Claim No. QBD-2022-BHM-000044

IN THE HIGH COURT OF JUSTICE
QUEEN'S BENCH DIVISION
BIRMINGHAM DISTRICT REGISTRY

BETWEEN:

(1) HIGH SPEED TWO (HS2) LIMITED
(2) THE SECRETARY OF STATE FOR TRANSPORT

Claimants

- and –

PERSONS UNKNOWN & OTHERS

Defendants

BUNDLE D
(Volume G)
for hearing on 26 and 27 May 2022

TAB	DOCUMENT	PAGE
37	D36 (Mark Keir) Submissions dated 16 May 2022	D2669-D2916

DLA Piper UK LLP
1 St Paul's Place
Sheffield
S1 2lX

Telephone: 0114 283 3312
Email: HS2Injunction@governmentlegal.gov.uk
Reference: RXS/380900/378

Solicitors for the Claimants

Heavy and unnecessary police presence (29 officers counted) – and no social distancing. Protestors had asked HS2 to produce a bat licence but they had not been able to – because of this the protestors tried to stop the illegal felling of a tree. 7 people were arrested for trying to stop illegal activities.

https://www.facebook.com/HS2rebellion/photos/a.116023260094015/195832435446430/

HS2 social distancing

5 June 2020. Video stills.
A protestor climbs onto a branch to stop the felling of a tree, after asking for proof that HS2 have access to the land they have expanded onto. HS2 were not able to supply any maps or paperwork to prove their ownership. They were not able to either supply a bat licence for felling this tree.
During this action HS2's contractors NET, risked the life of the protestor, who was not on or inside the contested land. After chopping the branch down while he was on it the protestor had to be taken to hospital.
The police were called by the protestors during this incident but didn't arrive at the site – HS2 security told them they were not needed.
The video ends after the chainsaw is started up but before the branch is cut – the camera person stopped filming due to the danger to herself, as well as the protestor.
https://www.facebook.com/HS2rebellion/videos/2607123479565683

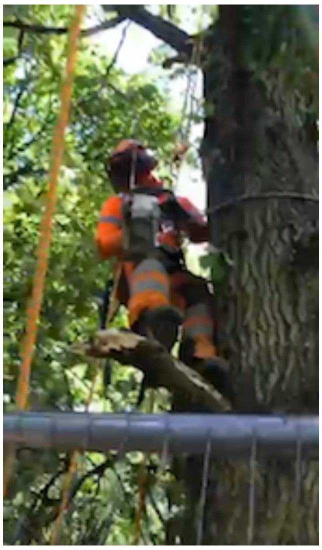
   

D2670









Protestor restrained by NET for half an hour, for no reason, and then arrested. This protestor had already had his finger broken and disfigured by the same NET officer.
Facebook-24th May 2020 – Video stills.




https://www.facebook.com/HS2rebellion/posts/150059286690412

12 May **Violent Evictions During the COVID Pandemic**
Illegal eviction without court order, plans, maps or proof of ownership. Undertaken without police presence.
NET tied up one protestor, and respected no social distancing.
https://www.facebook.com/HS2rebellion/videos/2651368548480981

Additional supporting material: Document 2-Update –
(<u>See with other additional supporting material: 1.Supporting information-Images</u>)
Images and video stills and links to video.

Statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

HS2 – visual reference - images and video stills including web-links

The issues highlighted in this document, in support of Stop HS2 protestors, Mark Keir, et al, relate to and are relevant to the issues raised in this Injunction case and potentially other related cases against HS2 Ltd. This information is to be considered with other supporting statements and the Relevant Reports.

Events illustrated in Supporting Douments-Images 1&2 include:
Illegal evictions.
Arrests when protestors were trying to stop illegal activities.
Attacking and unnecessarily restraining protestors.
Endangering protestors lives through illegal and reckless behaviour.
Destruction of bat nesting sites without a licence and during nesting season.
Destruction of birds nest and birds while destroying hedgerows during nesting season.
Covering of animal burrows.
Destruction of woodlands and the unnecessary shredding of timber to possibly destroy evidence of illegal activities.
Pollution of water through digging or drilling into the aquifer in the Colne Valley.
Concerns and serious worries raised by those living and working in the path of HS2 – including a local farmer, worried about its impact on his water supply.

Contents:

1. Violence against protestors & Stopping legal protest p2-12
2. Environmental impact and concerns p13
3. Impact on population – public responses p14-15

See also broad range of video and photographic reference available at:
• Documentary film maker William Watson: https://vimeo.com/user74680141
• https://www.facebook.com/groups/278249462657115
• https://www.facebook.com/HS2rebellion
• Photo-journalist Mark Kerrison: https://www.markkerrison.com/archive

1, Violence against protestors

HS2 tree protector's fall at Denham Country Park – support line removed.





image ref: Protestor cut from support-Denham 2020-07-24
Female protestor, suspended above the river had her support line cut by HS2 security and fell, while police stood by and watched.
(see also similar action below)
https://vimeo.com/441875390

Heavy police presence and heavy-handed police tactics at the above event. - Denham24.7.20

Police arresting protestors for documenting HS2's illegal and unnecessary activities – here cutting down a 400-600 year old tree without proper environmental checks or bat licenses, during nesting season.

