshore wind farms, marine energy, nuclear power and low carbon vehicles.

The UK government will put in place a levy system in order to finance the construction of four CCS demonstration projects, with the aim of boosting CCS research and market deployment in the UK as well as ensuring British leadership in the production and commercialisation of CCS technologies worldwide. In addition, the UK government will promote the creation of CCS technologies production and research clusters within the UK in order to foster internal development as well as to attract foreign firms to research, invest in and produce CCS technologies in the UK.

11 http://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/Pages/RenewablObl.aspx.

The UK government will spur continued research and development in offshore wind farms, as the UK is currently a global leader in the use of offshore wind technologies. The government wants to take advantage of this in order to export British offshore technologies and products as well as British expertise in the installation, use and production of offshore wind technologies, and sees this as a potentially large market, which could prove beneficial for the UK economy.

Investments will also be undertaken in marine energy technology, with potential internal growth estimated at 60% by 2016. The UK government sees this as an additional sector for economic growth, especially with regard to wave technology. To this end, the government is sponsoring a large-scale wave power project off the coast of Cornwall in order to spur further developments in marine energy technology and power plants.

Nuclear energy is also seen as beneficial for the UK economy, as the production of power plants within the UK will not only create jobs within the nuclear sector but also provide employment and growth for a large number of UK firms which can provide the materials and expertise needed in order to construct new nuclear power plants.

Low carbon vehicles are seen as a strategically important sector for investment in green technologies. The UK vehicles production market is already well established and the UK government believes that, with the right incentives, the industry could capitalise on future demand for low carbon vehicles by shifting production towards this particular sector.

Incentives and regulation for low carbon growth

Efforts to reduce carbon emissions within the business sector will focus on the EU Emissions Trading Scheme in order to fully involve the private sector in the carbon emission reduction process together with the provision of information for businesses. The CCL, a tax levied on non-residential energy users with the aim of incentivising the use of renewable energy supplies (which are tax exempt)[12] and also allowing businesses to become more efficient through the use of energy-efficient technologies, will be further used as instruments in order for business to reduce their carbon emissions and improve energy efficiency. The CCL is not applied to producers of CHP in order to encourage the use of CHP power plants (as they are deemed more energy efficient than conventional power or heat plants).

Changes to reduce carbon emissions within the transport sector include the introduction of the Renewable Transport Fuel Obligation Act in 2008, meant to ensure that at least 5% of all fuel used for road transportation comes from renewable sources (in practice, vehicles would use a mixture of biofuels (5%) together with more conventional fossil fuels (95%)) by 2010.[13]

The government will also further engage with the EU to make sure that aviation is included in the EU Emissions Trading Scheme as well as continued use of vehicle carbon emissions regulations. The government will make use of the vehicle excise duty in order to steer consumers towards the purchase of vehicles with lower carbon emissions, where the highest carbon-emitting vehicles will have to pay the highest tax band, and vehicles with emissions below a certain level will pay no tax. The government will continue funding the Low Carbon Vehicle Partnership, an action and advisory group set up in 2003 to accelerate the movement towards vehicles with low carbon emissions.[14] The government will also continue to support the EU voluntary agreements on new car fuel efficiency, set up in 1999 between the EU and car manufacturers for the manufacture of vehicles with lower carbon emissions.[15] Vehicle carbon emissions will be highlighted to the consumer through a colour-coded rating system that shows how high carbon emissions are for each vehicle. This will be linked to the vehicle excise duty classification scheme.

12 http://www.defra.gov.uk/environment/climatechange/uk/business/cca/levy.htm.
13 http://www.dft.gov.uk/pgr/roads/environment/rtfo/aboutrtfo.
14 http://www.lowcvp.org.uk.
15 http://www.dft.gov.uk/consultations/archive/2006/reducingnewcarco2emissions/reducingnewcarco2emissionswh1748?page=4.

In terms of residential housing, the programme pledges to update the Building Regulations Act implemented in 2006 (which include provisions for heat and energy conservation requirements within new and refurbished buildings) as well as introducing a new Code for Sustainable Homes, a voluntary environmental impact and sustainability rating system for residential property in England (the code was introduced in April 2008) aiming for a reduction in the environmental impact of residential property.[16] The government aims also to subsidise between 150,000 and 250,000 home insulation installations by 2008 as a means of increasing heat retention within homes, thus reducing heating requirements, hence carbon emissions. The government has also sponsored a multi-million pound study in order to improve consumer information on energy usage through a pilot study on improved electricity, water and gas meter systems.

The government aims to ensure that manufacturers provide better information to consumers on the energy efficiency of products purchased as well as providing better standards for energy efficiency for such products through voluntary schemes at the national level and at the international level through the 2005 EU eco-design of energy using products directive. This is intended to make sure that disparities do not exist among EU Member States in terms of regulation of the environmental impact of consumer goods, in order to facilitate trade among EU countries and promote the manufacture of more environmentally friendly products.[17]

South Korea snapshot

In South Korea, services account for 58% of GDP, manufacturing for 28% of GDP, the remainder of industry for around 12% of GDP and agriculture for only 3% of GDP.

Energy in South Korea is derived mainly from coal (38% of total electricity produced) and nuclear power (37%), with additional energy provided by gas (18%), oil (5%) and hydroelectric power (1%). Data on 2004 emissions (by economic sector) show that the majority of greenhouse gas emissions stem from energy production (83%), followed by industry (12%) and agriculture (3%).

South Korea established a Low Carbon, Green Growth vision in 2008, although a concrete national strategy on low carbon growth has not been issued.

The ECOREA 2008 report (an annual report on the status of the South Korean environment: Ministry of Environment, 2009) contains a short description of South Korea's efforts on carbon mitigation and low carbon growth:

- Both decreased carbon emissions (through carbon intensity) as well as increased energy efficiency (through eco efficiency);
- Increased use of renewable energy sources, from 2.24% in 2006 to 11% in 2030;
- Increased investment in eco-friendly public transport and increased regulation of carbon emissions from motor vehicles;
- Introduction of a carbon tax;
- Implementation of new regulations and standards to monitor and manage carbon emissions.

In addition, the Ministry of Knowledge Economy has set up two national policies, the National Climate Change Plan and the Green Energy Industry Development Plan. Documentation on these is not currently available for review.

16 http://www.planningportal.gov.uk/england/professionals/en/1115314116927.html.
17 http://ec.europa.eu/enterprise/eco_design/index_en.htm.

2.2 Middle-income countries

2.2.1 Brazil

Country context
Brazil has large and well-developed agricultural, mining, manufacturing and services sectors and its economy overshadows that of all other South American countries. Brazil is rapidly expanding its presence in world markets. The economy is based on services (66%), industry (28.5%) and agriculture (5.5%). Around 66% of the population is employed in the services sector, 20% in agriculture and 14% in industry. Per capita income has reached $10,000 (2008 estimate).[18] Despite high levels of economic growth, roughly 30% of the population remains below the poverty line.

Brazil creates an estimated 2.3 billion tonnes of CO_2e per year – making the country the world's fifth-highest GHG emitter (de la Torre et al., 2009). Land use change and forestry, particularly the deforestation of the Amazon, is estimated to account for 60% of the country's total GHG emissions, 14% from the energy sector (5.4% from transport, 4.1% from manufacturing and 2.2% from electricity), and 24% from agriculture (World Resources Institute Climate Analysis Indicators Tool (WRI CAIT) database).

At present, 45.8% of the energy portfolio consists of renewable energy: the global average is 12.9%. In terms of the electricity sector, 77.3% comes from hydro, 3.6% from natural gas, 2.8% from oil, 2.5% from nuclear, 1.3% from coal, 3.5% from biomass and 1.0% from industrial gases, and imports are 7.9%.

Policy motivations for low carbon growth
Brazil is actively seeking to harness low carbon development to enhance competitiveness and open new markets, particularly for bioethanol. It also recognises that low carbon growth opportunities are in line with social development and poverty reduction objectives. Brazil was the first signatory of the Convention on Climate Change and has taken significant steps to show its commitment to reducing emissions. It recognises that protection of the Amazon rainforest is a critical issue and has made reducing deforestation a major long-term priority. On the other hand, Brazil's latest National Plan on Climate Change admits that there are significant barriers to the implementation and enforcement of its low carbon policies.

Because of deforestation, Brazil is one of the world's highest CO_2 emitters, but other sectors of its economy are already comparatively low in carbon. As one of the world's largest producers of hydroelectric power, CO_2 emissions from the Brazilian electricity sector are among the lowest in the world in relation to population and GDP. Additionally, Brazil's early investment in sugarcane-based ethanol has made it the world's most efficient ethanol producer, with ethanol providing about 40% of the automotive fuel in the country. Combined with domestic oil production, Brazil is essentially energy self-sufficient.

Brazil's hallmark *Proalcool* programme was set up in 1974 to reduce dependency on foreign oil and used subsidies and tax breaks in order to encourage farmers to plant more sugarcane, to incentivise investment in distilleries and to encourage car manufacturers to design their vehicles based on bioethanol fuel production.[19] Brazilian bioethanol production uses the waste material from sugarcane as fuel for the distillery process. It is also price competitive, with production costs

18 https://www.cia.gov/library/publications/the-world-factbook/geos/br.html.
19 The Social Fuel Stamp Policy is part of the Lula administration's drive to encourage and reward biodiesel production by smallholders. The fuel stamp is granted to producers who purchase from family agriculture, sign contracts with family producers and provide family farmers with training. The benefits include: tax exemption from federal taxes according to the amount purchased; low rate loans; and overseas trade facilities.

well below that of oil, with a break-even point of $35 a barrel.[20] The period from 1990 to the present is known as Phase II of the *Proalcool* policy and is more flexible in terms of catering to market demands,[21] but is still meeting policy objectives: by 2002, 35% of all new cars in Brazil were running on 100% ethanol. By 2004, 26% of all new cars were flex-fuel.[22]

Brazil's new major offshore oil discoveries bring into question how robustly Brazil will continue to promote bioethanol. Today, Brazil is a net exporter of oil but recent statements from President Luiz da Silva indicate that Brazil has no plans to boost its export of crude from new fields but rather intends to use the oil to create value-added products, such as gasoline and petro-chemical products and use the profits to fund anti-poverty programmes. The government has recently taken steps to exert more state control over offshore oil finds to be able to funnel revenues into social spending (Associated Press, 2009).

In recent years, Brazil has also set out to create a more comprehensive national plan on climate change to direct sustainable development objectives and low carbon growth. Efforts to develop and implement such a plan show there is a high level of government support across multiple ministries for aggressive action on climate change. President Luiz da Silva has endorsed the national action plan on climate change.

The Brazilian National Plan on Climate Change (CIM, 2008) is an important milestone both in terms of outlining a set of programmes for low carbon growth and also for the integration and harmonisation of public policies. In 2007, the government created the Inter-ministerial Committee on Climate Change (CIM), charged with preparing the National Policy on Climate Change and the National Climate Change Plan. CIM is coordinated by the Office of the President of the Republic, and consists of 17 federal bodies and ministries and the Brazilian Forum on Climate Change (FBMC).

In 2008, the government launched the National Climate Change Plan (NPCC). In addition to members of CIM, the plan was developed in collaboration with other fora and institutions, including the National Conference on the Environment, the State Fora on Climate Change and a variety of civil society organisations (CSOs). The plan is to be delivered in phases, with most interim targets set between 2018 and 2020.

Targets will be met by promoting sustainable development in the industrial and agriculture sectors, maintaining a high proportion of renewable energy in electricity production, encouraging the use of biofuels in the transportation sector and reducing deforestation. The plan's recommendations are organised into four lines of action:

1. Mitigation;
2. Vulnerability, impact and adaptation;
3. Research and development;
4. Enhancement of skills and dissemination.

The NPCC states that, to ensure success, it will be implemented in successive phases, as a way to ensure constant evaluation of intended objectives, as well as to include other measures which may be identified and considered feasible, in later stages. The following phases will include mechanisms to evaluate the performance of ongoing actions and their respective results. Additional actions and instruments will also be presented, including pacts with Brazilian states in order to guarantee that the objectives stipulated here can be fully met. In this sense, studies

20 Production costs of ethanol average at around $0.18-0.25 a litre, with an average export price of $0.23 a litre. This compares with the US cost of bioethanol production of $1.14/gallon.
21 In terms of the price incentives for consumers to use either oil or ethanol.
22 This is shown by the difference between anhydrous and hydrous levels of ethanol production and total ethanol production.

related to new economic mechanisms for sustainable development will be carried out, also covering fiscal and tax incentives, among others.

The plan presents ambitious targets but lacks specific carbon emission targets, deadlines and implementation measures, stating that the specific implementation measures will be designed through ongoing consultations. Questions remain around, for example, cogeneration, which currently supplies only about 0.5% of Brazil's domestic energy, although the government's plan is to increase this to one-fifth of all domestic energy (it does not specify incentives or deadlines). The plan has received other criticisms from non-governmental organisations (NGOs), saying that inputs given during the initial consultation phase were not included in the plan. There may also be other clean energy opportunities missed by focusing only on biofuels, hydropower, cogeneration and nuclear for clean energy generation.

Brazil has made an attempt to harmonise its national strategy for low carbon growth with growth and poverty reduction strategies, stating that a key goal is to identify the most vulnerable groups and target adaptation assistance, education and infrastructure development in these areas. However, the NPCC does not specify how its proposals will be integrated across government departments or with local governments, leaving that again to future consultations. Another challenge will be to maintain momentum and emphasis on clean energy sources, given rising demand. Although the Brazilian energy sector is relatively clean – at present 45.8% of the energy matrix consists of renewable energy, while the global average is 12.9% – new targets are steep and newly discovered offshore oil could hamper efforts to meet renewable energy goals.

Low carbon growth pillars

Finance for mitigation and adaptation
Brazil has taken the stance that market mechanisms to fund reduced deforestation efforts are not sufficient. Therefore, securing public finance for forestry programmes is considered a priority. Brazil has created the Amazon Fund to fight deforestation in the Amazon rainforest, which aims to raise $21 billion by 2021. Norway has pledged up to $1 billion. Brazil has also proposed a Climate Fund to the National Congress as part of the NPCC. This would aim to finance actions concerned with preventing deforestation, among other things. In addition, the NPCC is expected to be funded by the National Bank for Social and Economic Development.

Human capital
The NPCC, in recognising that there is a strong need for increased capacity and education to deal with health and adaptation issues, particularly in vulnerable communities, sets out goals to strengthen measures to enhance communication and environmental education. Specific provisions related to education and health include: strengthening sanitation systems; providing incentives for studies, research and training on the impacts of climate change on human health, including developing indicators for monitoring impacts on health; strengthening environmental education; identifying threats, vulnerabilities and resources (financial, logistics, material, human, etc) to set up prevention, preparation and response plans for public health emergencies; expanding the technical capacity of professionals in the public health system; creating alert systems for harm and damage related to climatic events; and implementing dedicated climate change educational programmes in schools and universities that reach management, teachers and students.

Stimulating technological progress in energy/infrastructure/transportation
The NPCC sets out a number of ambitious goals to mitigate emissions by increasing renewable energy generation, especially hydro, to promote new sources of clean energy (nuclear and cogeneration) and to substantially expand the use of biofuels nationwide. More than 7000 MW of renewable sources will be brought online by 2010 in accordance with the Programme of Incentives for Alternative Sources of Electric Energy (PROINFA).

Several renewable energy provisions include: 1) increasing the electricity supply from cogeneration, mainly from sugarcane bagasse, to 11.4% of the total supply in the country in 2030, corresponding to 136 TWh; 2) encouraging energy generation from wind and biomass, particularly sugarcane bagasse; 3) expanding the national photovoltaic industry, predominantly in systems that are isolated and connected to the grid; and 4) reducing the non-technical losses – estimated to average 22,000 GWh per year – by a rate of 1000 GWh per year over the next 10 years.

Hydropower also emerges as one of the government's preferred solutions. The draft plan seeks to enlarge Brazil's hydropower network by 34,460 MW by the end of the next 10-year Energy Plan (2007-2016). Hydro already accounts for around 35% of the country's total energy consumption and 84% of its electricity generation. However, hydro projects are controversial in Brazil and civil society has expressed concern about the extent to which hydro will be expanded. Also controversial is the plan's endorsement of nuclear energy projects.

Biofuels figure prominently in the plan, given the country's longstanding policy on biofuels development. The NPCC anticipates increasing Brazil's biofuel production from its present rate of around 25.6 billion litres per year to 53.2 billion litres in 2017. Specifically, the plan prohibits the conversion of agricultural land for food production and forests, instead encouraging the use of degraded lands. The plan encourages industry to achieve an average annual consumption increase of 11% in the next 10 years by displacing fossil fuels. The NPCC suggests that a 5% biodiesel target may be added in the future. Research and development in agro-energy is ongoing.

Trade and investment opportunities

The subject of encouraging private sector finance is a sensitive one because Brazil does not want to encourage foreign investments that could compromise state sovereignty. Brazil sees strong value in the CDM as the main economic instrument existing for the promotion of voluntary measures to mitigate GHGs, but has been a strong proponent of the public fund approach rather than private finance for new CDM mechanisms such as REDD. However, the Brazilian government supports expansion of CDM projects in principle, given that there is still great potential to be harvested within the country.

In addition to trade of emissions reductions through the CDM, opportunities for bilateral trade of emissions offsets are being explored. There are talks of a potential Brazil–US agreement in which Brazil could sell offsets directly into the proposed future US Emissions Trading Scheme. Specifically, trading forestry credits are seen to be a major opportunity. According to McKinsey & Co. (2009), 85% of Brazil's abatement potential lies in deforestation and the agriculture sector. McKinsey & Co. found in its Brazilian GHG abatement cost curve that eliminating deforestation by 2030 accounts for 72% of all abatement opportunities, at a cost of less than €10/tCO_2e. The cost to reduce deforestation emissions is estimated at €5.7 billion annually, but a significant portion of this could be funded using international carbon credits.

Brazil hopes that biofuels will be its primary opportunity to enhance trade and investment. It is working to stimulate an international ethanol market, in part by engaging in technical cooperation with other countries possessing agricultural potential to increase sugarcane-based ethanol, with the aim of expanding and stabilising the supply of ethanol in the international market. The government is also currently engaged in talks at the World Trade Organization (WTO) to get bioethanol classified as an 'environmental good'[23] in order to enhance trade. There is also a memorandum of understanding between the US and Brazil to advance cooperation on biofuels. Brazil is seeking to expand South–South trade opportunities in flex-fuel vehicles. For example,

23 See Dufey (2007), who notes that the current lack of a clear classification of biofuels within the multilateral trading system constrains effective trade. At present, there is no agreement on whether biofuels are industrial or agricultural goods. This means a lack of agreement as to what constitutes Green Box non-actionable subsidies or an environmental good.

Sudan and Brazil have discussed signing an agreement on technology transfer and trade in flex-fuel vehicles.

Investment in agriculture and forestry
Reducing emissions from deforestation is a cornerstone of the Brazilian plan since it is estimated that at least 60% of the country's emissions come from deforestation. The NPCC sets out a goal to reduce deforestation in the Amazon by 70% by 2018, along with abolishing illegal logging by 2015.

There are also plans to double the area of reforestation from 5.5 to 11 million ha in 2020, including in indigenous areas. The objective is to promote territorial and land organisation, monitoring and control through high-precision satellite monitoring and incentives for sustainable activities and environmental enforcement, involving partnerships between federal bodies, state governments, city governments, CSOs and the private sector. Efforts will be made to mobilise instruments that can contribute to the achievement of this objective, including the reforestation and afforestation carried out in Brazil under the CDM. Furthermore, lines of credit adapted to forestry activity, technical assistance and technological research will be expanded.

Other elements include a moratorium on the selling of soybeans that come from deforested areas of the Brazilian Amazon, the creation of a National Forest Inventory to provide information about carbon stocks and a revision of current banking requirements to make forest management and reforestation activities more attractive.

To ensure the provisions on illegal logging are successful, the government will require certification of wood and forest products and attempt to strengthen forest management. Nevertheless, this provision has attracted scrutiny, because the new strategy calls for greater penalties for unlicensed loggers although, under the current system, state and municipal authorities are responsible for curbing deforestation in their respective jurisdictions, and there are no recommendations to centralise these efforts nationally.

Brazil recognises that agriculture and cattle raising are integrated systems and plans to provide incentives for sustainable practices concerned with: the recovering of a large part of the current 100 million ha of degraded pasture; carbon sinks via crop livestock integration; agro-forestry; adoption of a zero-tillage system and reduction in the use of nitrogenous fertilisers; and the organic enrichment of pasture to reduce methane emissions by cattle raising.

Incentives and regulation for low carbon growth
Brazil is taking a multi-pronged approach to developing a low carbon economy, including establishing programmes and incentives to reduce deforestation emissions, reduce emissions in the agriculture sector and encourage renewable power generation, as well as pursuing new trade opportunities in biofuels and offsets, as discussed above. Brazil sees improving energy efficiency as a key method to reduce the carbon content of Brazilian GDP, improving the competitiveness of Brazilian products in the international market, increasing income and generating an economic surplus that can lead to higher social welfare. The following are the main actions outlined in the NPCC specific to setting a low carbon plan, although they do not specify the measures that will be used to reach targets.