<u>Denham Country Park - police man-handle protestor for no reason -</u> <u>14 july 2020</u>

https://www.facebook.com/HS2rebellion/videos/1673622762801702/
posted 14 july 2020
"One of our Tree Protectors being UNLAWFULLY grabbed and handled by the Police
The law states -"If a Police Officer restrains a man, for example by grabbing his arm or his shoulder, then his action will also be unlawful, unless he is lawfully exercising his power of arrest."
Here the Police Officers physically handle one of our Tree Protectors without placing them under arrest or stating why they are physically moving them. This action is UNLAWFUL and UNJUST!"

<u>HS2 security attack protestor while he is documenting HS2 illegal activities – destroying a tree with nesting animals.</u>

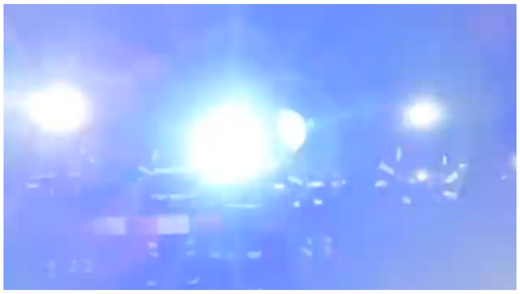
Mark Kerrison photographs – Denham CP
Date: July 2020 (posted on Facebook) - https://www.markkerrison.com/archive

<u>Illegal arrest of protestor by plain-clothed police, on a public footpath, for breaching an injunction which he was not doing.</u>

https://vimeo.com/445372890

<u>Flashing lights at protestors on a highway – strobe lighting - 26.7.20</u>





https://www.facebook.com/jacob.harwood.18/videos/2719156305075841/

Use of bright lighting, powered by a noisy generator, to disturb and keep protestors awake at night.

image ref: bright lights Denham1 2020-07-24 (See similar activity below)
Use of bright lighting, powered by a noisy generator, to disturb and keep protestors awake at night. Lights on South Bucks land, being used by HS2, and projecting onto land outside of HS2 control.
Video link:

D2678

<u>MET Police racially profiling HS2 activist</u>

MET Police racially profiling HS2 activist

https://vimeo.com/441604514

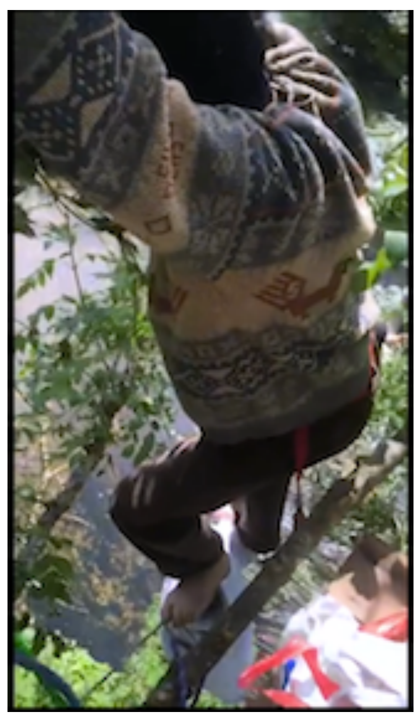
Protestor documenting HS2 illegally cutting down tree and HS2 activities while a protestor was in the tree. (see below). Only person arrested for no known reason.