- **Energy efficiency:** Implementation of the National Policy for Energy Efficiency, which will result in a gradual energy saving up to 106 TWh/year to be reached in 2030, avoiding emissions of around 30 million tons of CO_2;
- **Charcoal:** Substitution of charcoal for coal in steel plants, through the encouragement of forestation in degraded areas;
- **Fridges:** Replacement of 1 million old fridges per year, for 10 years, with the collection of 3 million tCO_2eq/year of chlorofluorocarbons (CFCs);
- **Replacement of refrigerant gases:** It is estimated that emissions of 1078 billion tCO_2eq of hydrochlorofluorocarbons (HCFCs) will be avoided in the period 2008-2040;

- **Solar heating:** Encouragement of the use of water solar power heating systems, reducing electricity consumption in 2200 GWh per year by 2015;
- **Urban solid waste:** 20% increase in recycling by 2015;
- **Sugarcane:** Phasing out of the use of fire for clearing and cutting of sugarcane in areas where harvesting mechanisation can take place; mechanisation to be adopted in at least 25% of each agro-industrial unit, for each five-year period, as determined by Decree 2.661/98;
- **Incentives for research and training related studies**, to expand knowledge about the impacts of climate change on human health.

Further demonstrating its interest in low carbon development, Brazil is also part of the Energy Sector Management Assistance Program (ESMAP) Low Carbon Growth Country Studies Program, a six-country programme in which each country government undertakes local studies to assess its development goals and priorities, in conjunction with GHG mitigation opportunities, and examines the additional costs and benefits of lower carbon growth. The Brazilian study focuses on land use and land use change models, including deforestation, energy sector options, transport, waste management and cross-sector issues. To provide more options and information to the Brazilian government, the study will produce a GHG cost abatement curve; a municipal and interstate transport model; reference points and low carbon scenarios for 2030; a simulation of GHG emissions owing to deforestation and agriculture; potential GHG mitigation opportunities; and policy options. These studies will be used to inform and design future low carbon incentives and regulation.

2.2.2 China

Country context

The Chinese economy is based mainly on manufacturing and services (WDI 2006 data). Industry in general accounted for nearly 49% of GDP in 2006, the services sector accounts for 39% of GDP and agriculture accounts for 11% of GDP.

The Chinese government estimates that total greenhouse gas emissions in 2004 were around 5600 million equivalent tons of CO_2. In 2005, coal-fuelled electricity accounted for 68.9% of primary energy consumption, oil for 21% and combined gas, nuclear and renewable energy for 10%.

According to the 2009 WWF/Allianz G8 Climate Change Scorecard, the major source of carbon emissions in China comes from energy production (accounting for 39% of all CO_2 emissions), followed by the industrial sector (with 33% of all CO_2 emissions), the agriculture sector (14%), the residential and services sector (7%) and finally the transport sector (5%).

Energy in China stems mainly from coal (80%) and hydroelectric power (15%), with the remainder (5%) coming from nuclear, oil and gas.

Policy motivations for low carbon growth

The Chinese National Climate Change Programme (CNCCP) was announced in June 2007, with the aim of reducing energy consumption per unit of GDP by 20% from its 2005 level by 2010. In addition the 11th Five-year Plan for National Economic and Social Development (2006-2010) considers it a major strategic task for China to build an energy-conserving and environmentally friendly society. In addition, China has signed both the Kyoto Protocol (as a non-Annex 1 country) and the UN Framework Convention on Climate Change (UNFCCC) as part of its international obligations to mitigate climate change. The Chinese strategy for mitigation and adaptation to climate change is based wholly on the ideal of mitigation and adaptation through economic development, hence economic growth and climate change mitigation are not seen as mutually exclusive by the government but rather as a way to promote sustainable economic development.

The CNCCP has four major objectives:

- Control greenhouse gas emissions;
- Enhance China's capacity to adapt to climate change;
- Improve research and development of green growth technologies;
- Raise public awareness of climate change and improve climate change management systems.

The major aim of the CNCCP is to achieve the target of a reduction of 20% in energy use per unit GDP by 2010, thus also reducing CO_2 emissions. To do so, the Chinese government aims to use a variety of tools, such as strengthened regulation on energy conservation and efficiency, and introduce market mechanisms for energy conservation, increased use of renewable and nuclear energy and increased research into better energy conservation procedures. Additional tools to be used include better natural resource management techniques, enhanced eco-friendly agricultural techniques and the dissemination of information on climate change adaptation and mitigation through modern communication systems.

Possibly the main impetus for Chinese low carbon growth, beyond the need to conform to international standards and expectations, is the need to achieve the highest efficiency possible from what resources are available, as the Chinese themselves state that China has a very high population but is low on natural resources, hence a sustainable development path is absolutely necessary for development. To further this aim, the Chinese government intends to restructure its industrial base in order to promote high-tech industries which require low inputs (such as energy and materials) and curb or reduce high consumption industries, while at the same time incentivising, promoting and helping current high consumption industries to adopt new techniques and technologies in order to reduce consumption levels.

Chinese low carbon growth is supported at the national level by the National Coordination Committee on Climate Change, which is part of the People's Republic of China's National Development and Reform Commission, whose main aim is to develop and implement mid- and long-term economic and social development plans in China. Working together with the NDRC are the Ministry of Science and Technology and the Ministry of Finance.

Low carbon growth pillars

Finance for mitigation and adaptation
China has been one of the main recipients of funds under the CDM, with considerable financing of large energy-related industrial projects.

The Chinese government has not set up any general funds for carbon mitigation or low carbon growth, but rather is incentivising the use of green growth technology on a sector-by-sector level, with funds usually attached to promote specific regulations or laws. Hence, these specific funds are placed in the categories below into which they best fit.

Human capital
China's Mid- and Long-term Development Plan for Science and Technology was established in 2006 with the aim of prioritising the research and development of energy efficiency and conservation and green growth technologies. In addition, the Science and Technology Program on Climate Change, implemented in 2007, established a set of timed goals for developments in green growth technologies to be achieved during the 11th Five-year Plan period (2006-2010) as well as more long-term goals leading up to 2020.

China also aims to enhance its pool of climate change research specialists in order to allow China to better mitigate and adapt to climate change. The government has set up national research institutes such as the National Climate Monitoring Network, in order to increase the number of climate change specialists within the country as well as to strengthen the research and development of green growth technologies, so as to hasten their introduction and application within the Chinese market.

Stimulating technological progress in energy/infrastructure/transportation

Financial support has been extended towards the research and development of green growth technologies, through both stable government funds as well as private investment, which the Chinese government is trying to attract more of in the coming years. The government has invested more than 9.5 billion yuan in the research and development of green growth technologies through programmes like the National Key Technologies R&D Program, the National High-Tech R&D Program and the National Basic Research Program.

The Chinese government will focus on energy saving and efficiency technology, research into better and more efficient forms of renewable energy, technology focused on the reduction of GHG, CCS technology, efficient use of coal and fossil fuels and more efficient nuclear energy production. The government is also promoting further research, development and construction of hydroelectric power generators (although construction locations will be decided based on their social and environmental opportunity costs) as well as the construction of wind-powered electricity generators and biomass-powered electricity generators.

Investment in agriculture and forestry

The Chinese government wishes to improve and enhance agricultural and forestry laws and regulations in order to promote more efficient agricultural production, protect and manage (in a sustainable manner) current agricultural land, reduce the use of harmful fertilisers and enhance CCS through agricultural procedures. The government is looking to promote the research and development of special high-yield and low GHG emission rice varieties together with methane reduction technologies to apply to both agricultural produce and livestock in order to reduce GHG emissions further. In terms of agricultural equipment, the government will try to phase out old agricultural machinery with high fuel consumption and encourage their replacement with energy-efficient, low carbon vehicles and equipment.

In addition to agriculture, the Chinese government is looking to further strengthen forestry laws in order to consolidate the protection of existing forests and promote the sustainable management of forest lands. In addition, regulations are being looked at in order to promote the voluntary reforestation of land for CSS, as well as to reduce the rate of desertification of land in China.

Key projects include the Natural Forest Protection Program (NFPP), the Conversion of Cropland to Forest Program (CCFP), the Sandification Control Program for Areas in the Vicinity of Beijing & Tianjin, etc.

Trade and private investment opportunities

Foreign investment in green growth technologies, especially energy generation, is being promoted by the Chinese government. The government is looking for foreign investors in order both to build cleaner energy production facilities and to promote technology transfer of cleaner and more advanced green growth technologies, with the aim of introducing (and possibly also producing) them in the Chinese market.

The Chinese government also wants to restructure the Chinese economy, not just by promoting low consumption industry, but also by promoting investments in high-tech and services sector enterprises in order to lower GHG emissions and decrease energy and product consumption, but also to encourage Chinese global competitiveness. China is already the world’s largest producer of photovoltaic cells; its market share could grow considerably as global demand for alternative energy sources increases.

Chinese low carbon growth market opportunities will be based on three pillars: vehicles, renewable energy and biofuels.

In terms of vehicles, China is a world leader in the production of electrical vehicles such as bicycles and motorbikes, and could thus extend its industrial capacity and research towards the wider production of electrical vehicles. In addition, China has successfully experimented with electrical vehicles through the production of its first fully electrical vehicle, the S18, produced by the company Chery (brand recognition and market awareness still remains a problem, however). Internally, the market value of the automotive industry has exceeded the market value of the motor industry within the US, hence there is great scope to serve electrical and low carbon emission vehicles to the internal market, as well as meeting any future external demand.

China is the world's leading producer of photovoltaics, hence the country is in a key position to capitalise on both external and internal demand for photovoltaics, In addition, renewable energy efforts will be focused on upscaling production of wind-powered electricity generators. Initial government efforts focused on photovoltaics include the promotion of internal use by various government ministries (including the Ministry of Finance and the Ministry of Housing and Rural-Urban Development), while the wind sector has been boosted through laws that require that 70% of wind-powered technology be produced internally, as well as offering tax breaks and tax havens to firms producing wind-powered technologies.

The Chinese government has also promoted the internal production of biofuels (as long as non-food crops are used in order to maintain food security) and aims to further enhance their commercialisation.

Incentives and regulation for low carbon growth

Energy conservation campaigns have been launched aimed at private sector enterprises with the objective of reducing energy consumption through voluntary energy audits, the creation of energy saving plans and the disclosure of energy being used within companies. In addition, the Chinese government has set out to make sure that private enterprises are conforming to energy efficiency standards set out by the government.

In 2005, the Renewable Energy Law was enacted in order to prioritise the use of and investment in renewable energy. The law forces the Chinese electrical grid operator to purchase all electricity generated through renewable sources at a competitive price, thus encouraging investment in the production of renewable energy. In addition, the law gives renewable energy users significant discounts on electricity prices. It also creates a fund to promote private sector investments into renewable energy production. Further, the law commits the Chinese economy to a renewable energy target whereby 15% of all energy must come from renewable sources. The Chinese government wishes to further strengthen the Renewable Energy Law through additional legislation and policies, together with further incentives to promote use of and investment in renewable energy.

The Chinese government launched the Cleaner Production Promotion Law in 2002. The aim of the law is to encourage (through funds and regulation) the use of cleaner production processes in private enterprise. Companies need to audit their production process and make results public; those which are deemed to be too polluting or are using toxic materials not approved by the government will have to change their production process in order to meet government regulation; other companies will be encouraged to use cleaner production mechanisms through the use of incentives, guidebooks and a special fund created to support the law.

In addition, a number of policies aimed at reducing GHG emissions have been, or are in the process of being, either implemented or strengthened. These laws include the Energy Law of the People's Republic of China, the Coal Industry Law and the Electric Power of the People's Republic of China Law. The Chinese government sees the implementation or amendment of these laws as a legitimate way of increasing carbon mitigation and energy efficiency in China.

The Chinese government is also trying to reduce GHG emissions coming from the transport sector. The government has set carbon emission standards for vehicles both built in and imported into China, setting a ban (together with a monitoring system) on the import or construction of vehicles that exceed government regulation on CO_2 emissions. The government is encouraging the production and use of low carbon or zero carbon emission vehicles as well as the use of rail transport and electrical vehicles in public transport systems. Vehicle emission policies will be supplemented by reforms in fuel taxes in order to encourage the purchase and use of more fuel-efficient and low carbon-emitting vehicles.

Within the construction and residential sector, the Chinese government will promote the construction of new environmentally friendly energy-efficient buildings and the use of sustainable materials for their construction. Offices and homes are also targeted in order to improve their energy efficiency and to reduce carbon emissions through the implementation of an energy efficiency label set up by the government to promote the use and commercialisation of energy-efficient products within the Chinese market.

2.2.3 Guyana

Country context

The Guyanese economy has exhibited moderate economic growth in recent years and is based largely on agriculture and extractive industries. The economy is heavily dependent on the export of six commodities: sugar, gold, bauxite, shrimp, timber and rice. Agriculture is 32% of GDP, services 47% and industry 21%. Economic recovery since the 2005 flood-related contraction has been buoyed by increases in remittances and foreign direct investment in the sugar and rice industries as well as the mining sector.

According to Guyana's Initial National Communication to the UNFCCC, emissions are just 4 million tonnes CO_2e, because the country is a net sink for CO_2 emissions. Net CO_2 emissions were estimated at 1.4 million tonnes in 1994 but removals totalled 26 million tonnes. The WRI CAIT database similarly estimated total CO_2e emissions at 1.5 million tonnes in 2005. The National Communication states that the agriculture sector was the major source of CH_4 and N_2O emissions, with emissions totalling 51,000 tonnes and 1000 tonnes, respectively, in 1994. Under this sector, rice cultivation and enteric fermentation in animals are the main sources of CH_4; that of N_2O emissions is from the use of synthetic nitrogen fertiliser on agricultural soils. There is a perceived need for better data collection for future inventories, particularly in the energy sector.

Policy motivations for low carbon growth

Over the past two decades, Guyana has transitioned to a multiparty democracy and market-based economy. Most of Guyana's population of less than 800,000 are located on a coastal strip 1.4 metres below sea level. In 2006, floods caused major economic losses. In order to upgrade sea defences, Guyana needs financial resources; it views carbon assets as a way to provide this.

With the release of its LCDS in June 2009, the government outlined how Guyana can work with the international community to provide a model on how to create a low deforestation, low carbon, climate-resilient economy. Its proposal centres on payments for preserving its rainforest through the mechanism known as REDD Plus. The government asserts that payments for avoided deforestation can provide a platform to enable Guyana's economy to be realigned with a low carbon development trajectory. The government has stated that its top development priorities are to further stimulate investment, economic growth and job creation, as well as to improve security and social services, protect vulnerable groups and deal with increased climate change-induced flooding.

In the LCDS, Guyana views its forests as its most valuable asset. The majority of the 16-18 million ha rainforest (depending on estimates) is suitable for timber extraction and agriculture, and significant mineral deposits exist below its surface. The Guiana Shield, which comprises southern Venezuela, Guyana, Suriname, French Guiana and northern Brazil's Amapa and Para states, has one of the world's highest percentages of primary forest cover: over 90% of the region is tropical forest.

If the forest were harvested and the land put to its highest-value subsequent use, the value of this rainforest[24] – known as the Economic Value to the Nation (EVN) – is estimated by McKinsey & Co. (Office of the President, Republic of Guyana, 2008) to be between $4.3 billion and $23.4 billion.[25] This translates into a likely average annual annuity payment of $580 million. Conservative valuations of the Economic Value to the World (EVW) provided by Guyana's forests suggest that, left standing, they contribute $40 billion to the global economy each year.[26] Payments between the EVN and EVW are to be considered sufficient to disincentivise deforestation (see Finance for Mitigation and Adaptation, below).

Guyana plans to use REDD Plus payments as the basis for funding priority investments in clean energy (predominantly hydropower), adaptation (flood defence), development of village economies and health care and education. The plan sets a four-phase timeline for implementation from 2009-2020. The initial phases are to attract 'transition' donor grants that will be to used to ramp up the country's REDD Plus programme and make initial low carbon investments. The latter phases transition to market-based funding from avoided deforestation credits through REDD Plus.

Guyana sees its low carbon strategy as providing long-term benefits in terms of:

- Promoting a low carbon economic infrastructure;
- Facilitating investment and employment in low carbon economic sectors;
- Generally enhancing the nation's human capital and creating new opportunities for forest-dependent and other indigenous communities.

The governments of Norway and Guyana have worked together to implement Guyana's LCDS, providing a model of how to quickly implement policies to avoid deforestation. The partnership aims to support the creation of low carbon employment and investment opportunities in Guyana, sustained efforts to avoid deforestation and forest degradation, strengthening transparent forest governance, and establishing an international monitoring, reporting, and verification system for Guyana's forests.

To further support its strategy, Guyana has pledged to institute a number of new organisational units and systems, including an Office of Climate Change to coordinate all climate-related activities for the nation, a Low Carbon Strategy Project Management Office to drive major low carbon programme priorities and a Guyana Low Carbon Finance Authority to manage forest payments and related investment flows into the country and to promote investment efficiency, although the precise logistics behind which ministry or department will manage received money has yet to be finalised.

In addition, safeguards and systems will be developed to ensure avoided deforestation credits are globally verified and other land use governance standards are transparent and accountable.

---

24 This estimate includes the State Forest Estate, and excludes lands under the jurisdiction of indigenous peoples, who will be able to 'opt in' to the forest protection programme through the national consultation process.
25 Amerindian lands were omitted from the calculation of EVN because they are not legally obligated to protect the forest. The decision to participate will likely be based on whether participation will lead to improved access to opportunities and services for forest-dependent communities.
26 Based on 2030 marginal abatement cost from McKinsey & Co (2007).

The government was advised by a multi-stakeholder steering committee, which comprised governmental agencies and NGOs, to hold a three-month period of countrywide consultations and awareness building on Guyana's draft LCDS. A principal stakeholder group consisted of the country's forest-based Amerindians, who make up 9.1% of the population. Amerindian communities with titled lands were given time to decide whether to opt in to a forest payment scheme for avoided deforestation as set out in the LCDS. Initial consultations were planned for summer 2009, along with awareness and outreach activities utilising the local media and internet. An updated version of the LCDS will be published, incorporating feedback.

The draft strategy is supported by Guyana's R-Plan, a document produced for the World Bank's Carbon Partnership Facility, which sets out more details on Guyana's participation in the REDD Plus process. Guyana's R-Plan, produced by the REDD Secretariat at the Guyana Forestry Commission, sets out detail on how the forest's carbon stocks will continue to be managed, to ensure that the forests are managed in a way that is as close as is reasonable to carbon neutral over time.

Guyana's strategy is one of the most comprehensive and ambitious plans yet prepared by a developing country. It tries to achieve a high level of collaboration internationally, while building strong domestic support through consultations and outreach, and directly ties prioritised projects with a funding source. However, the plan rests entirely on the premise that the country will receive payments for preserving their vast tracts of rainforest, which at present is far from certain. In terms of policy coordination, the LCDS contains a provision which aims to align all land use policies with the LCDS, most importantly forestry and mining policies, but there is little clarity about how the government will go about this. The strategy aligns well with development goals set out in Guyana's (now several years old) poverty reduction strategy paper (PRSP) and goals outlined in its 2002 Initial National Communication.

Low carbon growth pillars

Finance for mitigation and adaptation

Guyana will establish the Guyana Low Carbon Finance Authority (GLCFA) to fulfil two functions: to collect, manage and monitor forestry payments; and to work with the Guyana Office for Investment to address the challenge in attracting investors to Guyana who are willing to underwrite their investments in low carbon sectors.

The GLCFA will seek to address investment barriers and help improve investment returns. Owing to lack of capacity to promote investment in Guyana, the GLCFA will likely require a reputable international services provider in the near term. At a later point, the GLCFA will build its own staff capability.

Guyana, as mentioned, plans to obtain financing for its low carbon growth through payments for avoided deforestation, scaled up in four phases. Phase I in 2009 is to launch the local carbon strategy and attract donors to initially fund its deforestation efforts. In Phase II (2010-2012), Guyana will receive increased payments from partners (starting with Norway and scaling to additional global partners). Phase III (2013-2020) is integrating the economy with a global climate deal. During this phase, interim forest payments should gradually increase to approach the level of EVN. In parallel, REDD Plus payments from carbon compliance markets should ramp up. During these years, Guyana will continue to invest in infrastructure and adaptation priorities, combined with capacity building and expanded education and health programmes, expecting to start to see transformations toward a low carbon, services-centred economy. Phase IV (post-2020) focuses on operating 'at scale' with a full REDD Plus regime in place and payments at or exceeding EVN, with no requirement for fund-based payments.

Human capital
Guyana recognises that, in transforming its economy, it will require a balance between attracting large, long-term private investments and making significant investments in human capital and social services to provide the population with the capacity to take advantage of the new economy. Guyana will invest a significant share of the forest protection funds it receives in initiatives aimed at developing jobs, diversifying the jobs base and improving the general standards of living including: investing in targeted education initiatives to fuel economic growth, potentially including specialised vocational training and supporting social services such as basic infrastructure (road maintenance, reliable supplies of potable water) and health and education services through discrete projects funded by forestry payments.

Stimulating technological progress in energy/infrastructure/transportation
Guyana has identified more than $1 billion in essential capital projects that can be fully or partially funded through private investment, assisted by an in-country infrastructure investment fund built from forest compensation payments. These targeted low carbon infrastructure projects include:

Hydropower ($400-600 million): Guyana currently relies on expensive and carbon-intensive imports for its electricity generation (in 2008 the fuel import bill was 35% of GDP). Guyana has identified a site at Amaila Falls and completed the technical design for a hydropower dam which could deliver energy security by meeting all of the country's domestic power needs for the 'foreseeable future'.

Draining, irrigation and road development to improve access to unused, non-forested land ($300-500 million): By developing infrastructure into these parts of the country, economic activity and employment can be oriented away from areas which put pressure on the forest.

Fibre optic cables/technology park ($10-30 million): According to estimates by Accenture (Office of the President, Republic of Guyana, nd), Guyana's outsourcing industry has the potential to more than double the number employed by 2013. Guyana is competitive in all inputs to cost per seat (the key industry metric), with the exception of the cost of telecommunications bandwidth.

In terms of adaptation infrastructure, total estimated near-term adaptation costs for Guyana are projected to exceed $1 billion. By 2030, the annual loss as a result of flooding in Guyana is projected to be $150 million (~10% of current GDP). Therefore, immediate priority investments include:

- Upgrading infrastructure and assets to protect against immediate flooding concerns;
- Addressing systematic and behavioural concerns – strengthening building codes and expanding the early warning system;
- Developing financial and risk/insurance measures to boost resiliency post-flooding – these are contingent funds to provide immediate financial assistance following flooding;
- Switching to flood-resistant crops;
- Establishing the climate change adaptation needs of Guyana's inaccessible regions, including forest communities.

Trade and investment opportunities
The government's goal is to make non-forested parts of the country accessible to private investors, who can catalyse low carbon economic development and employment (largely in high-end agriculture and aquaculture). Guyana is concerned that it is not well known to major investors outside of its traditional industries. Attracting large-scale investors to Guyana will require incentives to finance industry-specific infrastructure and overcome perceived country investment risk.

Guyana has identified six priority low carbon economic sectors: fruits and vegetables, aquaculture, sustainable forestry and wood processing, business process outsourcing, ecotourism and possibly bioethanol. Initially, Guyana will focus on three sectors: fruits and vegetables, aquaculture and sustainable forestry.

Fruits and vegetables: Based on a global assessment, Guyana will need to provide significant financing incentives, offer a substantial land area to attract leading operators and improve its investment support to new investors.

Aquaculture: Guyana will work to attract potential investors to help it establish its aquaculture industry, which will entail developing a system of pond excavation, drainage and irrigation pipes and predation defence measures.

Sustainable forestry and wood processing: In order to ensure that its forestry practices are in accordance with global sustainable forest management practices, Guyana has begun to establish a framework for national-level environmental certification, with the long-term goal of achieving Forest Stewardship Council certification.

Other potential investment opportunities (business process outsourcing (BPO), ecotourism and possibly bioethanol): By investing in its infrastructure, workforce, business environment and marketing, Guyana can expand its nascent business process outsourcing industry, providing a variety of services and employment opportunities. Guyana has the potential to develop its ecotourism industry, although tourism development requires a gradual build-up of capabilities, infrastructure and brand over time. Guyana could enter the clean energy market by becoming a bioethanol producer. The 142,000 ha tentatively set aside for biofuel production at the Canje Basin would allow it to produce bioethanol at commercial scale.

Investment in agriculture and forestry
The government of Guyana is playing a leading role in developing strategies to implement REDD. Its proposals move away from the idea of narrow payments contingent solely on a baseline of deforestation, towards a broader, more inclusive view that provides low carbon development investments to keep what remains of forests intact.

Guyana proposes that, with the right low deforestation economic incentives, it will avoid 1.5 gigatons of CO_2e by 2020, which would have been produced by an otherwise economically rational development path. These incentives are to be generated through interim forestry payments from Guyana's partnership with the Norwegian government, other sources and the REDD programme.

To actually generate these funds over the long term, Guyana recognises that the forestry sector must be part of a global carbon trading system or a series of linked regional trading systems. The Eliasch Review (UK Office of Climate Change, 2008) estimates that including REDD and sustainable forestry management in a global carbon market could generate incentives to reduce deforestation by up to 75% by 2030. In the near term, the LCDS proposes that these funds be allocated through bilateral partners and other transitional mechanisms, and in the longer term through REDD. However, Guyana is also willing to turn over rights to its forests to foreign holders if necessary, as indicated in a recent deal in which an investment company, Canopy Capital, based in London, bought the rights to create a financial deal for the forest's services.[27]

Incentives and regulation for low carbon growth
Guyana's LCDS states that payments for preserving its forests will allow it to follow a low carbon development path. Key initiatives to set Guyana on a low carbon trajectory have been described above, but can be summarised as follows:

27 http://blogs.tampabay.com/energy/2009/05/when-money-does-grow-on-trees-think-carbon.html.

- Investment in strategic low carbon economic infrastructure, such as hydro; improved access to unused, non-forested land; and improved fibre optic bandwidth to facilitate the development of low-carbon business activities;
- Investment in low carbon sectors with high potential, such as fruits and vegetables, aquaculture and sustainable forestry and wood processing;
- Investment in other low carbon business development opportunities, such as BPO and ecotourism;
- The expansion of access to services and new economic opportunities for indigenous peoples through improved social services (including health and education), low carbon energy sources, clean water and employment which does not threaten the forest;
- Improved services to the broader Guyana citizenry, including improving and expanding job prospects, promoting private sector entrepreneurship and improving social services with a particular focus on health and education;
- Investments in priority climate adaptation infrastructure, which could reduce the 10% of current GDP estimated to be lost each year as a result of flooding.

India snapshot

India's economy consists of services (53.7%), industry (29.1%) and agriculture (17.2%). Services account for more than half of India's output, although 60% of the population is dependent on agriculture. With a rapidly expanding number of middle-class consumers, India's economy has one of the fastest-rising energy demands in the world.

India's largest sources of emissions are from energy (67%) and agriculture (24%), with more than 50% of total energy demand met through coal, 6% from hydroelectric power plants, 1% by nuclear power plants and less than 1% from renewables. India's GHG emissions were estimated at 1.55 billion tonnes in 2000 (WRI CAIT database).

Concerns over energy security and scarcity are a high priority for the government. The Prime Minister, Manmohan Singh, has a Council on Climate Change which has recently launched a National Mission to Green India. The Prime Minister released India's first National Action Plan on Climate Change (NAPCC) in 2008, outlining existing and future policies and programmes addressing climate mitigation and adaptation. The plan identifies eight core 'national missions' running through 2017 and directs ministries to submit detailed implementation plans to the Prime Minister's Council on Climate Change. At the end of August 2009, India announced its intention to implement mitigation targets in the form of 'perform, achieve, trade (PAT)' targets for the most energy-intensive industries, as a contribution to international pressures to address climate change.

The country has invested heavily in recent years in renewable sources of energy, including wind, solar, biomass and hydro energy. As of 2008, India's installed wind power generation capacity stood at 9655 MW, making it the fourth-largest in the world. Through a variety of programmes and policies, India is encouraging low carbon energy generation, including:

- A strengthened policy framework and subsidies to reduce upfront costs to wind power investors;
- Capital subsidies, sales incentives and reimbursement of fees for solar thermal projects and automatic approval for foreign direct investments. Solar water heating systems are required for some building types in New Delhi. In July 2009, India unveiled a $19 billion plan to produce 20,000 MW of solar power by 2020;
- Accelerated deployment plans and incentives for hydro and nuclear;
- Incentives for biomass power generation, biofuels for transport and compact fluorescent lamps;
- Retirement of inefficient coal power plants and plans for coalbed methane power generation;
- Reforestation programmes to increase forest cover by 1% a year until 2012. The Green India programme aims to reforest 6 million ha of degraded forest lands;
- Mandatory (E5) ethanol blending nationwide by April 2008 and fixed purchase prices for biodiesel.

2.2.4 Mexico

Country context

Mexico's economy is based mostly on the services and industrial sectors. In terms of gross value added (as a percentage of GDP) in 2006 (Organisation for Economic Co-operation and Development (OECD) data), the most important sectors in Mexico were industry (with 29% of GVA) followed by services (with 28% of GVA) and the financial sector, including real estate and retail (20% of GVA). The public sector accounted for 12% of GVA and construction for 7%; agriculture accounted for only 3% of GVA in 2006.

Trade is an important aspect of Mexico's economy, accounting for nearly a third of Mexico's GDP in 2006 (OECD data). However, the country is a net importer of both goods and services, and is also a net receiver of foreign direct investment.

The 2006 CO_2 emissions data provided within the Special Climate Change Program report shows that total CO_2 emissions for 2006 added up to 715 metric tonnes, the majority stemming from energy producers (28% of total CO_2 emissions) and the transport sector (20%); agriculture is the third-largest CO_2 emitter, with 18% of all emissions, followed by industry, with 8%.

Policy motivations for low carbon growth

The Federal Government of Mexico, through the Ministry of the Environment and Natural Resources, has launched the Special Climate Change Program[28] for the period 2008-2012. Within the programme and in conjunction with the National Climate Change Strategy of 2007, a number of carbon abatement and low carbon growth initiatives are specified. The programme plans a reduction of 50% on carbon emissions (based on 2000 levels) and an average production of 2.8 tons of CO_2 per inhabitant by 2050. The focus is to allow economic development to occur within the country without compromising the environment, as well as to give the initial push towards a reduction (or removal) of carbon emissions from the Mexican economy.

The programme is divided into three major stages. The first (between 2008 and 2012) will be an evaluation of the greatest risks the country is facing as well as an identification of the economic priorities to tackle, during which an executive progressive framework for adaptation and mitigation will be introduced. The second stage (2013-2030) will consist in reinforcing the strategic capacities to adapt and mitigate, through a strategic evaluation of the balance between deforestation and reforestation, the introduction of sustainable agricultural procedures, the introduction of carbon mitigation procedures, the removal of procedures and incentives that lead towards environmentally degrading procedures as well the introduction of public policies to incentivise a sustainable and eco-friendly economic climate. The third stage (2031-2050) will be the consolidation of the mitigation procedures created during the previous two stages, leading to a positive balance between deforestation and reforestation, implementation of sustainable economic development procedures and a reduction in environmental risks.

Carbon mitigation and low carbon growth in Mexico will be based on changes in energy supply, in management and production, in consumer habits, in manufacturing production procedures, in natural resource management and in the way the national territory is occupied and used.

The programme includes carbon reduction targets across economic activities, with the greatest reductions found in energy production (from 196 metric tonnes of CO_2 in 2006 to 24 in 2012) and energy consumption (an aggregate of industry, transportation, commercial, residential and government sectors).

---

28 http://www.semarnat.gob.mx/queessemarnat/consultaspublicas/Pages/peccconsultacomplementaria.aspx.

The low carbon growth pillars

Finance for mitigation and adaptation

The Mexican government wants to make sure that carbon emissions and low carbon growth are integral parts of private sector investment decisions and not treated just as externalities. To this end, it wants to implement a number of funds to incentivise private sector companies to invest in low carbon technologies as well as to create economic instruments aimed at blocking, or redirecting, private sector and residential development in areas deemed at high risk in terms of negative environmental impact.

The Mexican government also refers to the $500 million World Bank Clean Technology Fund as a source of funding to assist in the implementation of its low carbon growth programme, and has also set up the Mexican Carbon Fund to promote carbon abatement investments.

Within the energy sector, the Mexican government has identified a number of measures to reduce carbon emissions. In terms of oil and gas electrical production, 47 projects are identified, in which $1.5 billion will be invested to increase energy efficiency and reduce carbon emissions, together with a $1.4 gas recovery project. The main objective is to allow PEMEX[29] to reduce carbon emissions and increase its energy efficiency as well as to reduce gas leaks and improve the gas distribution infrastructure. The programme identifies the use of both biomass as a combustible fuel and photovoltaic technologies as good alternatives to traditional fossil fuels in generating heat.

Human capital

In terms of human capital, the Mexican approach to low carbon growth is based on increased education on climate change in both the formal educational system (at all levels) and for the population as a whole as well, strengthening the technical knowledge of public sector workers in order to better implement the low carbon growth plan through distance learning and specialised workshops within individual administrative regions. The government also wishes to strengthen its technical capacity to investigate the causes and consequences of climate change in Mexico through integrated climate change control and monitoring systems and enhanced research on carbon mitigation and GHG emissions.

Technological progress in energy/infrastructure/transportation

The Mexican government is developing a strategy for carbon mitigation, including the identification of innovative green growth technologies, the enhancement of currently available carbon abatement techniques as well as increased availability of green growth technologies within the Mexican market through the right incentives to promote the research and diffusion of such technologies.

The Mexican government recognises that the use of renewables for electricity production is beneficial both for the Mexican economy and for the environment, by reducing pollutants as well as improving national energy security. The use of renewable energy sources will be promoted and boosted by 2012. Currently, renewable energy sources represent 24% of total energy production; through investment, the programme foresees an increase to 26% by 2012. Electricity generation through renewable sources will be based on social, environmental and economically viable forms of wind, solar, geothermal and hydroelectric technologies. Investment in renewable energy will be undertaken by both the government and the private sector with government incentives.

The Mexican government is looking at increased investments in the transport infrastructure in order to reduce the use of fossil fuels and increase the use of public transport as, currently, the transport sector accounts for 20% of all carbon emissions, of which automobiles account for the highest proportion. The programme sets out to make sure that new fossil fuel-powered vehicles from 2010 will have generate lower carbon emissions and that there will be reduced carbon emissions from cargo and passenger carriers through the Clean Transport Program. The transport infrastructure

29 The Mexican state-owned petrol and gas company, http://www.pemex.com/index.cfm.

will also be modernised in order both to facilitate connections between different regions within the country and to make road transport more energy efficient. Public transport and state-owned vehicles will be replaced with more modern, energy-efficient, low carbon vehicles. The rail network infrastructure will also be modernised in order to introduce energy-efficient trains.

CCS technologies will also be considered. The government also considers nuclear energy a viable alternative to carbon energy sources, owing to the volatile price of combustible materials as compared with electricity produced through nuclear power plants.

Investment in agriculture and forestry

The agriculture sector is seen as a key component for low carbon growth in Mexico, as it accounted for 19% of national carbon emissions in 2006. The government wants to reclaim land with low productivity potential into sustainable land (including the conversion from grazing to crop growing) and to introduce sustainable agricultural practices. The government is pursuing means to use its forests as a form of carbon offsetting through REDD and is trying to increase the carbon sink capacity of forests through reforestation programmes. Government is participating in the World Bank's Carbon Partnership Facility to prepare for a potential international REDD programme in which Mexico would receive payments to conserve its forests. The government also plans to establish clear frontiers between forests and agricultural land in order to further strengthen the preservation of forests and reduce illegal deforestation.

Trade and private investment opportunities

In terms of electricity production, the objective is to stimulate private investment in low carbon, high efficiency electricity plants together with a reduction in electrical loss across the supply infrastructure. The private sector is seen as an important partner in reducing carbon emissions and thus the government is aiming to promote investment in carbon-reducing technologies, as the private sector represented 28% of carbon emissions in 2006. The climate change programme also recognises the importance of regulatory frameworks and legislation to promote greater reductions in carbon emissions within the private sector, and notes the importance of dialogue with representatives of the private sector in order to engage business in the carbon emissions reduction initiative.

Incentives and regulation for low carbon growth

The programme looks at the use of energy in Mexico as a way to increase energy efficiency. It highlights the use of the official Mexican regulation for energy efficiency as the main tool to increase the energy efficiency of appliances used within the Mexican economy.

The promotion of eco-friendly and energy-efficient residential homes is considered. Energy efficiency within households will be promoted through the Trust Law for Electric Energy Savings (FIDE[30]) and will involve the use of more energy-efficient air conditioners, replacing old refrigerators with modern eco-friendly models and the insulation of households for heat retention. The To Live Better[31] programme will be implemented to save energy through the substitution of electrical equipment with more energy-efficient models. The programme also highlights the use of national regulation to reinforce energy efficiency and looks at energy efficiency and carbon reduction in the construction sector. The government will promote the construction of energy-efficient buildings through public financing schemes, and a specific programme to develop sustainable households.

The Mexican government wishes to implement a national carbon trading mechanism (by 2012) based on its previous experience with a virtual carbon trading scheme developed by PEMEX in 2004. The carbon trading scheme is seen as an integral part of 'internalising' carbon emissions

30 http://www.fide.org.mx/.
31 http://www.presidencia.gob.mx/vivirmejor/.

and will be an important stimulus for companies to invest in low carbon growth technologies and reduce carbon emissions.

Industry will also be targeted, as the industrial manufacturing and construction sector accounted for 15% of national carbon emissions in 2006. FIDE will be extended to industry as well as to SMEs. Carbon emissions will be reduced through the implementation of the National Commission for the Efficient Use of Energy (CONUEE).[32] New energy-efficient lighting systems and generators for industrial buildings will be installed. A study will also be undertaken in order to assess the feasibility of combined heat and electricity generation within the country.

The energy efficiency of the tourism sector is considered within the low carbon growth programme. The programme highlights the fact that the majority of carbon emissions from the tourism sector stem from transport and hotels. The program aims to reduce demand for energy in the tourism sector by issuing compliance certificates to industry members, funding a feasibility study on carbon reduction in the industry and informing industry representatives through conventions and other public events how they can reduce carbon emissions and the benefits of energy efficiency.

2.2.5 Nigeria

Country context

Nigeria‘s economy is heavily dependent on the production and export of petroleum, which provides 95% of foreign exchange earnings and about 80% of budgetary revenues. Industry accounted for 41% of GDP value added in 2006, agriculture for 31% and services for 28%.

Data from WRI's CAIT database from 2000 show that most CO^2 emissions in Nigeria stem from the land use change and forestry sector, accounting for 44%. This is followed by the energy sector at 28%, of which fugitive emissions are at 16.4%, manufacturing and construction 9%, transport 4.7% and electricity 2.8%. Agriculture is responsible for about 23% of all CO_2 emissions, with the remainder from waste and industrial processes. Nigeria's submission to the UNFCCC shows that energy and land use change sectors were the main contributor to CO^2 emissions (40%), followed by gas flaring (30%). Energy production data from the World Development Indicators (WDIs) show that the majority of electricity produced in Nigeria comes from gas-powered electricity plants (58%), followed by hydroelectric power (33%) and oil-fuelled power plants (9%).

Motivations for low carbon growth

The government of Nigeria advocates low carbon growth because of the negative effects that climate change will have on the world's poorest people, including those living in Nigeria. Nigeria is suffering from a number of environmental problems, such as sand storms, flooding and desertification, the causes of which need to be mitigated to avoid further increases in poverty within its territory. As such, the government is ready to increase its efforts in order to reduce GHG emissions down to an acceptable level to which the country may be able to adapt.

Moving towards a low carbon economy not only brings positive environmental effects but also will allow developing countries such as Nigeria to take an active part in the low carbon growth market, giving the country a good opportunity to participate in the production of goods and services that are currently in high demand. The government believes that any losses accrued to traditional industry and industrial methods owing to a move towards a low carbon economy will be offset by the advantages of participating in the low carbon growth market.

The government thus wishes to move its economy towards low carbon growth and, through incentives and regulations, allow its businesses to become ecologically friendly, thus helping them

32 http://www.conae.gob.mx/wb/CONAE/Que_es_conae.

not only to become sustainable in the long run but also to increase their efficiency levels (in terms of both energy use and production), improving their competitiveness and growth possibilities.

In order to move forwards, the Nigerian government, especially supported by Nigeria's Prime Minister, Umaru Musa Yar'Adua, has set up the Vision 2020 initiative, with the ultimate aim of transforming Nigeria into one of the world's top 20 economies by 2020. Within its strategy (which has yet to be fully formulated), the government will include both sustainable development and energy efficiency strategies. As the strategy has yet to be enacted or completed, the low carbon growth pillars discussed below represent the suggested national strategies that the Nigerian government could adopt in order to reach its goals. These all stem from Vision 2020 Technical Working Groups (TWGs) set up within the Nigerian government.

Some of the recommendations given by the TWGs relate to the strengthening of national institutes and ministries in order to allow them to effectively manage the nation's sustainable development. The TWGs recommend that the Federal Ministry for the Environment be reinforced in its capacity to make policy and enforce green growth laws. The National Council on the Environment should also be strengthened, as this would promote cross-governmental linkages pertaining to environmental protection and sustainable development. A policy framework should be created to harmonise green growth laws and allow for greater enforcement of such laws by the relevant national institutions.

The low carbon growth pillars

Finance for mitigation and adaptation

The TWG on Energy recommends the introduction of fiscal incentives (such as tax rebates) to incentivise companies to comply with pollution standards, through a rewards system for compliant industries and companies. The TWGs also recommend that special funds be set up to finance sustainability advocacy groups, to allow them to grow and increase their authority and outreach across the country.

Fiscal packages will be provided to promote private investment into renewable energy sources, such as wind farms, hydroelectric power, solar power and biomass. Fiscal incentives proposed to increase private sector investment in renewable forms of energy include import exemption duties, tax holidays and investment grants. These fiscal incentives not only will be applied to national investors but also would be extended to foreign investors in order to facilitate foreign investment in green growth technology within the country.

Human capital

The TWGs recommend the government begin a national campaign aimed at creating awareness within Nigeria on climate change and its effects. This should be implemented through both informal education (i.e. through public communication channels) and the formal education system.

The TWGs also recommend the government promote capacity building in environmental management techniques across all levels of academia and within professional institutions, in order to increase the number of qualified professionals within Nigeria's labour pool. Such professionals should also be hired across all levels of government, in order to give the sustainable development perspective on all policy options.

Technological progress in energy/infrastructure/transportation

Informational and technical knowledge sharing is seen as critical by the TWGs and, as such, an important recommendation is to set up internal information-sharing networks on best practices, techniques and technologies aimed at the facilitation of low carbon growth within Nigeria. The TWGs recommend Nigeria set up a system like the Global System for Sustainable Development, using modern telecommunication technologies (such as the internet) to facilitate information sharing across the country.

In addition to imported techniques and technology, the TWGs consider indigenous knowledge particularly important to create sustainable green growth technology that is not reliant on (potentially expensive) imports from abroad and can thus be perpetuated within the country through locally available resources. In addition, local knowledge of the environment should be used to promote sustainable development, especially in rural communities. The TWGs believe that rural communities often have a large amount of informal (but nonetheless valid) information on their local ecosystem and often have valuable traditional techniques to conserve it. Hence, the TWGs believe these techniques should also play an integral part in the Vision 2020's goal of a sustainable economy.

Research and development of renewable energy sources are also considered important. Although Nigeria's main sources of energy are fossil fuels (on which most of the TWG on Energy report is focused), and are likely to remain so by 2020, the TWGs consider the development of renewable energy sources important for reasons of national energy security. To this end, the TWGs recommend the Nigerian government promote research and development into renewable energy sources, such as hydroelectric power, wind farms and tidal energy facilities. The TWG also consider the local development of nuclear power plants viable alternatives to fossil fuels in order to attain national energy security.

Although fossil fuels (mainly gas, and through a substantially increased capacity for electricity generated by coal) will still be the primary energy sources in 2020, hydroelectric power is still seen as an important renewable energy source (and in fact currently accounts for a third of all electricity produced in Nigeria). Thus, one of the main targets in the TWG on Energy report is to increase the amount of electricity produced in this way and to make good use of all viable hydroelectric power generation sources, especially in rural areas. This will be promoted through the establishment of a national coordinating agency for alternative energy development as well as through the promotion of energy micro-generation in rural areas.

Investment in agriculture and forestry

The TWGs believe it is necessary to increase the forested area of Nigeria from the current 6% of national land, to 15% in 2020. To do so, they propose the use of large-scale reforestation and afforestation programmes, as well as the promotion of the reforestation of degraded agricultural land through agro-forestry and incentive schemes aimed at farmers in potentially suitable areas.

In addition, the TWGs propose a strengthening of national laws and regulations in order to preserve existing national parks, including all wildlife within the parks. Biodiversity will also be conserved through the creation of local small-scale enterprises that can harness local flora and fauna to produce commercially viable (but sustainable) products.

Green technologies will also be used to facilitate sustainable agricultural production. Sustainable agricultural development will be linked to the use of renewable forms of energy, especially small-scale energy generation in rural areas using wind, solar and hydroelectric power. Organic farming techniques as well as enhanced controls and regulations on soil and water quality levels will also be promoted in order to improve the sustainability of the agriculture sector.

Trade and private investment opportunities

In terms of private sector growth opportunities, as the Vision 2020 process has not been completed yet, no real green sectors of growth have been identified by the Nigerian government or the TWGs. On the other hand, the TWG on Energy has been focused mostly on innovations and efficiency gains within the fuel and carbon industries within Nigeria, for which the government sees real growth opportunities in terms of internal and external fossil fuel supplies.

Incentives and regulation for low carbon growth

The TWGs recommend that the government strengthen pollution controls through a national Pollution Standards Index (air, water and earth pollution), the establishment of pollution monitoring stations and guidelines and standards for vehicle pollution levels based on the PSI, in order to promote the use of low emission vehicles as well as curb the use of vehicles with high pollutant levels (this will also be achieved by setting age limits on vehicles imported into the country) and enforce the Environmental Assessment Law. The PSI will also be applied to industry through the enforcement of pollutant guidelines by 2012 as well as incentives to retrofit old manufacturing plants in order that they may comply with pollution standards.

Industry compliance with the pollutant guidelines and laws will be assessed through the implementation of a national database showing compliance levels across all industrial sectors. Industries will also be encouraged to reduce industrial wastes and adapt to environmental standards through agencies such as the National Environmental Standards and Regulations Enforcement Agency (in charge of the enforcement of sustainable development policies).[33]

Gas flaring is a major source of pollution within Nigeria (as is stated in Nigeria's latest submission to the UNFCCC in 2003), thus the TWGs recommend the practice be stopped immediately. In addition, the TWGs recommend a monitoring system be set up to prevent oil and gas leaks, and a clean-up of all areas affected by oil leaks be completed by 2015. In order to eliminate CO_2 emissions from gas flaring, the government is currently passing the Gas Flare Prohibition Bill,[34] as well as considering reinforcing current laws that penalise companies undertaking gas flaring.

The TWG on Energy recommends that energy efficiency be promoted throughout the economy, through national campaigns aimed at the promotion of energy efficiency, increased tariffs on electricity consumption, both for large-scale electricity users as well as for the residential sector, and promotion of the use of energy-efficient appliances.

South Africa snapshot

In South Africa, the services sector accounted for 65% of GDP in 2007 (WDI data), industry for 31% and agriculture for just 3%. Electricity production is nearly wholly based on coal, with 94% of total electricity produced coming from coal, with the remaining 5% coming mainly from nuclear energy and in small part from hydroelectric power. South African carbon emissions stem mainly from electricity production (44%), industry (15%) and transport (11%), and currently account for nearly 50% of all CO_2 emissions in Africa.

In July 2008, the South African government launched People – Planet – Prosperity: A National Framework for Sustainable Development in South Africa. However, the framework provides only a general outline in relation to the achievement of reductions in carbon emissions. In 2006, the Long-term Mitigation Scenario strategy paper was launched looking at carbon abatement opportunities in South Africa. The strategy paper shows a number of scenarios for carbon abatement, from 'no action' up to scenarios whereby all carbon abatement opportunities are implemented. Economic growth outcomes for each scenario are analysed and key recommendations relate to:

- Increased energy efficiency;
- Investment in renewable energy;
- Cleaner electricity supplied by coal-powered plants and better CCS facilities;
- Cleaner transport vehicles.

The South African government does not currently have a specific green growth/low carbon economy national strategy; however, the government is currently in the process of creating such a strategy based on the papers outlined above.

33 http://www.nesrea.org/about.php.
34 http://allafrica.com/stories/200906090507.html.

2.3 Low-income countries

2.3.1 Bangladesh

Country context

Since Bangladesh achieved independence in 1971, GDP has grown fivefold, GDP per capita has doubled, food production has increased threefold and the population growth rate has declined from around 2.9% per annum in 1974 to 1.4% in 2006. The economy has grown at over 6% for the past three years and the country could become a MIC by 2020. Between 1991 and 2005, the percentage of people living in poverty declined from 59% to 40%. Despite much progress, however, some 56 million people still live in poverty (MoEF, 2008).

More than half of GDP is generated through the services sector; industry contributes close to 28% and agriculture makes up about 19% of GDP (WDI). Nearly two-thirds of Bangladeshis are employed in agriculture. Garment exports and remittances from Bangladeshis working overseas also fuel economic growth. Garment exports account for around 84% of total manufactured exports; the industry employs approximately 3 million workers (of a total estimated labour force of 70 million), 90% of whom are female migrant workers. According to Hussain (2009), revenues from remittances now exceed various types of foreign exchange inflows, particularly official development assistance and net earnings from exports.

Bangladesh emitted only 142 million tonnes of CO_2e (excluding land use change and forestry) in 2005 (WRI CAIT database). The largest source of CO_2e emissions is agriculture (66%) followed by energy, of which 8.7% came from fuel combustion, 8% from electricity generation, 7.5% from manufacturing and 2.7% from transport. Land use change and forestry resulted in net removals of 9.3 million tonnes of CO_2e (-8%) according to the country's UNFCCC submission. The country's energy consumption in 2004-20005 was just 89kg per capita (MoEF, 2002).

Policy motivations for low carbon growth

Bangladesh is already one of the most vulnerable countries in the world to weather and natural disasters. Floods, tropical cyclones, storm surges and droughts are predicted to become more frequent and severe in the coming years. The government thus recognises that climate change is a development as well as an environmental priority, and is committed to developing and incorporating potential response measures that reduce the impacts of climate change into the overall development planning process. Bangladesh is focusing primarily on building a platform for climate-resilient growth through adaptation measures, but is also taking steps to pave the way for mitigation and low carbon growth.

Given that Bangladesh has very low levels of GHG emissions, its climate change strategies are couched within the government's long-term vision to eradicate poverty and to achieve national economic and social wellbeing. The immediate goal to halve poverty by 2015 is a key target set out in its PRSP, finalised in 2005. Recognising the threat climate change poses to poverty alleviation goals, adaptation has become the foremost priority for Bangladesh. Low carbon growth has not been an explicit policy priority to date, as Bangladesh has low levels of industry and is struggling to extend energy services to much of its population.

On the adaptation side, with the support of development partners, over the past 35 years the government has invested over $10 billion (constant $ 2007) to make the country less vulnerable to natural disasters. These investments include flood management schemes, coastal polders, cyclone and flood shelters and the raising of roads and highways above flood level. The government has also developed state-of-the-art warning systems for floods, cyclones and storm surges, is expanding community-based disaster preparedness and has research centres developing climate-resistant varieties of rice and other crops (ADB, 2009).

In addition to adaptation efforts, the government has expressed a commitment to doing its part to reduce emissions and has made low carbon growth one of the pillars of its Climate Change Strategy and Action Plan (BCCSAP). Programmes to reduce emissions from the agriculture and energy sectors have been proposed, and the government emphasises sustainable development as the guiding paradigm for future development. Other planned programmes tackle social, health and food security issues, enhancing infrastructure and disaster preparedness.

Bangladesh's low carbon growth strategies are in the beginning stages, and much of the government's 10-year climate change strategy focuses on strengthening building blocks for good policy, including institutional capacity, awareness building and education, mainstreaming of climate change policies in national and sector development programmes and coordinating policies between ministries. However, the programmes generally lack detail on how specific measures will be carried out, with further implementation details, particularly on mitigation actions, not yet provided. Funding for programmes remains unclear and depends on whether there is HIC commitment to fund adaptation and mitigation activities in developing countries. For example, the series of detailed adaptation projects proposed as part of the 2005 NAPA remain unfunded.

The Ministry of Environment and Forests (MoEF) has been designated the focal ministry for all work on climate change, including international negotiations. The Department of Environment (DOE), under the MoEF, has also set up a Climate Change Cell to act as Secretariat for the recently established National Environment Committee, which ensures a strategic overview of environmental issues. Immediately after the COP13 Bali Conference, the government formed the National Steering Committee on Climate Change (NSCCC). This comprises secretaries of all relevant ministries and civil society representatives and is tasked with developing and overseeing implementation of the national BCCSAP. There are also five TWGs, on Adaptation, Mitigation, Technology Transfer, Finance and Public Awareness.

Four primary documents outline the government's approach to climate change and its strategy for adaptation and mitigation: the 2002 Initial National Communication to the UNFCCC, the 2005 PRSP, the 2005 NAPA and the 2008 BCCSAP. The government's Initial National Communication to the UNFCCC in 2002 set forth future policy priorities, including: protection of arable lands; improved water management; improving agro-technology research; formulating land use policies; coastal zone management; food security; strengthening disaster warning and disaster preparedness systems; trans-boundary cooperation; GHG emissions reductions; a sustainable development programme (integrated with poverty reduction activities); a unified, internally consistent climate change policy; formulation of a NAPA; national capacity building; and the institutional creation of a climate cell. Reflecting on progress made since the first UNFCCC submission, Bangladesh has taken significant steps to follow through with these priorities.

The government has also made climate change an integral part of the latest PRSP, which identified key future policy priorities, including the need to integrate climate change into existing policies and strengthen programmes for resilience in agriculture and water management, disaster reduction and health, with a focus on coastal areas.

The Bangladesh NAPA identified vulnerabilities and impacts and outlined 15 priority activities to combat climate change impacts, including general awareness raising, technical capacity building and implementation of projects in vulnerable regions, with a special focus on agriculture and water resources. Because little has been done to implement proposed NAPA projects, it remains to be seen whether a strong framework for evaluation of activities develops.

Bangladesh's NAPA was prepared by MoEF, guided by the Project Steering Committee and members from other key ministries, departments and agencies, including the Ministry of Finance and Planning. The NAPA reflected strong government participation and diverse consultations, including contributions from government policymakers, local government representatives, scientists from various research institutes, researchers, academicians, teachers, lawyers, doctors, ethnic groups, media, NGO representatives and indigenous women (MoEF, 2005).

In 2008, the government launched the BCCSAP, a 10-year programme (2009-2018) built on the country's 2005 NAPA to increase capacity and resilience, with a strong focus on adaptation and disaster risk reduction. The BCCSAP was developed by the government in consultation with civil society, including NGOs, research organisations, development partners and the private sector. The first five-year programme (2009-2013) of the BCCSAP concentrates on six thematic pillars:

1. Food security, social protection and health;
2. Comprehensive disaster management;
3. Infrastructural development;
4. Research and knowledge management;
5. Mitigation and low carbon development;
6. Capacity building and institutional strengthening.

The six themes encompass 37 programmes to be implemented over the next 10 years, with further implementation details to be worked out in consultations with stakeholders. The needs of the poor and vulnerable, including women and children, will be prioritised in all activities implemented under the BCCSAP. Programmes funded under the BCCSAP will be implemented by relevant ministries or line agencies, under the guidance of the National Environment Committee, with overall coordination provided by MoEF. BCCSAP aims to involve civil society and the private sector as appropriate. Bangladesh is currently receiving technical assistance to implement BCCSAP programmes from the Asian Development Bank (ADB).

There was strong collaboration between government ministries to produce the NAPA and the BCCSAP, but both documents emphasise that there is a need for much greater coordination and integration of climate change into the policy agendas of different Ministries. The BCCSAP specifically called for a complete review of national policies to revise and enhance consideration of climate change issues. The NAPA presented adaptation activities as a set of measures complementary both to national goals and to the objectives of other multilateral environmental agreements to which Bangladesh is a signatory.

A number of national policies have addressed climate change concerns, including the National Water Policy, the National Action Plan on Biodiversity, the National Water Management Plan and the Disaster Management Plan, but other policies, such as the National Energy Policy, the National Environmental Action Plan, the Environment Conservation Rules and the Environmental Conservation Acts, would benefit from greater coordination.

Low carbon growth pillars

Finance for mitigation and adaptation
The government has established the National Climate Change Fund by allocating about $45 million to it in the FY2009 budget. A Multi-donor Trust Fund was also established to pool funds from development partners to implement a long-term strategy to mitigate the adverse effects of climate change. The UK launched a £75 million ($130 million) grant-funded programme, to be administered by the World Bank, to support the creation of the Multi-donor Trust Fund (ADB, 2009). However, an estimated $500 million is needed over the next one to two years to support immediate action initiatives in Bangladesh. The total cost of programmes in the first five years of the plan could reach $5 billion. Because of this significant shortfall, Bangladesh has been actively pushing for strong funding commitments by industrialised nations in international negotiations.

Human capital
Bangladesh has recognised that one of the first steps in dealing with climate change is to develop institutional and human resources capacity. The BCCSAP outlines specific programmes over the

next years to address issues of capacity, education and health. Education and awareness raising are recognised as key, both within the government and also for the public. Within government, the aim is to strengthen human resources capacity and institutions for climate change management, particularly to handle natural disasters. Bangladesh will establish a centre for knowledge management and training on climate change and create programmes to raise public awareness and education on climate resilience, including mainstreaming climate change issues in the media.

In terms of health and social needs, adaptation programmes have been created to improve water and sanitation, particularly in vulnerable areas, and to implement a surveillance systems for existing and new disease risks to ensure health systems are prepared to meet future demands.

Programmes are also outlined on livelihood protection in ecologically fragile areas, particularly for vulnerable groups and women.

Stimulating technological progress in energy/infrastructure/transportation
Bangladesh recognises that there are mitigation opportunities in raising efficiency in the production and consumption of energy. A detailed assessment of mitigation options has not been done since a preliminary assessment was prepared as part of Bangladesh's 2002 Initial National Communication, which identified possible measures for the energy, land use/forestry and agriculture sectors. The UNFCCC submission outlined current abatement activities underway, including: fuel switching to gas-based power generation, dissemination of improved cooking stoves, phasing-out of two-stroke engines, conversion of vehicles to compressed natural gas (CNG), installing home photovoltaic systems, switching to compact fluorescent lamps, switching brick making from wood based to natural gas based and promotion of environmental management systems in industry. The National Energy Policy also places emphasis on energy efficiency as well as renewable energy development, particularly on solar homes and biogas plants. The extent of the impact from these efforts is unclear.

In terms of adaptation infrastructure, the BCCSAP outlines programmes to: repair and rehabilitate existing coastal embankments, river embankments and drainage systems and ensure effective operation and maintenance systems; plan, design and construct urgently needed new infrastructure (e.g. cyclone shelters, coastal and river embankments and water management systems; urban drainage systems, river erosion control works and flood shelters); and undertake strategic planning of future infrastructure needs, taking into account the likely future patterns of urbanisation and socioeconomic development and the changing hydrology of the country. The BCCSAP and the PRSP also urge preparatory studies on impacts of rising sea levels, including modelling climate change impacts at the national and sub-national levels on a variety of sectors.

Trade and investment opportunities
In public documents there has not been a great deal of focus on encouraging private investment and pursing new opportunities for trade. Most discussions have centred on enhancing access to the CDM, given that the country only has two projects, on solar energy and waste management. The BCCSAP states that the goal is to increase the number of CDM 'programmes' and to experiment with new instruments to generate carbon credits and facilitate carbon market financing in future. For example, under a proposed programme to manage urban waste, the BCCSAP proposes using the CDM to set up small power plants by capturing methane from waste dumps.

Investment in agriculture and forestry
Bangladesh has expressed a great concern over the potential effects of climate change on its agriculture sector and has also identified opportunities in agriculture and forestry to reduce emissions. The BCCSAP focuses on lowering emissions from agricultural land through improvement in agronomic practices and by developing an expanded afforestation and reforestation programme. On the adaptation side, programmes are being developed to enhance institutional capacity for research and dissemination on climate-resilient cultivars, development of

climate-resilient crop systems and promotion of adaptation measures in the fisheries and livestock sectors.

Aquaculture, in particular, could be significantly affected. It contributes around 5% to GDP[35] and provides a valuable source of protein as well as export income. Increasing salinity, storm surges and flooding, along with changes in ocean currents and sea level rises, present the most significant risks. The BCCSAP encourages developing greater research and prediction capabilities for climate change risks in general, and specifically calls for more research into potential threats to fish spawning and impacts from increasing salinity and increased water temperatures.

Incentives and regulation for low carbon growth

Under the BCCSAP pillar dedicated to mitigation and low carbon development, the government has pledged to undertake a number of activities to lower emissions and facilitate technology transfer, including to:

1. Develop a strategic energy plan and investment portfolio to ensure national energy security and lower greenhouse gas emissions;
2. Expand social forestry on government and community lands throughout the country;
3. Expand the 'greenbelt' coastal afforestation programme with mangrove planting along the shoreline;
4. Seek the transfer of state-of-the-art technologies from developed countries to ensure that we follow a low carbon growth path (e.g. 'clean coal' and other technologies);
5. Review energy and technology policies and incentives and revise these, where necessary, to promote efficient production, consumption, distribution and use of energy.

The plan describes actions that will be taken under specific programmes that will be developed to further the mitigation and low carbon development pillar. These are as follows.

Low carbon development programme	**Proposed actions**
Improved energy efficiency in production and consumption of energy	• Study least cost energy supply path that satisfies future energy needs • Raise energy efficiency in power production, transmission and distribution, agricultural and industrial processes, domestic and service sectors and transport sector
Gas exploration and reservoir management	• Invest in gas exploration • Invest in reservoir management
Development of coal mines and coal-fired power stations that use clean technology	• Review coal mining methods and undertake a feasibility for new coals plants • Potentially invest in coal mining and clean coal-fired power generation plants
Lower emissions from agricultural land	• Support to research and on-farm trials of new water management technologies for rice • Support to agricultural extension service for new water management techniques for rice
Renewable energy development	• Investments to scale up solar programmes • Research and investment to harness wind • Feasibility studies for tidal and wave energy • Study potential for improved biomass stoves
Afforestation and reforestation programmes	• Support afforestation programmes • Develop wetland afforestation programme • Study scope for carbon credits under REDD • Provide support to existing and new homestead and social forestry programmes

35 http://www.fao.org/fishery/countrysector/naso_bangladesh/en.

	• Research the suitability of various tree species for reforestation programmes
Management of urban waste	• Design of urban waste dumps so that methane can be captured in all major urban areas • Use the CDM to set up small power plants that capture methane from waste dumps

Beyond listing the targeted areas above, the BCCSAP does not provide further guidance on how these objectives will be achieved. The stated focus of the above activities is to 'play our part in reducing emissions now and in the future'. It is clear that Bangladesh sees the value of pursing low carbon development but its climate strategy document does not make it a specific goal to seek out and harness new opportunities for economic development and trade, develop new industries or foster in-country technological innovation. Rather, the goals focus on pursuing best practices, technology transfer, energy security and undertaking programmes that foster poverty reduction.

2.3.2 Ethiopia

Country context

Ethiopia's economy is based to a large degree on agriculture, accounting for almost half of GDP, 90% of export earnings and 85% of total employment. Services make up 41% and industry 12%. Agriculture suffers from frequent drought and poor cultivation practices. Coffee is critical to the economy, with exports of some $350 million in 2006, but historically low prices have caused many farmers to switch to other crops to supplement income. Under Ethiopia's Constitution, the state owns all land and provides long-term leases to tenants. A major drought struck late in 2002, leading to a 3.3% decline in GDP. Normal weather patterns helped agricultural and GDP growth recover during 2004-2008. GDP grew by 8.5% in 2008. With a growth rate of 2.8% per year, the country's population is expected to reach 129 million by 2030, from almost 80 million today.

According to the WRI CAIT database, Ethiopia's total GHG emissions were 73.5 million tonnes in 2005. 67% was from agriculture, almost 12% from land use change and forestry and 12% from energy, including 8% from fuel combustion, 2.4% from transport and 1.2% from manufacturing. Total emissions are about 1 tonne per capita, one of the lowest rates in the world. Biomass fuels account for nearly 95% of total national energy consumption, with the balance from petroleum (4%) and hydro (1%).

Policy motivations for low carbon growth

Ethiopia's heavy dependence on agriculture, coupled with a high population growth rate, makes the country particularly susceptible to the adverse effects of climate change. Negative climatic impacts on crop and livestock production could exacerbate nationwide food shortages, increase poverty and slow economic growth. Ethiopia has taken steps to address climate change but is also broadly representative of the limited level of integration of climate change policies into the national agenda and the lack of strategic planning on climate change across many African countries. The country's objectives are not so much to achieve low carbon growth, but rather to strengthen climate resilience through adaptation, and to enhance food and energy security.

Ethiopia's Plan for Accelerated and Sustained Development to End Poverty (PASDEP) for 2005-2010 emphasises that the country's immediate socioeconomic priorities are adequate food production, basic health services, capacity building, primary education, containing AIDS and reducing environmental degradation, but does not make an explicit connection between development needs and climate change mitigation and adaptation.

However, the 2001 Initial National Communication to the UNFCCC (by the Ministry of Water and Natural Resources) states that a number of options to mitigate emissions and adapt to climate change could combine twin objectives: sustainable economic development and GHG mitigation.

Options identified include energy efficiency improvements, renewable energy generation, ethanol blending, forest preservation, reforestation and afforestation and waste composting.

In its 2007 NAPA,[36] Ethiopia aims to increase climate change resilience by developing programmes and projects that ameliorate worsening natural resource depletion and environmental deterioration while securing energy supplies, reducing poverty and improving basic services. The NAPA also developed criteria for prioritising potential adaptation projects that would meet these goals, although a comprehensive strategy for implementation has not been developed. Projects that are included relate mainly to physical adaptation measures – to early warning systems for drought and floods, agricultural improvement, irrigation and water systems, capacity building, research and development and carbon sequestration. One project relates to health – strengthening malaria containment. There is no mention of programmes to encourage behavioural change and very little progress has been made to date on implementing any of these projects. A variety of ministries are charged with leading on implementation for many of the adaptation projects, most commonly the National Meteorological Agency.

Expansion of hydro power and biofuels are currently the mainstays of national energy policy, with a major dam project proposed and expansions planned in molasses-based bioethanol and jatropha-based biodiesel. The 2007 Biofuels Development and Utilisation Strategy established biofuels as a priority for the government as a means to improve agricultural revitalisation, access to alternative energy sources, employment and energy security, as Ethiopia is a net importer of oil. NGOs and other civil society groups have criticised the government's plan as premature, lacking environmental safeguards and a threat to biodiversity. However, the government expects Ethiopia to benefit from bioenergy technologies to grow more food, rejuvenate its vast land resources and further strengthen its economy through 'home-grown energy sources'. Ethiopia is also promoting energy efficiency and conservation measures, as well as utilising blended ethanol (E5) in the Addis Ababa transport system. However, these measures fall short of aspiring to an economy-wide transition to clean energy sources.

Meles Zenawi, Prime Minister of Ethiopia, has emerged as a strong champion of the climate change agenda and has underlined the need to transform the relationship between agriculture and bioenergy in Africa in general as a primary means of adjusting the continent's economy to the challenges of climate change. Mr. Zenawi has also promoted the idea that the new bioenergy technologies have the potential to drive growth in the region, from transport fuels to green electricity. Concerns relating to the potential for increased GHG emissions because of land clearance for biofuels production – given carbon sequestration in soils – may need to be given greater consideration and appropriate regulation and certification measures devised.

Ethiopia has thus taken initial steps to address climate change, but coordination and implementation of policies proposed to date has remained disjointed. While the mitigation options submitted to the UNFCCC in 2001 are linked to growth and poverty reduction strategies, little progress has been made in implementing them. Similarly, the NAPA links criteria for prioritised projects to their ability to continue to reap sustainability benefits and contribute to poverty reduction. But it is not clear how integrated proposals will be in practice across ministries and the extent to which mitigation options will be verified and linked to mitigation finance options. Ethiopia's PASDEP does not integrate mitigation and adaptation measures within its growth and poverty reduction strategies to any extent. Ethiopia is currently developing a national climate change strategy with assistance from the World Bank – the document will need to be more comprehensive and provide clearer operational guidance if it is to progress the agenda.

36 Preparation of the NAPA was initiated and coordinated by the National Meteorological Agency, with a Steering Committee made up of 10 government ministries/agencies, university and NGO representatives. The NAPA was guided by a participatory process involving stakeholders and a multidisciplinary and complementary approach building on existing plans and programmes, including national action plans under the UN Convention to Combat Desertification, National Biodiversity Strategies and Action Plans, the Convention on Biological Diversity and national sectoral policies on climate change and air pollution. Consultants were used to prepare technical reports used as inputs into the NAPA.

In sum, Ethiopia has shown interest in climate-resilient growth and taken some initial steps, but it does not have a clear institutional lead nor has it developed a national climate change strategy with a long-term vision for dealing with climate risks to growth and poverty reduction, or a plan to harness emerging opportunities. There is some recognition in the policy documents that climate change presents major risks to the development agenda but its policy documents are fragmented and inconsistent. Mention of emissions mitigation activities are restricted to expanding hydro and biofuels to improve energy access, supporting an efficient and revitalised agriculture sector and reforesting and protecting existing forests.

Low carbon growth pillars

Finance for mitigation and adaptation

There appears to be a lack of funding for activities proposed in both the National Communication and the NAPA. Ethiopia is urging developed nations to provide funding for its NAPA projects through grants rather than loan programmes. The National Biofuels Strategy also states that part of the aim of a national biofuels programme is to take advantage of additional finance available through the CDM. However, there is no approved CDM methodology for biofuels derived from other crops or plants, such as sugarcane, since land may have been cleared to produce the biofuel crop, and this issue remains controversial. Thus, development of appropriate national certification infrastructure that meets an internationally accepted methodology is likely to be necessary prerequisite before Ethiopia effectively taps into the CDM.

Human capital

Ethiopia's NAPA recognises that capacity building for climate change adaptation at all levels, particularly at federal level and regional levels, is important to achieving its climate change goals. The NAPA prioritises the establishment of a National Research and Development Centre for Climate Change and the establishment of a National Environmental Education programme.

In terms of moderating health impacts, the NAPA contains a Malaria Containment Programme (MCP) in selected areas of Ethiopia-Gambella, the Ethiopian Rift Valley and Somali. The government hopes to enhance community capacity building to initiate and implement environmental health programmes and projects in regional states.

Stimulating technological progress in energy/infrastructure/transportation

With the financial help of developed countries, Ethiopia aims to exploit its significant hydro, solar, wind, biomass and geothermal energy resources, although the motives are as much to improve access to energy and energy security as they are about mitigation. The government is currently looking at developing renewable energy projects that would supply both Ethiopia and its neighbours, including the recently launched Ashegoda Wind Power Project, the country's first wind farm, which will have an installed capacity of 120 MW and will generate annual energy production of 400 GWH to 450 GWH. With support from Germany's Solar Energy Foundation, about 2000 solar systems have been installed in the rural village of Rema and in nearby Rema ena Dire, making it the largest solar power project in East Africa. The project has brought power to roughly 5500 residents (only about 1% of people in rural areas have access to electricity in Ethiopia).

Given that the vast majority of households rely on biomass sources for energy and cooking needs, the government sees harvesting bioenergy efficiently as a cornerstone strategy. The Initial National Communication highlights the need to expand the use of improved cook stoves and of biofuels for transport. The 2007 National Biofuels Strategy calls for the production of 128 million litres of ethanol by 2013. The government has also allocated 24 million hectares for jatropha plantations, asserting it will not affect food production. Currently, there are more than 50 developers (many of whom are foreign) registered for the cultivation of biodiesel crops for biodiesel, of which 14 had begun operations in 2008 (MELCA, 2008). For bioethanol, however, there are only six projects in the country, of which four are government-owned sugar estates. Over 300,000 ha of land have been dedicated to bioethanol production and over 80% of these developments are happening in arable lands, forest lands and woodlands (ibid).

Through the Ethiopian Electric Power Corporation, the government is distributing 5.4 million compact fluorescent lamps country wide to help electricity consumers save money on their electricity bills and cut carbon emissions. To improve climate resilient infrastructure, the NAPA prioritises strengthening and enhancing drought and flood early warning systems, although little progress has been made on this front.

Trade and investment opportunities

Policy documents do not specifically propose the development of new low carbon growth industries or technologies, although the government is currently looking at developing renewable energy projects that would supply both Ethiopia and its neighbours, as noted above.

Ethiopia is looking to expand its participation in the CDM by assessing potential for projects and programmes, particularly in agriculture. A World Bank study (Gouvello et al., 2008) on CDM opportunities across sub-Saharan Africa's energy sector found an estimated technical potential of more than 3200 clean energy projects, including 361 large programmes of activities. In Ethiopia, potential projects to generate power from agricultural residues, roundwood residues, wood-processing residues and jatropha biodiesel were found to total over 25 million tonnes of CO_2e reductions, generating 39,200 gigawatt hours per year. The Initial National Communication and NAPA do not specify how this potential may be harvested and no specific policies were proposed to try to encourage the CDM but Ethiopia is supportive of a reformed CDM that expands programmes of activities and provides special incentives for small-scale projects. It also recognises that, to take advantage of potential projects, it must build up training and technical expertise in project design and preparation. The need to create a good investment climate for such projects is not specifically mentioned in policy documents.

Investment in agriculture and forestry

As the mainstay of Ethiopia's economy, agriculture has been the central target for climate adaptation efforts. Changing rainfall patterns and drought are the largest risks to agricultural productivity from climate change. The NAPA proposed a number of projects related to irrigation and water and crop management to help adapt to these risks. Six out of 11 NAPA projects relate to agriculture, including:

- Promoting a drought/crop insurance programme;
- Development of small-scale irrigation and water harvesting schemes in arid, semi-arid and dry sub-humid areas;
- Improving/enhancing rangeland resource management practices in pastoral areas;
- Community-based sustainable utilisation and management of wetlands in selected regions;
- Enhancing food security through a multi-purpose, large-scale water development project in Genale-Dawa Basin;
- Promotion of on-farm and homestead forestry and agro-forestry practices in arid, semi-arid and dry-sub humid parts of Ethiopia.

Some have argued that the NAPA priorities in agriculture fall short of long-term needs. Crop insurance, for example, may reduce short-term vulnerability by mitigating the risk of severe fluctuations in rainfall from year to year. However, it does not build resilience to the long-term fundamental impacts of climate change that will alter production systems, such as cultivation moving higher into the hills as temperatures rise or changing rainfall patterns that will affect where and how agriculture activities take place. Similarly, as climate modelling cannot accurately predict how rainfall patterns will change, developing new irrigation systems and reservoirs does not advance a more flexible approach that can adapt as a greater understanding of national-level impacts emerges.

On the mitigation side, agricultural measures discussed include: increasing livestock productivity through improved nutrition with supplementation and treatment of forages to improve digestibility and through improved genetic characteristics; promoting sustainable agriculture; promoting mixed crop livestock farming practices where appropriate; promoting the use of manure management system facilities; adopting appropriate fertiliser application; promoting conservation tillage techniques to sequester carbon in cultivated soils; rehabilitation of overgrazed watering points and long-term settlement areas; and redistribution of manure that is accumulated near these settlements. These activities are targeted more at adopting best practices to improve productivity but do also contribute to the country's mitigation actions.

In forestry, Ethiopia's UNFCCC submission found that protecting existing carbon reserves and enhancing carbon sequestration through reforestation had significant potential for reducing emissions. Ethiopia has already been active in reforestation, including contributing more trees than any other nation – over 1 billion – towards the UN Environment Programme (UNEP) Billion Tree Campaign global target of planting 7 billion trees by December 2009. Reforestation has been a major target for proposed programmes as well, including a NAPA project on community-based carbon sequestration in the Rift Valley to rehabilitate the acacia woodlands. The UNFCCC national submission set the goal to reforest 21,000 ha over the following 30 years. Ethiopia also aims to improve forest management practices, promote agro-forestry and develop and restore gallery forests along river banks.

Incentives and regulation for low carbon growth

Beyond encouraging renewable energy generation, other pillars of a mitigation and low carbon growth strategy are noted as:

- Promoting the use of fuels with low carbon content (fuel switching), e.g. exploiting the Ogaden natural gas reserve;
- Promoting the use of smaller cars through tax differentiation based on engine size, expansion of public transport infrastructure, improving the efficiency of operating vehicles by carrying out maintenance, inspections and training, improving urban traffic, promoting environmentally friendly transport modes such as bicycles;
- Integrated waste management, composting solid waste of Addis Ababa city and landfill gas recovery from solid waste site of Addis Ababa city.

Ethiopia was also the first African nation to join the Climate Neutral Network (CN Net)[37] – an initiative led by UNEP to promote global action to decarbonise national economies and societies.

Malawi snapshot

Based on WRI CAIT data from 2000, Malawi is a small net emitter of GHG. Last estimates for annual per capita emissions were in the region of 3.0 tonnes of CO_2e. The greatest contribution of emissions arises from the land use change and forestry sector (99.7%) and industrial processes (0.3%). Although Malawi is not obligated to meet emissions reductions targets, the government recognises that its reduction and use of carbon sinks provides opportunities as well as challenges for the socioeconomic development of the country. The domestic energy system is dominated by biomass.

Malawi's 1994 National Environment Action Plan (NEAP), its Vision 2020 launched in 1998 and its 2002 PRSP outline measures and priorities to promote sustainable use of the environment, including following priority development pillars: rapid sustainable pro-poor economic growth and structural transformation; human capital development; improving the quality of life of the most vulnerable; and good governance. The NAPA, developed by the Ministry of Lands and Natural Resources, built on these priorities by providing

37 Based on a free of charge, interactive website, CN Net gives participants a platform to present their strategies in climate neutrality to network members. It functions as a network for information exchange and sharing of practical experiences, making the best practices on climate neutrality widely available.

concrete measures to tackle effects of climate change and prioritises the creation of buffers for the most vulnerable from the socioeconomic implications of climate shocks.

Malawi's energy resources include biomass, coal, hydropower, solar and wind. The government has established a National Sustainable and Renewable Energy Programme (NSREP) to increase access to and coordinate implementation of renewable energy technologies. To this end, Malawi's Initial National Communication to the UNFCCC targets the following mitigation options in agriculture, energy and forestry:

1. Use of briquettes instead of firewood;
2. Improved mud and ceramic stoves;
3. Use of biogas for lighting and cooking;
4. Rural electrification through grid extension, mini/micro hydropower and solar photovoltaic heaters and cookers which would reduce demand for biomass energy;
5. Increased use of public transport and catalytic converters to reduce GHG emissions;
6. Wind water pumping instead of diesel and petrol engines;
7. Promote re-vegetation and natural regeneration, forest protection and agro-forestry;
8. Improved nutrient management in livestock and rice fields and better water management.

The market-based mitigation options considered in the National Communication include energy pricing, fiscal incentives, regulation and demand-side management. The submission also recommends the removal of duty and sur-taxes on renewable energy technologies. Mitigation options in its 2002 communication to the UNFCCC did not include alternatives to petrol and diesel for transport. Lack of funding continues to be a fundamental barrier to implementation of these programmes.

Rwanda snapshot

Rwanda's largest source of CO_2e emissions, mostly from methane, is the energy sector, followed by agriculture, according to 2002 data in its Initial National Communication to the UNFCCC. It has negative net CO_2 emissions owing to the sequestration capacity of its forests. Rwanda has demonstrated commitment to low carbon energy growth, with a focus on the development of indigenous and renewable energies.

Rwanda is working to increase access to electricity under its sector-wide approach, which aims to increase electricity access from 6% of the population to at least 35% by 2020. Access in rural and off-grid areas will be supported by solar and micro-hydro power solutions. Rwanda also has a model methane project at Lake Kivu, which extracts methane to produce large amounts of electricity which could potentially be exported.

The government has defined additional policies and measures in its national submission to the UNFCCC to encourage low carbon development in energy, forestry, agriculture and waste. Key measures are:

Sector	**Activity**
Energy	• Promote and extend use of biogas, solar photovoltaic, solar water heaters and micro-hydro • Intensify regional collaboration in electricity generation and integration of supply network and promote energy commerce at regional level • Promote power generation from waste and algae in small-scale industries • Promote low consumption lamps and efficient cooking stoves • Introduce efficient wood charcoal-making technologies
Forestry	• Support programmes involved in reforestation, forest preservation, such as in Nyungwe, and sustainable forest management, such as in Bugurama • Wetland preservation and management
Agriculture	• Nitrogen runoff management and use of organic fertilisers • Management of manure and enteric fermentation • Controlled burning of savannah and on-site burning of farm residues • Intensification of agriculture and animal husbandry
Waste and waste disposal	• Banning wastewater flows on public roads and areas • Banning use of cesspools for disposal of residuary urban waters • Imposition of a water treatment tax • Extension of lagoon purification technology

Rwanda has identified the tools needed to achieve expected results including training, education, tax exemption, low interest loans and other financial incentives. Rwanda has stressed that it is critical for the country to receive financial support from developed countries and international institutions beyond conventional forms of aid to support its goals to transform the energy sector. It sees supporting the energy sector in developing countries as an investment opportunity for energy companies, as it can create employment and will encourage the sector to develop along a sustainable, low carbon path.

Summary table of low carbon growth and resilience policies and measures proposed by selected countries

	Base of economy/ largest emission source	GNI/ capita ($, 2008) (WDI)	Finance Sources	Human capital	Infrastructure	Transport	Clean energy	Agriculture and forestry	Trade and investment opportunities	Incentives for low carbon growth	Policy documents
Germany	Services/ energy	$42,440	Efficiency Fund, sector funding	Education	Smart grid	Electro-mobility	Wind, PV and bioenergy/ CHP, CCS	NA	Technology exports, green services sector, jobs	EE, CAT, consumption taxes, biofuel quota	Energy roadmap, LC growth strategy
UK	Services (finance)/ services	$45,390	LC Investment Fund, Environment Transformation Fund, ECAs, CCA, LC building funds	Behavioural change, training, Skill Funding Agency	Low carbon building programme	Low carbon vehicle partnership, increase fuel efficiency standards	Renewables, nuclear, wave/tidal, R&D (CCS, biofuels, fuel cells)	Feasibility study on CAT for agriculture	Green technology and services sector, job growth	CC Levy, LC fuel quota, LC Vehicle Partnership, Code for Sustainable Homes	Climate Programme, LC Industry Strategy, LC Transition
Brazil	Services/ deforestation	$7350	National Climate Fund, Amazon Fund	CC education, health and sanitation, studies, alert systems	Biofuels stations	Bio ethanol and flex-fuel vehicles	Hydro, cogeneration, nuclear, off-grid solar	Grant-based REDD, cattle management, organic fertilisers	Flex-fuel vehicles, ethanol trade, forestry offsets	EE, appliances, solar heating, recycling, research and training	National Plan on Climate Change
China	Industry, services / energy and industry	$2770	CDM	Training of climate specialists for R&D	Building standards	Efficient vehicles and public transport	Efficient use of coal/ nuclear, hydro, wind and biomass	Reforestation, less fertiliser, new rice crops, sustainable forest management	Wind, PV, electric vehicles, technology transfer, restructured economy	Lower energy intensity/EE, clean power and transport, green buildings, R&D	China's National Climate Change Program
Mexico	Services, industry/ energy	$9990	Mexican Carbon Fund, World Bank Clean Technology Fund, sector funding	CC education –all levels, CC monitoring systems	More efficient plants, lower losses	Low carbon vehicles, clean transport program	CCS, nuclear, wind, solar, hydro, geothermal	Sustainable agriculture practices, REDD, combat illegal deforest.	Ecotourism	EE, CAT, efficient appliances	Special Climate Change Program
Bangladesh	Services/ Agriculture	$520	National Climate Change Fund, Multi-donor Trust Fund	Awareness, health surveillance, institutional capacity building, livelihoods protection	Flood and disaster defence, preparatory studies	Efficiency, conversion to CNG, phasing out two-stroke engines	Clean coal, EE, fuel switching, biogas, cook stoves, studies for other types including tidal	Climate-resilient crops, improved cultivation practices, reforestation, protection for aquaculture	CDM	Technology transfer, impact and feasibility studies, EE, cleaner coal, renewables, reforestation, waste management	Climate Change Strategy and Action Plan, NAPA, PRSP, UNFCCC submission
Ethiopia	Agriculture/ Agriculture	$280	International grants	R&D Centre, malaria containment	NA	Biofuels, smaller cars	Hydro, demo renewables projects, CFLs	Reforestation, irrigation, rangeland and agro-forestry management, crop insurance	CDM – agriculture projects	Fuel switching, LC vehicles, waste management	NAPA, UNFCCC submission, PASDEP
Guyana	Agriculture, industry/land use change and forestry	$1420	Low Carbon Finance Authority, REDD	Education and job training	Roads, fibre optic cables, flood defence, alert system	NA	Hydro	Irrigation systems, flood-resistant crops, REDD	REDD, aquaculture, fruits/vegetables, sustainable forest prods, BPO ethanol, ecotourism	Investments in low carbon sectors, new social services, REDD readiness	Low Carbon Development Strategy, PRSP, UNFCCC submission
Nigeria	Industry (oil)/land use change and forestry	$1160	Tax holiday, investment grants, rebates for pollution standards compliance	National awareness campaign, capacity bldg in government	Low emission vehicles	NA	Hydro, wind, PV, biomass and tidal & nuclear R&D	Reforestation, organic farming, use of traditional knowledge	Technology transfer, EE in fossil fuel industry	Pollution controls, EE, halt gas flaring	Vision 2020

Summary table of low carbon policies and measures in snapshot countries

	Base of economy/ largest emission source	GNI/ capita ($, 2008) (WDI)	Transport	Agriculture and forestry	Incentives for low carbon growth	Policy documents
India	Services/energy	$1070	Biofuels	Reforestation	Wind, PV, solar thermal, CFLs, retire old coal plants, nuclear, biofuels, reforestation, PAT system	
Malawi	Agriculture/land use change and forestry	$290	Catalytic converters, public transport	Reforestation/forest protection, improved nutrient management, water management	Biogas, improved cook stoves, micro-hydro, PV, solar thermal, demand-side management, removal of duties on renewable techs	NAPA, UNFCCC submission
Rwanda	Agriculture/energy	$410		Reforestation, agricultural management, fertiliser management, better waste handling	Bioenergy, solar, micro-hydro, EE, regional clean electricity grid	NAPA, PRSP, UNFCCC submission
South Africa	Services/energy	$5820	Cleaner vehicles		Renewables and EE, CCS and clean coal	People – Planet – Prosperity: A National Framework for Sustainable Development in South Africa, Department of Environmental Affairs & Tourism, South Africa – the paper highlights only the need to implement a national strategy to combat climate change, but has no actual strategies
South Korea	Services/ energy	$21,530	Public transport and regulation of vehicles		Lower carbon intensity and EE, carbon tax, renewables	ECOREA 2008 – (document contains only a few brief non-specific paragraphs on carbon abatement), Ministry of Environment, Republic of Korea The Ministry of Knowledge Economy has set up two national policies, the National Climate Change Plan and the Green Energy Industry Development Plan, but documentation for both is not available

Table acronyms: BPO = Business Process Outsourcing; CAT = Cap and Trade; CC = Climate Change; CCA = Climate Change Agreement; CCS= Carbon Capture and Storage; CDM = Clean Development Mechanism; CFL = Compact Fluorescent Lamp; CHP = Combined Heat and Power; CNG = Compressed Natural Gas; ECA = Enhanced Capital Allowance; EE = Energy Efficiency; GNI = Gross National Income; LC = Low Carbon; NAPA = National Adaptation Programme of Action; PASDEP = Plan for Accelerated and Sustained Development to End Poverty; PAT = Perform, Achieve, Trade; PRSP = Poverty Reduction Strategy Paper; PV = Photovoltaic; R&D = Research and Development; REDD = Reduced Emissions from Deforestation and Degradation; UNFCCC = United Nations Framework Convention on Climate Change.

3. How does low carbon growth challenge the traditional growth agenda?

3.1 How does low carbon growth challenge traditional growth theory, and how might it affect the global rate of growth?

Achieving low carbon growth clearly has major implications for policy, and implies considerable adjustment of the traditional growth agenda. Having said that, low carbon growth does not actually present a major challenge to traditional growth *theory* - it simply requires the internalisation of the environmental costs of production of goods and services. Because the impact of carbon emissions on climate change has not been captured in the prices of goods and services to date (more specifically, because the cost of energy has been sub-optimally low, having not factored in the impact on climate change), growth and development have occurred in a way that undervalues carbon, and hence results in a greater use of energy than would be the case if energy was properly priced. In practical terms, examples might include the development of sprawling modern cities that rely heavily on travel by car, or the intensification of food production in a way that relies on the use of machinery and fertilisers that consume high levels of fossil fuels, or the growth of a ‘throw-away culture’, rather than the reuse or recycling of existing materials.

In theory, it is simple to resolve this problem through the appropriate pricing of carbon emissions, which would incentivise producers and consumers to take into account the environmental costs associated with the carbon emissions created in producing or consuming goods and services. Thus, the main requirement to establish the right conditions and incentives to achieve a low carbon growth path is to establish an appropriate carbon price.

(While establishing a carbon price internalises the necessary environmental externalities, some have argued that a transition to a low carbon economy also requires a broader altering of what is counted on national balance sheets. Conventional measures of GDP do not take into account the depletion of natural resources, or the environmental consequences (e.g. pollution) of production. Thus, Joseph Stiglitz and Amartya Sen conclude as part of the Commission on the Measurement of Economic Performance and Social Progress (2008)[38] that GDP is an insufficient metric by itself and that additional measures of sustainability and human wellbeing should be included when assessing economic progress.)

An international agreement which sets an overall global ceiling on emissions, and allocates emissions allowances to every country in the world, would effectively set a carbon price. But in order to achieve this (and, indeed, in the absence of such an agreement), countries will need to implement national policies that will facilitate the achievement of the necessary emissions reductions or constraints on emissions growth. These policies could include fiscal incentives (through taxes or subsidies), regulation (through standards or labelling), an emissions permit trading scheme or government support for research and development.

However, the potential impact of mitigation policies on growth is rather unclear. While much of the literature suggests a negative impact from mitigation on growth, a recent report by The Climate Group finds that a global climate agreement could lead to an increase in global GDP by 0.8% by 2020 relative to projected GDP with no climate action. The literature on this issue is very mixed, and modelling results often depend enormously on the assumptions used.

On the one hand, emissions constraints raise the cost of energy, which reduces the output that can be achieved with a given set of inputs. However, there is no consensus on the costs of mitigation in

38 The Commission was created by French President, Nicholas Sarkozy, to review the adequacy of GDP.

the literature. Some studies argue that the costs of mitigation could be lower than expected. This could be because of the discovery of new, cheap technologies which can facilitate a low-cost switch from fossil fuel to fossil-free sources of energy (Gerlagh, 2006), or because of international spillover effects (Buonanno et al., 2003) or because of synergies between green research and development investments and general output-increasing research and development investments (Cantore, 2006). The cost of mitigation will also depend on the nature and efficiency of the mitigation policies adopted. Emissions trading schemes, for example, are seen as a way of minimising mitigation costs by allowing flexibility in where emissions reductions are made, thus providing opportunities and incentives to keep down the cost of mitigation.

Mitigation policies will affect different sectors differently, and are likely to imply adjustments to the sectoral sources of growth previously enjoyed by some countries. For example, mitigation policies which drive down the cost of oil will generate a net loss for oil-exporting countries, and a net gain for oil importers. Air transport taxes might reduce demand for tourism, or for air-freighted exports such as fruit and vegetables. Carbon taxes may generate carbon leakage (i.e. the shift of dirty industry to pollution havens), and reduce income associated with carbon-intensive products. Thus, the impact of these policies will vary significantly by country, depending on their sectoral composition. Analysis of the potential impact of different kinds of mitigation policies on growth has been fairly limited to date, and is the subject of a forthcoming Overseas Development Institute (ODI) study.

Notwithstanding the costs that are bound to be associated with mitigation, there are also opportunities associated with mitigation that some argue could potentially outweigh the costs (e.g. UNCTAD, 2009). In other words, the growth stimulus deriving from policies devoted to enhancing environmental technological progress could outweigh the growth-reducing effect associated with a higher cost of carbon. This could be the case if there is fast growth in the demand for environmental goods and services, for example. Moreover, there may be major co-benefits associated with mitigation. If – as noted above – there are strong synergies between green technological change and general, industrial technological progress (a key source of growth), then policies designed to promote green technological innovation and technology transfer could potentially also increase growth. In addition, efforts to restore forests or avoid deforestation or land degradation in some countries may also have beneficial economic effects, if they help improve flood controls in watersheds.

Some mitigation policies generate revenues (e.g. carbon taxes) and thus provide opportunities to stimulate growth through the judicious use of the revenues raised. For example, a recent paper from Tol et al. (2008) shows that, if revenues from a carbon tax are spent on health and education, the overall impact of a carbon tax would be positive.

Thus, the way national mitigation policies are designed will have a significant impact on the overall growth effects. At an international level, if revenues raised from international mitigation policies (e.g. auction revenue from the sale of carbon permits in CAT schemes) are then spent in developing countries, this could generate significant gains for recipient countries.

Regardless of the overall impact of mitigation on global growth, the distribution of mitigation efforts will also affect growth prospects. Some have argued that rich countries may need to reconsider their pursuit of continued economic growth, if developing countries are to have the space to grow their way out of poverty.

There are also significant practical uncertainties and constraints associated with mitigation in both developed and developing countries, including:

- The potential success of future innovation in energy production technologies in driving down the price of low carbon energy;

- The ease with which countries can switch to green energy, which depends on the extent to which they are locked into existing technologies. The adoption of low carbon energy sources will depend on their relative price and convenience as compared with fossil fuels. If the upfront costs of switching to a greener energy infrastructure are high, this could reduce uptake, even if energy costs would be lower in the long run;
- Constraints to technology transfer, as a result of barriers to foreign direct investment, limited capacity to adopt and learn from new technologies, intellectual property rights, or behavioural inertia;
- Constraints to innovation arising from uncertainty about the future carbon price/return on investment, potential to free ride on the back of other country's innovation and the possibility that public investment in research and development activities could 'crowd out' private investments, i.e. entrepreneurs could be discouraged from innovating if they have the perception that they could 'free ride' by exploiting technological knowledge generated by public authorities, or if they think they will not be allowed to keep the rents associated with green innovation;
- Informational constraints relating to technology availability and associated benefits and costs, including uncertainty about future energy prices;
- Financial constraints associated with lack of access to capital, and asymmetric information problems in the credit market;
- Political constraints e.g. political instability and political economy problems associated with removing subsidies to fossil fuels;
- Institutional constraints relating to the slow development of markets (including issues such as the difficulties associated with measuring, reporting and verification), and potential transactions costs associated with trading mechanisms such as the CDM and Joint Implementation;
- Knowledge constraints, e.g. there are some significant gaps in understanding about the impact of certain reforms on emissions (such as the role of land use in carbon sequestration, and the impact of different types of agricultural production practices).

A key determinant of the impact of mitigation on developing countries, and their ability to achieve sustained, low carbon growth, depends on the policies they adopt in order to mitigate and adapt to climate change, to develop the necessary institutional arrangements to manage reform and to position themselves strategically in order to benefit from international mitigation responses.

Appropriate policies can help to position countries to take advantage of new economic opportunities that may arise which will help to increase their growth rate, such as new sources of finance for mitigation or adaptation, or new export opportunities in environmental goods and services. Appropriate policies can also help to protect countries from *threats* to their growth arising from climate change or its mitigation, e.g. the loss in agricultural productivity arising from changing weather patterns, or the reduction in demand for the exports of dirty industries.

3.2 How does low carbon growth challenge conventional growth policies?

In this section we consider each of the growth pillars in turn, assessing what adjustments are required in order to ensure that they will facilitate low carbon growth, and then describing the range of policy options discussed in the policy documents reviewed. At the end of each section, we list possible policy lessons that can be drawn for both developing countries, and for donors and international policymakers.

3.2.1 Finance for mitigation and adaptation

Investment underpins growth, but requires access to finance, which is something many developing countries lack. Adaptation and mitigation will clearly require huge amounts of investment (e.g. in flood-resistant walls, or in the conversion of fossil fuel energy production into green energy sources, etc). The Human Development Report 2007/08 estimates adaptation funding needs for the developing world to be $86 billion per year by 2015 (UNDP, 2007).[39] The HDR also presents an estimate for the investments in low carbon technology needed to transition to a sustainable emissions pathway at an additional $25-50 billion per annum in developing countries.[40]

Developing countries will clearly need external sources of finance for adaptation and mitigation, whether it is through public funds or through private capital which can be incentivised to move to developing countries through mechanisms such as carbon markets. There is currently a debate about how much of the required finance will actually be attainable through private markets. The achievement of an international agreement which establishes a clear international price for carbon will help to create greater certainty about the value of green investments, and hence should help to unlock greater private finance for mitigation.

The negotiations have generally emphasised that private finance is expected to kick-start low carbon investments and public finance will close the gap. But this is a large assumption and may be relevant mostly for HICs and MICs. MICs have been more successful in attracting private finance (e.g. through the CDM), in part because they are larger emitters with more ‘low hanging’ mitigation options; LICs have struggled to attract private finance at the best of times, given their often poor investment climates. With the lack of international public funding commitments and low domestic budgets, LICs cannot rely exclusively on public monies to fund their adaptation and mitigation actions. They will also need to strengthen their national investment climates (e.g. by investing in infrastructure to tackle the high costs of doing business, undertaking regulatory reform and reducing policy and regulatory uncertainty) to attract greater levels of private finance for green investments, including through the CDM. Without such reforms, it remains unclear how much private finance will in fact be forthcoming in LICs.

Some countries with major carbon assets (such as forests) could expect increased sources of private finance arising from carbon markets in the longer term, but others will not, and will have to rely more heavily on sources of public funding, which may or may not turn out to be additional to conventional development aid. Some of the countries reviewed say that they will be unable to implement the low carbon growth strategies they are developing without additional resources from the developed world. If countries are perceived to be particularly vulnerable to climate change, they may even face reduced access to private capital, as their growth prospects are expected to deteriorate. If public funding is used to plug gaps in finance left by private markets, this could suggest that a reallocation of funding is needed, towards developing countries with fewer carbon assets. Currently, mitigation projects qualifying under the CDM are quite narrowly defined, and thus most of the financial benefits it generates are going to a small number of countries, i.e. China and India. In order to facilitate a much wider impact, the carbon market will need to be reformed and widened in scope quite considerably, e.g. to cover forestry/reduced deforestation, for example. There are a range of proposals on the table for discussion about how carbon market flows can be scaled up going forward to provide a much wider set of countries with increased finance for mitigation. Proposals to expand and scale up the carbon market include:

1. **Reforms** to the rules governing what activities can be carried out under the CDM (for example expanding the scope to cover a broader range of project types, such as agriculture, forestry, nuclear power, etc) and the methodologies that are used (for example simplified methodologies to increase access by LICs and expanded programmatic CDM);
2. **Sectoral mechanisms**, in which emissions reductions from whole sectors (as opposed to individual projects) can generate carbon credits. Other sector-based approaches include

39 $44 billion for climate-resilient investments, $40 billion for poverty reduction and $2 billion for disaster relief. This would be in addition to official development assistance.
40 A new reviewed study published by the International Institute for Environment and Development and the Grantham Institute for Climate Change at Imperial College London suggested that real costs of adaptation are likely to be two to three times greater than estimates made by the UNFCCC, which were put at $40-170 billion annually.

'no lose targets' for developing countries, and mechanisms to focus on technology transfer and avoided deforestation (REDD).

Proposed NAMAs would expand the scope and scale of participation by developing countries further. Countries would implement a suite of policies and measures covering multiple sectors and using multiple instruments to achieve reductions. Certain activities under NAMAs could be supported with instruments such as the CDM applied either to projects or sectors. NAMA activities could also potentially qualify for emissions credits issued directly by the Conference of the Parties (COP). NAMAs would offer the most potential for expanded access and participation, since a variety of mechanisms would be included, but sectoral crediting and expanded programmatic approaches to the CDM would also provide greater opportunities for LICs.

The low carbon growth strategies reviewed in this paper show that finance is fundamental to implementation and is linked to all proposals made under countries' low carbon development plans, yet it remains scarce, particularly for LICs. In policy documents, countries have specified financing to come through dedicated climate change funds, government earmarks, the CDM and requests for international support. Some of the countries studied have implemented a climate change fund, including Bangladesh, Germany, Guyana, Mexico and the UK.

Bangladesh is trying to position itself well for receiving international support by establishing a Multi-donor Trust Fund, and Brazil has its Amazon Fund for deforestation funding. Bangladesh and Ethiopia have expressly stated that they hope to expand CDM opportunities but other LICs do not target CDM specifically in their policy documents. Guyana has been the most aggressive of LICs in terms of pursing financing options, working with McKinsey & Co and other international institutions to develop support for its plan to finance low carbon growth through REDD payments.

Significant questions remain over how and to what extent funding will be provided for the mitigation and adaptation agendas in developing countries. NAMAs have yet to be developed but will need to be funded along with adaptation plans (e.g. NAPAs) that some LICs have already prepared. For example, Bangladesh, Ethiopia, Rwanda and Malawi have stated they cannot move forward with their NAPAs without international funding, but it remains to be seen what level of developed country support for both mitigation and adaptation is agreed in Copenhagen. For example, the EU Commission in its Global Finance Blueprint for Ambitious Action by Developing Nations has proposed contributing some €2-15 billion[41] a year by 2020 to mitigation and adaptation in developing countries, contingent on reaching a robust agreement in Copenhagen, but other nations, including the US, have not yet committed funds.

There is also a question as to what extent existing aid budgets will or should be diverted towards adaptation and mitigation activities. This could result in significant reallocations of aid spending across countries and sectors which, particularly in a climate of reduced public expenditure generally (coming out of the financial crisis), could have significant implications – positive or negative – for many highly aid-dependent developing countries.

Adaptation and mitigation activities planned in low carbon strategies are directly dependent on available finance, but LICs like Ethiopia, Malawi, Nigeria and Rwanda have no specified funding source if CDM financing or international adaptation funding does not materialise. Similarly, Bangladesh and Guyana are in danger of falling short of funding if the Multi-donor Trust Fund and the Low Carbon Finance Authority, respectively, fail to attract sufficient international donors. Industrialised countries, including the UK and Germany, tend to have more mitigation financing available, but even these countries face budget constraints for energy investments, even more so in the wake of the global financial crisis.

41 The EU Commission estimates that €100 billion will be needed annually to fund adaptation and mitigation activities in developing countries http://ec.europa.eu/ireland/press_office/news_of_the_day/climate-change-developing-countries_en.htm.

All of this suggests the following possible policy lessons:

- For the international policy community, the achievement of an international agreement on emissions reductions is a priority to help unlock private finance for mitigation.
- Countries can be strategic in how they position themselves to attract finance for mitigation and adaptation. For example, the development of a 'Climate Change Fund'/multi-donor trust fund, and an appropriate policy framework e.g. a NAPA, NAMA, and/or a low carbon growth strategy, can help to convince donors that climate change is taken seriously in that country, and that any funding will be spent transparently and effectively.
- Developing countries need to continue to lobby for financial support for mitigation and adaptation, and for reform that will help them benefit more from carbon markets, including the Clean Development Mechanism (CDM).
- For countries with carbon assets, strategic positioning, policy development, and lobbying for financial support for mitigation and adaptation, may help to both influence the international agenda, and the development of international mitigation mechanisms, such as Reduced Emissions from Deforestation and Forest Degradation (REDD) and CDM, in their favour, both in terms of scope and scale.
- Widening the scope of carbon markets to enable more LICs to benefit, and improving the investment climate in developing countries may also help them to maximise financial inflows of private finance for mitigation.
- Not all developing countries will be able to obtain private finance for mitigation and adaptation. Increasing the availability of public finance will also be important in supporting developing countries' low carbon growth efforts.

3.2.2 Human capital

The development of human capital, through investment in education, training and health services for example, is an important underpinning of growth. Educating the population about the impact of climate change, and giving them the skills and knowledge to adapt to it, to understand the changing global policy environment and hence the potential impact on their livelihoods and to capitalise on any new opportunities will help to improve countries' growth prospects. A number of the countries reviewed here have proposed or implemented policies to raise awareness on these issues.

The development of skills to design and implement new, green technologies will also be crucial to facilitating low carbon growth internationally. It is likely that a relatively high proportion of technological innovation will take place in HICs, where education levels and investment in research and development are higher.

Measures to protect the health and wellbeing of the population in light of future threats from climate change, such as natural disasters and disease, will also be important in order to preserve human capital.

The reviewed policies show that most countries recognise the importance of awareness building, education and training in order to underpin and provide public support for both mitigation and adaptation. Bangladesh, China and Nigeria focus broadly on awareness building; Brazil, Ethiopia, Germany, Guyana and Mexico focus on integrating climate change into the education system; Mexico and Ethiopia specify incorporating education at all levels. Bangladesh hopes to establish a knowledge centre to conduct training, awareness raising and education on climate change, and is the only country specifically to target women in this effort. However, few countries specifically acknowledge the link between awareness raising, education and behavioural change in their policy documents; rather, it seems to be implied that they expect to build public support for action and encourage behavioural change. No countries, except the UK and Guyana, even mention behavioural changes or discuss how they plan to go about encouraging these changes.

Bangladesh, Brazil and Ethiopia focus on addressing health concerns arising from climate change through surveillance, research and water and sanitation programmes. Both MICs and LICs included programmes to study the causes and impacts of climate change further.

Germany's strategy document calls for new growth and job opportunities within the green services and technology sectors but makes no mention of how training and skills can be improved. The UK does propose to develop a Skill Funding Agency to provide training in anticipation of high demand for low carbon technologies, and targets behavioural change. Guyana is the only LIC specifically to pledge to make significant investments in job development and training in a new economy.

Apart from Guyana's ambitious LCDS, developing human capital is approached in a piecemeal fashion, with no country proposing a full suite of measures to address education, training, job creation and health across the board. Developing and developed countries alike provide few details on how new education curricula and awareness campaigns will be implemented or how widespread these measure will be.

Possible policy lessons:

- Broad awareness raising may help increase public understanding of climate change and its effects, and the implications for people's livelihoods and welfare going forward. This can be implemented formally, for example through schools, or informally, through public awareness campaigns.
- Training in skills relating to green technologies and industries can help position countries to take advantage of any new low carbon growth opportunities and markets.
- Targeted investments in health, water and sanitation may help increase climate resilience by protecting human capital from the potential negative health impacts of climate change.

3.2.3 Technological progress in energy, infrastructure and transportation

Technological progress is a key driver of economic growth, and energy, infrastructure and transportation all play an important role in underpinning economic growth.

Energy demands are growing fast in the developing world, as a result of rising populations and economic growth. Growth policy has traditionally focused on increasing access to energy at the lowest possible price, but this may now need to change in light of the need for mitigation. Cleaner, greener sources of energy are currently more expensive than fossil fuel-based energy sources, so utilising these new technologies will impose a cost on developing countries, at least in the short term. Developing countries may argue they should not bear this cost themselves, and there may well be considerable private finance available to help fund this switch in developing countries, as a result of offsetting through the CDM and other mechanisms going forward.

Given that many developing countries still have relatively low access to electricity, and that the development of new power plants is happening much faster than in developed countries, this represents a significant opportunity to ensure that the high carbon development trajectories of developed countries are not replicated in developing countries going forward, e.g. by prioritising donor funds on investment in green energy sources in the developing world. This will require more joined-up donor engagement than currently exists, as there are still significant investments being made in fossil fuel-based energy generation projects in many developing countries.

This may have significant co-benefits for developing countries, for example if green micro-generation technologies facilitate improved access to energy in rural areas that are not connected to the national electricity grid, for example. It can also help to contribute to energy security in the longer term, and reduced costs for net oil importers.

Developing countries are also calling for greater efforts to be made to facilitate technological diffusion, given that much technological innovation takes place in the developed world. However, increasing technological diffusion may not always be in the interests of private companies, who wish to protect their innovations in order to profit from their efforts. Some developing countries have argued that intellectual property provisions in the WTO should be re-examined in light of these kinds of considerations. Greater efforts to promote international cooperation on research and development may help to promote technological diffusion.

Strategic thinking and strong policy management of patterns of urbanisation may also be required, to increase climate resilience and prevent high carbon development trajectories, e.g. by preventing the growth of new towns and cities in areas vulnerable to climate change, such as coastal areas, and preventing urban development patterns which are heavily reliant on individual transportation rather than public transport.

From the policy documents reviewed in this paper, it is clear that provisions related to energy, infrastructure and transportation form the backbone of many countries' climate change plans, largely because energy and transportation are the largest sources of emissions for most countries, and infrastructure development is critical both for setting a low carbon growth trajectory and for building climate resilience. Government can play an important role in clarifying the future direction of policy and the key decisions that will be made on energy production and infrastructure development, to give business the confidence it needs to undertake low carbon investments. Energy security is a primary objective for all countries but low carbon energy is not the only factor in achieving energy security, as all countries are simultaneously developing domestic oil, gas and coal reserves.

In the energy sector, aspirations for lower carbon and renewable sources of energy are largely tied to income levels. Lower-income countries focus on off-grid PV, solar heating, modest amounts of wind power, wind pumping, micro-hydro, various types of bioenergy[42] and 'clean coal' technology transfer. The lowest-income countries – Ethiopia, Malawi and Rwanda – also focus on expanding usage of efficient cook stoves. Nigeria is exploring options for nuclear as well, for energy security reasons, but would need significant international support and technology transfer. In general, LICs are more vocal in their plans to harness co-benefits through increased access to clean, smoke-free forms of energy and off-grid applications that avoid costly transmission lines. The co-benefit of job creation is not a primary focus.

MICs and HICs have included large-scale hydro and wind, grid and off-grid PV, cogeneration, CCS and nuclear in their plans. China, the UK, Nigeria and Bangladesh have included research and feasibility studies for tidal and/or wave energy. For Nigeria and Bangladesh, again, these energy sources would only be possible to develop with international assistance. Germany, the UK, Mexico and China have included programmes to promote energy-efficient appliances as well. The UK and Germany are the only countries specifically to target low carbon energy technologies as a source of employment growth, although Guyana alludes to this as well.

Countries where coal is the primary source of energy – chiefly, Bangladesh, China, India and South Africa – are pursuing cleaner fossil fuels, including advanced coal plants, CCS, coal mine methane capture, fuel switching and development of gas fields. Others, like Ethiopia, Malawi and Rwanda, are promoting charcoal in cooking and power generation. Most countries intend to pursue a portfolio of low carbon technologies, although Guyana noticeably focuses only on tapping its hydro resources. Energy efficiency is factored into plans of all income groups to some degree.

Infrastructure improvements aimed at lowering emissions take a variety of forms. A number of HICs and MICs aim to strengthen building codes, and Germany is advancing its smart grid. Mexico and Brazil hope to build more efficient power plants and reduce technical losses. Guyana plans to

42 Bioenergy includes biomass gasification, cogeneration and digesters.

capitalise on new growth opportunities in BPO by installing more than $10 million worth of fibre optic cables. Brazil aims to expand ethanol service stations. Specific infrastructure plans for adaptation tend to be in coastal countries, including Bangladesh, Guyana and the UK, which plan to build flood and seawall defences and boost disaster preparedness.

Transportation measures focus on mitigation from biofuels, promoting public transport and encouraging smaller and/or more efficient vehicles, although only the UK and Germany propose to work on all of these areas. China, Brazil, Ethiopia and potentially Guyana plan to expand biofuels for transport. Brazil clearly has an advantage in bioethanol production efficiency and it is willing to export its technology to other Southern countries to enhance opportunities for global trade. Lower-income countries tend to focus only on encouraging public transport, although Ethiopia wants to impose a tax on large vehicles. China has programmes for both public transport and efficient vehicles. Despite the fact that some countries are already using other cleaner-burning transport fuels such as CNG in cities, policy documents reviewed for this study do not mention fuels other than biofuels as an option.

Possible policy lessons:

- Infrastructure improvements and the development of clean energy options should be made as soon as possible to reduce emissions as well as adapt to potential impacts. This will avoid locking in high-carbon technologies and processes as demand for energy rises. The development of decentralised grids may offer co-benefits between greener energy production, and increased access to energy.
- Strategic thinking and strong policy management of patterns of urbanisation may be required to increase climate resilience and facilitate low carbon growth.
- Government can play an important role in clarifying the future direction of policy and the key decisions that will be made on energy production and infrastructure development, to give business the confidence it needs to undertake low carbon investments.
- It is critical for low-income countries to receive international support and technology transfer to facilitate their transition to a low carbon economy. Greater efforts to promote international cooperation on research and development may help to promote technological diffusion. A re-examination of intellectual property provisions in the World Trade Organization (WTO) may also be needed.
- Countries should identify renewable resources that provide the greatest advantage in view of local conditions, resources, and state of development.
- The future development, demonstration and transfer of technology for carbon capture and storage will be very important for countries that continue to develop their large coal reserves.
- Governments in all countries can benefit from working with the private sector and civil society to scale up renewable technologies, from improved cook-stoves to large-scale wind and solar to hydropower.
- Transport is best approached holistically and should include public transport, clean, sustainable fuels, and efficient vehicles.
- Biofuels offer a potentially important new export opportunity for some developing countries, although major developed countries still impose protection on biofuel imports.

3.2.4 Investment in agriculture and forestry

Growth in LICs is often heavily agriculture based initially, and such growth can be strongly pro-poor. The donor community has put considerable effort into promoting increased agricultural productivity in developing countries. However, this has sometimes resulted in increased intensification of production and reliance on fertilisers etc, which is now seen as less desirable, given the higher carbon emissions associated with such production. Thus, agricultural development projects may need to be re-examined in light of new priorities for low carbon growth. It may be that more extensive methods of agricultural production that are utilised by small farmers in the developed world may become a source of comparative advantage, given increasing global demand for low carbon and organic agricultural produce.

At the same time, climate change is expected to reduce agricultural productivity and may also affect patterns of comparative advantage across countries. Shifting patterns of demand will also affect agricultural growth strategies; for example, biofuels represent one possible growth area for some countries. The demand for some exports may decline, such as for air-freighted fresh fruit and vegetables.

Forestry has been a major source of income for some developing countries, and given the great importance of forests as a carbon sink, the potential value of avoided deforestation and reforestation could be a significant source of finance for those countries through mechanisms such as the CDM and REDD, although considerable progress still needs to be made in developing these mechanisms. The extent to which these potential flows of funds actually result in alternative livelihoods and sources of growth being successfully developed will depend crucially on how those funds are spent. For some such countries, alternative livelihood options and sources of growth are not easy to identify.

The limited participation of sub-Saharan Africa in the first commitment period of the CDM is to some extent to be expected: large developing country emitters, such as China, have benefited the most from the CDM to date because they emit more and therefore have emissions ready to be offset.[43] But the recognition of avoided emissions in both the forestry *and* the agriculture sector may, in the future, increase the level of participation towards primarily agricultural societies.[44] Should some of the issues of monitoring and verifying the increased storage and permanence of carbon sequestration be resolved, investing in the agriculture sector in non-Annex 1 countries and offsetting emissions produced elsewhere could become increasingly attractive.

There is an ongoing debate about whether REDD payments should be fund based or provided through carbon markets. Brazil and some LICs are firmly on the side of a fund or grant-based mechanism because it feels foreign investments in its forest resources compromise national sovereignty. Many others feel that the only way to attract and sustain the level of funding required to conserve the world's forests is through the carbon market. It is not clear which form REDD will take in upcoming international negotiations, if an agreement is reached at all. Guyana has taken a proactive approach to establishing an interim fund for international support while it improves governance and transparency mechanisms to support a monitored and verified source of emissions reduction credits from forests.

All countries reviewed specified policy measures to improve practices and reduce emissions from forestry and agriculture. These activities figure more prominently in countries with a large dependence on agriculture, such as Ethiopia and Malawi, or countries with large forest reserves, like Brazil and Guyana. Measures for agriculture are seen as a way to increase productive efficiency while protecting against climate change impacts. For countries with forest reserves, standing forests present a potential source of finance.

Countries with heavy dependence on agriculture, including Bangladesh, Brazil, China, Ethiopia, Mexico and Rwanda, are targeting a variety of agriculture activities: from improved soil management and improved agronomic practices through management of fertilisers and nitrogen runoff, to use of climate-resistant crop varieties and improved irrigation and water management for adaptation. Water management, irrigation and reservoirs are seen as especially key by Ethiopia,

43 As of August 2008, over half of all registered projects were based in either India (30%) or China (22%), with only 2% located in sub-Saharan Africa (ODI, 2008). This bias towards MICs has also been highlighted in the recently published World Development Report 2010 (World Bank, 2009).
44 A recent policy brief produced by the Food and Agricultural Organization (FAO, 2009) also makes this point: it states that inclusion of agriculture in developing country NAMAs may also help to balance the exclusion of most forms of agricultural mitigation from the CDM of the Kyoto Protocol.

but these are not explicitly targeted in the policy documents of other African states, including Malawi, Rwanda and South Africa, which may potentially face severe water shortages. These practices require programmes to educate farmers and that the right kind of support and incentives are provided to maintain implementation. Use of climate-resistant crop varieties may be more successful with dedicated research and development programmes, such as that proposed by Bangladesh.

Nigeria and Brazil are the only countries to specifically promote organic fertilisers, although Nigeria is interested in it partially as a cost-saving measure. Brazil and Ethiopia, both large livestock producers, target improved management of grazing lands, and China, Brazil and Ethiopia include measures to reduce methane emissions from livestock. Rwanda proposes agricultural intensification as a measure to reduce emissions. The UK is exploring options for a CAT system for agriculture; Ethiopia is the only country to mention a drought/crop insurance programme.

Nearly all developing countries – Bangladesh, China, India, Brazil, Ethiopia, Mexico, Nigeria and Rwanda – have specified plans for reforestation. Countries with significant forest stocks, such as Brazil, Guyana and Mexico, are also actively involved in developing and promoting a REDD system of payments, although Brazil favours a fund-based approach while Mexico and Guyana prefer a crediting mechanism in the long run and are part of the World Bank's REDD readiness programme. For Guyana, other parts of its plan to transition to a low carbon economy rest on whether it obtains financing through REDD. However, other countries with forest reserves, including India, China and Rwanda, are not so actively pursuing REDD finance. Brazil, Ethiopia, and Guyana also state that sustainable forest management will be promoted; Guyana in particular sees sustainably sourced forest products as a major new industry. Other than a common emphasis on reforestation for all developing countries, Guyana and Brazil come closest to a comprehensive forestry approach in terms of promoting reforestation, conservation, sustainable forest management and efforts to combat illegal logging through certification. Incentives for sustainable forest management and forest conservation are crucial to these efforts, as are government programmes in reforestation.

Possible policy lessons:

- Greater understanding and awareness of the impact of climate change on agricultural productivity, and shifts in demand for agricultural produce will help developing countries to improve climate resilience and take advantage of possible new growth opportunities. Education of farmers will be an important component in this.
- Comprehensive approaches that include improved agronomic practices; climate-resistant crop varieties; water, soil and fertiliser management, and better livestock management are needed.
- Adaptation efforts in agriculture may be most important in poor countries that rely disproportionately on agriculture and are likely to be most affected by climate change.
- Forestry payments present a significant potential financing opportunity for some countries, if international mechanisms such as REDD can be successfully developed.
- Countries that develop a rigorous, comprehensive, transparent and inclusive process around sustainable forest management may be more likely to secure international investments and future CDM benefits and turn them into successful alternative growth strategies and conservation of forests.
- Agriculture offers considerable potential sequestration benefits though there are significant barriers to attracting carbon finance for this sector.

3.2.5 Trade and private investment opportunities

Integration into global markets has been seen as a necessary prerequisite for growth, and will continue to be key if countries are to benefit from new private flows of finance through mechanisms such as the CDM, and new export opportunities, e.g. of environmental goods and services. Trade and foreign direct investment will also be key in facilitating the diffusion of new, clean technologies. However, international mitigation policy is likely to result in shifts in comparative advantage, and new export opportunities and risks, to which the developing world will need to adapt. For example, emissions caps could create incentives for relatively ‘dirty’ industries to move to countries without emissions caps. This represents an opportunity for increased foreign direct investment into developing countries, albeit of a rather environmentally unfriendly kind. However, border tax adjustments are being considered in part by some developed countries to prevent this carbon leakage, which could have consequences for access to other export markets that were previously open to developing countries.[45]

The introduction of carbon taxes, carbon labelling and associated regulation or changes in consumer behaviour could also shift comparative advantage, and could damage prospects for the growth of markets such as air-freighted fruit and vegetables, or tourism. If fuel taxes are introduced which significantly push up the costs of freight, it is also possible that more goods will be sourced locally, to reduce transportation costs. In these sorts of scenarios, export-based growth strategies may need to be reconsidered.

The increased cost of energy, which is likely in a carbon-constrained world, may incentivise more local production and consumption of goods. This may mean that it is more carbon efficient to process some raw materials close to their site of production. However, in other cases, it may mean that some export-orientated growth strategies need to be reconsidered. The country strategies reviewed generally have very tailored perspectives on where opportunities lie in the future with respect to climate change. Countries with the most proactive plans to harness new opportunities, all of which are seen to generate job growth and provide competitive advantage, include:

- Brazil – trade in ethanol fuel and technology and flex-fuel vehicles;
- China – production and export of PV technology;
- Guyana – new industries in aquaculture, forest products, BPO, ecotourism, ethanol and export of fruits/vegetables;
- Mexico – ecotourism;
- UK and Germany – new high-tech energy industries and green services sector with opportunities in export and expertise.

LICs, particularly Bangladesh, Ethiopia and Nigeria, are hoping for new investment opportunities through the CDM. Rwanda is also interested in developing regional cooperation on clean electricity generation. Generally, there is much less vision for ‘new growth’ industries and opportunities in these countries, as they are severely constrained by lack of financing and capacity. Collaboration between the private sector, NGOs and the government is important to be able to identify and act on new opportunities, but this is generally weak in LICs.

Possible policy lessons:

- Countries that identify, target and secure new green investment and growth opportunities stand to benefit more from the transition to a low carbon economy.
- There is a role for government leadership to identify low carbon growth sectors which may provide competitive advantage and employment growth.
- The development of new opportunities must be backed by sufficient support and funding from government and the international community. This includes the creation of an appropriate policy environment; provision of the necessary training/education; investment promotion and awareness raising; and collaborative partnerships between the public, private and NGO sectors.

45 The EU, for instance, is considering the use of border tax adjustments as a way to prevent European businesses from relocating to countries that do not have a carbon tax or other mitigation policies in place.

3.2.6 Incentives and regulation for low carbon growth

The achievement of low carbon growth is likely to require increased regulation and taxation, which will inevitably increase the cost of doing business to some extent. Where regulatory action is not coordinated internationally, there is also a risk of a race to the bottom, where countries compete for investment by minimising the regulatory burden they impose. Evidence from reviewing the impact of other regulatory policies suggests that this outcome is unlikely, however, given that such regulatory costs are fairly small compared with other factors affecting market entry. However, it is possible that the implementation of regulation and taxes or subsidies to achieve low carbon growth objectives could affect trade and investment flows at the margin, vis-à-vis a country's neighbours, or other similar nations.

LICs have relatively limited regulatory capacity, so a new set of low carbon growth policies and regulations may well create considerable challenges for developing countries to implement effectively, particularly in this new, relatively untried area. Thus, donor support for policymaking and regulation could help. These countries similarly lack capacity to participate in climate change negotiations at the international level. Here, again, donor and NGO assistance can be useful to facilitate developing countries' ability to participate in and shape an international climate agreement. There are efforts already underway, for example, in the area of REDD negotiations, with a number of civil society initiatives helping to provide a voice for developing country parties in REDD negotiations, particularly in the area of indigenous peoples' rights, such as the Coalition for Rainforest Nations. Strong capacity-building support across mitigation and adaptation activities can help improve the likelihood that an international climate regime will not disadvantage developing countries and that countries have the ability to adapt to and mitigate climate change in an effective, equitable and transparent way.

Having a good overall investment climate and competitive market environment should enable developing countries to take advantage of any new financing, export or inward investment opportunities that arise as a result of international mitigation policies. Having dynamic, competitive markets, which respond effectively to price signals, should also help countries to adapt their production more quickly in response to the new policy environment associated with low carbon growth.

The policy documents reviewed show that the measures used to promote low carbon growth are as diverse as their objectives. The following is a collection of financial incentives and regulatory measures proposed by various countries in their reviewed policy documents:

Financial incentives:

- Low-interest loans for clean energy installations (India and Germany);
- Feed-in tariffs for renewable energy (UK and Germany);
- Subsidies (India);
- Capital subsidies, sales incentives, and reimbursement of fees for renewables projects, and automatic approval for foreign direct investments (India);
- CAT (UK, Germany, Mexico, South Korea);
- PAT system (India);
- Taxes (road tax, Germany and UK), reduced taxes for public transport (Germany), tax differentiation based on engine size to promote the use of smaller cars (Ethiopia);
- Fund to promote private sector investments into renewable energy production (India).

Regulation:

- Decreased speed limits – Germany;
- Quotas – biofuels (Brazil, Germany);
- Fuel – efficiency standards (UK, Germany, China);

- Pollution controls (China);
- Regulation to promote renewables, e.g. the Renewable Energy Law in China forces the Chinese electrical grid operators to purchase all electricity generated through renewable sources.

These incentives and regulations are clearly crucial to the successful implementation of low carbon policies, as they represent the means through which the necessary change is brought about. However, in LICs specifically, there is little discussion of the financial incentives or regulation with which their planned policies will be implemented, reflecting the early stage they are at in developing low carbon policies.

Possible policy lessons:

- Internationally coordinated action to mitigate climate change can help reduce the risk of a 'race to the bottom' in relation to the taxation and regulation needed to stimulate low carbon growth.
- Donor support for low carbon regulation and taxation could help build developing countries' capacity to implement such policies effectively.
- An ongoing review of the efficacy and cost-effectiveness of measures by different countries to incentivise the necessary changes in behaviour and stimulate low carbon growth, could help improve policy-making in this area.
- Many of the barriers to low carbon growth, mitigation financing and technological transfer in developing countries are the same as the barriers to growth and investment generally i.e. a poor investment climate and uncompetitive markets. Policies to tackle these remain important.

3.2.7 Macroeconomic stability

Good macro policy which is able to avoid instability and mitigate the impact of adverse shocks promotes economic growth. Although macroeconomic stability has not been an issue highlighted in the low carbon growth policies reviewed, there are justifiable concerns as to the potential impact of significant flows of new financial resources into countries with sizeable carbon assets. Countries with significant carbon assets may experience Dutch Disease if they are unable to absorb and effectively use significantly increased flows of funds for mitigation.[46]

The negative effects of Dutch Disease can be avoided through judicious economic management that focuses on diversifying the economy, investing in human and physical capital and a certain amount of capital 'sterilisation' through the use of funds. Unfortunately, many emerging economies experiencing major windfall gains from the discovery and subsequent export of 'new' resources have economic management systems that are too weak to mitigate the negative effects of Dutch Disease. In such cases, the discovery of such 'new' resources becomes more of a curse than a blessing.[47]

This suggests that particular attention should be paid to the development of mechanisms for accountability and transparency in the use of funds along with a sound macroeconomic and public expenditure framework for countries which are likely to benefit from these kinds of large inflows. As formalised by Levy (2007), increased public investments can help mitigate the potential negative effects of Dutch Disease on other sectors of the economy.

---

46 Typically, countries that start to export a 'new' resource face upwards pressure on their exchange rate. As the real exchange rate appreciates, imports become relatively cheaper, which crowds out domestically produced goods. There is a risk that the non-oil economy declines as domestic production falls, and with it employment. As a result, economic growth may slow and become unbalanced. This model is known as Dutch Disease, named after the experience of the Netherlands in 1959 and formalised by Corden and Neary (1982).
47 Weeks (2008) points out that a 'resource curse' is not necessarily cast by inexorable forces but by seriously misguided economic policies.

To the extent that climate change results in increased volatility of weather patterns, and climatic shocks on the agriculture sector (but not exclusively), it may also result in greater macroeconomic instability. This suggests that countries should be considering increasing their reserves or other kinds of fiscal buffers that may be used to smooth economic shocks, in addition to their access to other international mechanisms designed to cope with exogenous adverse shocks (such as compensatory finance mechanisms). Weather-based insurance (mentioned in policy documents from Ethiopia and Guyana) and better access to capital markets can also help countries to manage such risks more effectively.

3.2.8 Security and protection from predation

The institutional framework in a country should also provide a reasonable degree of certainty that investors will be able to reap the rewards of their investment. Political instability, corruption, crime and weak contract enforcement can all threaten potential returns and make investment unattractive. This is another area rarely addressed explicitly in the low carbon growth strategies reviewed. However, there may be concerns relating to the potential impact of large financial flows from carbon markets and public finance for mitigation and adaptation. Such large flows can generate strong incentives for rent-seeking behaviour, resulting in corruption and undermining growth prospects. This can also result in very inequitable outcomes, which can exacerbate political instability and conflict. Climate change can also contribute to conflict, as people are displaced or fight for increasingly scarce resources. This suggests that emphasis should be placed on mechanisms to maximise the accountability of governments and other bodies in relation to the management of climate change policies, and particularly in relation to the management of finance for mitigation and adaptation.

3.2.9 Policy processes and barriers

Next, we consider the policy processes that the reviewed countries have adopted in developing their low carbon development and climate change response strategies. Countries have developed their plans and proposals in different ways, but most have tried to: 1) involve a number of ministries/departments; 2) hold a consultation phase and obtain recommendations from external experts; and 3) promoted an open and transparent process.

First, most countries involved multiple ministries in both drafting and implementing proposed plans. However, coordination between those ministries remains an issue. Lack of policy coordination is a significant barrier, and several policy documents (Bangladesh, Brazil, and Guyana) recognise the need for harmonisation across policies. For example, PRSPs may lack linkages to poverty impacts from climate change (e.g. Ethiopia), or ministries might have competing priorities (e.g. Brazil). Furthermore, across the board, policy proposals tend to lack specific targets, timelines and implementation guidelines. This affects all countries, as even the UK and Germany could have implementation problems owing to lack of policy guidance. Guyana plans to work out implementation guidelines through a consultation phase but others, particularly Ethiopia and Bangladesh, have no clear road to implementation.

Second, many countries seem to have conducted consultation phases between the public sector and civil society. Bangladesh, for example, included a very broad range of people in its consultations for both its NAPA and its BCCSAP. Brazil involved a variety of CSOs in the development of its NCCP, although there were criticisms that their inputs were ignored. There seemed to be a lower level of involvement by civil society in China. For countries participating in REDD, consultations are a required component of draft readiness plans, but there has been controversy over whom to include and how. Guyana has been praised for developing a robust consultation process which, while not perfect, provides a good framework for other countries to follow.

If the private sector was involved in the process, it was generally by way of contracting external experts, but it is not evident that the private sector was included in most developing country proposals.

One key exception is Guyana, which seems to have benefited by working closely with DFID, the management consultancy McKinsey & Co and other donors, private sector partners and experts to develop its comprehensive proposal. Nigeria used TWGs in its Vision 2020 to recommend specific target technologies and strategies.

Third, countries with consultation processes generally have the most transparent process overall, including Bangladesh, Brazil and Guyana. These countries also specify that implementation guidelines will be worked out in ongoing consultations. Guyana, for example, specifically aims to develop transparent forest governance and to ensure that avoided deforestation credits are globally verified and other land use governance standards are transparent and accountable.

By and large, a considerable shortcoming in most of the policy documents is that they do not spell out specific actions that will be taken or specific implementation plans. Countries such as Guyana have specified the actions they will take in a certain timeframe, but other plans, such as those for Brazil or Ethiopia, offer few details on how they intend to carry out their plans. A few countries suggest that they will work out guidelines in future consultations, and others delegate certain ministries to be in charge of future implementation. Most of the policy documents are more statements of intent than plans of action.

Overall, capacity in LICs presents the most significant barrier to implementation, including lack of training and expertise in climate change issues and weak enforcement and oversight. Therefore, a key prerequisite for developing countries to successfully implement their plans is to build training and awareness, enhance coordination between ministries and provide adequate finance to enable enforcement.

In MICs, the biggest issue seems to be a lack of coordination between implementing bodies, unaligned policies and weak enforcement at the local level. Brazil and Guyana recognise that they need to conduct an assessment of policies and promote alignment, but other countries do not mention policy alignment in their policy documents. HICs also suffer from implementation issues, largely because of a lack of policy guidance.

Possible policy lessons from reviewed countries:

- Policy statements should go beyond ‘statements of intent’ to provide a roadmap for specific measures and an implementation plan.
- Policy is strengthened by underpinning studies.
- Consultations help to obtain ideas and include various stakeholder viewpoints; promote coordination and collaboration, and enhance transparency and trust in the process.
- The inclusion of civil society helps build support for policies and thus aids in implementation. Consulting and partnering with the private sector can help increase the feasibility and market-friendliness of policies that are proposed. This can facilitate greater private sector engagement in achieving low carbon growth and improve the sustainability and scale-up of green investments.
- Training and education can help with coordinating different government departments and policies.
- Providing strong policy guidance is crucial to implementation.

3.2.10 Assessing progress to date, and learning lessons

The countries we have reviewed have already taken steps to develop a climate change or low carbon development strategy, and thus are already ahead of most other countries (within their income category, at least). However, there are a still a number of issues that most countries either have not addressed, or could not resolve, in their policy documents, including:

- Specification of a (potential) funding source for climate mitigation and adaptation activities;
- An implementation roadmap with specific measures;
- Anti-corruption and pro-transparency measures governing the use of mitigation/adaptation funds;
- A framework for macro management and measures to combat Dutch Disease;
- Identification of new green growth opportunities and the policies needed to achieve them;
- A rigorous consultation process;
- The need for policy alignment and intra-governmental cooperation.

Thus, although many of these countries are ahead of the game in terms of policies to promote low carbon growth and climate resilience, it is clear that improvements could still be made.

Nonetheless, the policies they have set out, and the processes they have pursued to arrive at them, can provide valuable lessons for other countries, which are only now beginning to think about how they will respond to climate change. While it is too early to judge the efficacy of many of the policies that have been set out (and indeed many of them are still only being planned at this stage), ongoing monitoring of the efficacy of these policies will be important in ensuring that lesson are learned globally, thus speeding up the effective response to this most pressing of problems.

References

Asian Development Bank (2009) 'People's Republic of Bangladesh: Supporting Implementation of the Bangladesh Climate Change Strategy and Action Plan'. Technical Assistance Report. Dhaka: ADB.

Assefe, T., ed. (2008) *Ethiopia's Policies, Strategies and Programs*. Addis Ababa: Forum for Social Studies.

Associated Press (2009) 'Brazil Boosting State Control for New Oil Finds'. 31 August.

Buonanno, B., C. Carraro and M. Galeotti (2003) 'Endogenous Induced Technical Change and the Costs of Kyoto'. *Resource and Energy Economics* 25(1): 11-34.

Cantore, N. (2006) 'Endogenous Technology as an Environmental Kuznets Curve Driving Force: An Impact Assessment'. *Mechanisms of Economic Regulation* 4: 13-28.

Corden, W.M. and J.P. Neary (1982) 'Booming Sector and De-industrialization in a Small Open Economy'. *The Economic Journal* 92(368): 825-848.

de Gouvello, F., B. Dayo and M. Thioye (2008) *Low-carbon Energy Projects for Development in Sub-Saharan Africa: Unveiling the Potential, Addressing the Barriers. Washington, DC:* World Bank.

de la Torre, P. Fajnzylber and J. Nash (2009) *Low Carbon High Growth: Latin American Responses to Climate Change*. Washington, DC: World Bank.

Dufey, A. (2007) *International Trade in Biofuels: Good for Development? And Good for Environment?* London: IIED.

Edwards-Jones, G., B. Hounsome, L. Mila I Canals, L. York, K. Plassmann and D. Jones (2008) 'Vulnerability of Exporting Nations to the Development of a Carbon Label in the United Kingdom'. *Environmental Science & Policy* 12(4): 479-490.

Energy Sector Management Assistance Program (2009) *Low Carbon Growth Country Studies Program*. Washington, DC: ESMAP.

Ethiopian Ministry of Finance and Economic Development (2006) *Plan for Accelerated and Sustained Development to End Poverty (PASDEP) (2005-2010)*. Addis Ababa: MoFED.

Ethiopian Ministry of Water Resources/National Meteorological Services Agency (2001) *Initial National Communication to the UNFCCC*. MoWR and NMSA.

Ethiopian Ministry of Water Resources/National Meteorological Agency of Climate Change (2007) *National Adaptation Programme of Action (NAPA)*. Addis Ababa: MoWR and NMACC.

Food and Agriculture Organization (2009) 'Anchoring Agriculture within a Copenhagen Agreement'. Policy Brief for UNFCCC parties. Rome: FAO.

General Economics Division and Planning Commission, Bangladesh (2005) 'Bangladesh: Poverty Reduction Strategy Paper'. Prepared for the IMF.

Gerlagh, R. (2006) 'ITC in a Global Growth-Climate Model with CCS. The Value of Induced Technical Change for Climate Stabilization'. *The Energy Journal:* 55-72.

German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2009a) *New Thinking, New Energy: Energy Policy Roadmap 2020.* Bonn: Government of Germany.

German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2009b) *Climate Protection Pays Off: Opportunities for Innovation, Growth and Employment.* Bonn: Government of Germany.

German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2009c) *Executive Summary Report on the Environmental Economy 2009*. Bonn: Government of Germany.

Goodluck J. (2008) 'Advocating a Low Carbon Economy'. Keynote Address by the Vice President of Nigeria, November.

Government of Guyana (2009) 'Conceptual Framework on Process for the Multi-Stakeholder Consultations on Guyana's Low Carbon Development Strategy (LCDS)'. Produced in consultation with the Multi–Stakeholder Steering Committee and with input from IIED. Georgetown: Government of Guyana.

Government of Guyana (2002) *Guyana Initial National Communication.* Georgetown: Government of Guyana.

Government of the UK (2009) *The UK Low Carbon Transition Plan: National Strategy for Climate and Energy*. London: GoUK.

Hussain, Z. (2009) 'Remittances in Bangladesh: Determinants and 2010 Outlook'. http://blogs.worldbank.org/remittances-bangladesh-determinants-and-2010-outlook-0.

Information Office of the State Council of the People's Republic of China (2007) *China's Energy Condition and Policies*. Beijing: Government of the People's Republic of China.

Inter-ministerial Committee on Climate Change (2008) *Brazil National Plan on Climate Change*. Brasilia: CIM.

International Monetary Fund (2006) *Guyana: Poverty Reduction Strategy Paper Progress Report 2005*. Washington, DC: IMF.

Levy, S. (2007) 'Public Investment to Reverse Dutch Disease: The Case of Chad'. *Journal of African Economies* 16(3): 439-484.

McKinsey & Co (2007) 'A Cost Curve for Greenhouse Gas Reduction'. McKinsey Quarterly 2007(1).

McKinsey & Co. (2009) *Pathways for a Low Carbon Economy for Brazil*. Rio de Janeiro: McKinsey & Co.

Mexican Secreteria de Medio Ambiente y Recursos Naturales (2009) *Programa Especial de Cambio Climatico 2008-2012.* Mexico City: Government of Mexico.

Ministry of Environment and Forests, Bangladesh (2002) *Initial National Communication under the United Nations Framework Convention on Climate Change (UNFCCC)*. Dhaka: Government of the People's Republic of Bangladesh.

Ministry of Environment and Forests, Bangladesh (2005) *The National Adaptation Programme of Action (NAPA)*. Dhaka: Government of the People's Republic of Bangladesh.

Ministry of Environment and Forests, Bangladesh (2008) *Bangladesh Climate Change Strategy and Action Plan*. Dhaka: Government of the People's Republic of Bangladesh.

Movement for Ecological Learning and Community Action (2008) *Rapid Assessment of Biofuels Development Status in Ethiopia and Proceedings of the National Workshop on Environmental Impact Assessment and Biofuels*. Addis Ababa: MELCA Mahiber.

Nigeria National Planning Commission (2009a) *Vision 2020 National Technical Working Group on Environment & Sustainable Development*. Abuja: Government of Nigeria.

Nigeria National Planning Commission (2009b) *Vision 2020 National Technical Working Group on Agriculture & Food Security*. Abuja: Government of Nigeria.

Nigeria National Planning Commission (2009c) *Vision 2020 National Technical Working Group on Energy Sector*. Abuja: Government of Nigeria.

Nigeria National Planning Commission (2009d) *Vision 2020 National Technical Working Group on Manufacturing*. Abuja: Government of Nigeria.

Nigeria National Planning Commission (2009e) *Vision 2020 National Technical Working Group on Transport*. Abuja: Government of Nigeria.

Office of the President of Guyana (2008) *Creating Incentives to Avoid Deforestation.* Georgetown: Office of the President.

Office of the President of the Guyana (2009) 'Low Carbon Development Strategy: Transforming Guyana's Economy While Combating Climate Change'. Draft for Consultation.

Office of the President, Republic of Guyana (nd) "Stimulating Growth in the Business Processing Outsourcing Sector" . Unpublished document.

Overseas Development Institute (2008) *Achieving Green Growth in a Carbon Constrained World*. Background Note. London: ODI.People's Republic of China's National Development and Reform Commission (2007) *China's National Climate Change Programme.* Beijing: Government of the People's Republic of China.

Sisay, A. (2009) 'Ethiopian PM Underlines Biofuels as Crucial for Combating Climate Change'. 22 June, http://en.afrik.com/article15830.html.

South Korean Ministry of Environment (2009) *ECOREA 2008.* Seoul: Ministry of Environment.

Steinmeier, F. and S. Gabriel (2009) ‘A Growth Strategy for Germany: New Jobs Through Investment in Energy and the Environment’. Strategy Paper on the occasion of the IVth Innovation Conference. Berlin, 22 June.

Stern, N. (2007) *Stern Review on The Economics of Climate Change*. London: HM Treasury.

Stiglitz, J., A. Sen and J.P. Fitoussi (2009) ‘Report by the Commission on the Measurement of Economic Performance and Social Progress’. September.

The Climate Group (2009) *Breaking the Climate Deadlock: Cutting the Cost. The Economic Benefits of Collaborative Climate Action*. London: The Office of Tony Blair

Tol, R. (2009) *An Analysis of Mitigation as a Response to Climate Change.* Copenhagen: The Copenhagen Consensus Center.

Tol R., T. Callan, T. Conefrey, J. Fitzgerald, S. Lyons, L. Valery and S. Scott (2008) *A Carbon Tax for Ireland.* Working Paper 246. Dublin: ESRI.

UK Department for Energy and Climate Change, Department for Business, Enterprise and Regulatory Reform and Department for Innovation, Universities and Skills (2009) *Investing in a Low Carbon Britain*. London: DECC, BERR and DIUS.

UK Department for Energy and Climate Change and Department for Business, Enterprise and Regulatory Reform (2009) *Low Carbon Industrial Strategy: A Vision*. London: DECC and BERR.

UK Department for Environment, Food and Rural Affairs (2006) *Climate Change: The UK Programme 2006*. London: DEFRA.

UK Department for Environment, Food and Rural Affairs (2008) ‘UK Climate Change Programme’. Annual Report to Parliament, July.

UK Office of Climate Change (2008) *Climate Change: Financing Global Forests: The Eliasch Review*. London: UK Office of Climate Change.

UN Conference on Trade and Development (2009) *Trade and Development Report 2009. Responding to the Global Crisis – Climate Change Mitigation and Development*. Geneva: UNCTAD.

UN Development Program (2007) *Human Development Report 2007-08: Fighting Climate Change: Human Solidarity in a Divided World.* New York: UNDP.

Weeks, J. (2008) *Is a ‘Resource Curse’ Inevitable in Resource-Rich Countries?* Development Viewpoint 13. Washington, DC: CEPR.

World Bank (2009) *World Development Report 2010: Development and Climate Change.* Washington, DC: World Bank.

DFID Department for International Development