<u>HS2 Endangers life – Protestors life put at risk.</u> <u>23.7.20</u>

HS2 Rebellion Activist fall from tree

More from William Watson

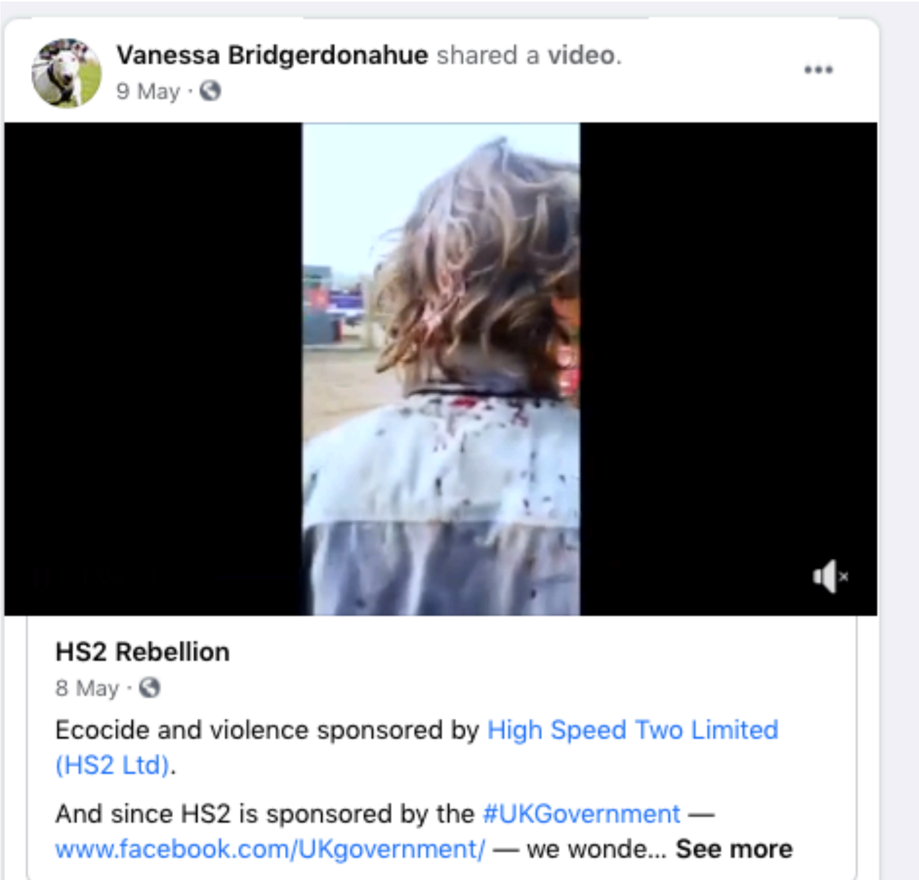
Autoplay next video





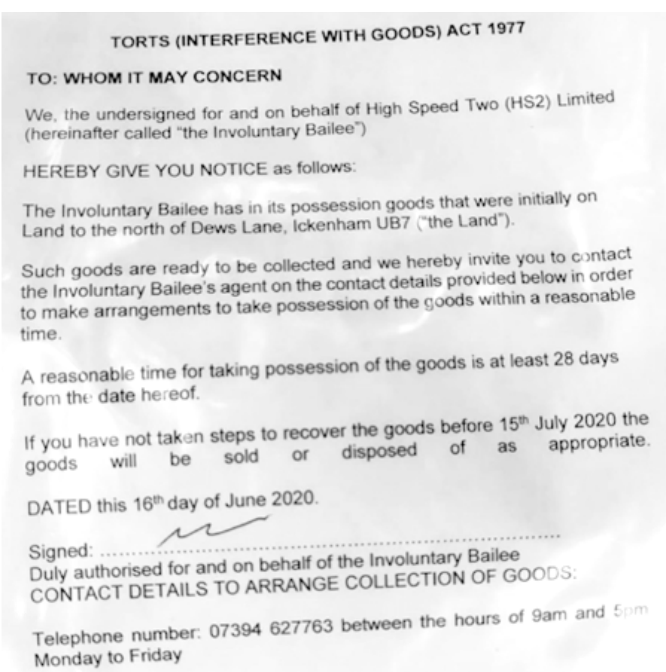

HS2 Train line Lowered a cable without ensuring the safety of the HS2 rebellion activists and which lead to one of them falling and being taken to the hospital. Denham Country Park 23.7.20 - **while being watched by police, ambulance and fire services. He injured his leg and was taken to hospital.**
[**https://vimeo.com/441277465**](https://vimeo.com/441277465)

D2680



Facebook : StoppingHS2, 8 May 2020. Protestor has his head cut open by HS2 security at Harvil Road.

<u>NET withhold possessions and lie to protestors –</u> <u>18.6.20</u>
<u>Possessions still not returned</u>



TORTS (INTERFERENCE WITH GOODS) ACT 1977

TO: WHOM IT MAY CONCERN

We, the undersigned for and on behalf of High Speed Two (HS2) Limited (hereinafter called "the Involuntary Bailee")

HEREBY GIVE YOU NOTICE as follows:

The Involuntary Bailee has in its possession goods that were initially on Land to the north of Dews Lane, Ickenham UB7 ("the Land").

Such goods are ready to be collected and we hereby invite you to contact the Involuntary Bailee's agent on the contact details provided below in order to make arrangements to take possession of the goods within a reasonable time.

A reasonable time for taking possession of the goods is at least 28 days from the date hereof.

If you have not taken steps to recover the goods before 15th July 2020 the goods will be sold or disposed of as appropriate.

DATED this 16th day of June 2020.

Signed: ....
Duly authorised for and on behalf of the Involuntary Bailee
CONTACT DETAILS TO ARRANGE COLLECTION OF GOODS:

Telephone number: 07394 627763 between the hours of 9am and 5pm Monday to Friday

The net gave a document telling activists that their belongings are ready for pickup no they claim they are not ready any more. 18.6.20 HOAC
https://vimeo.com/430402535

<u>Water cut off and non-violent protestors attacked – both illegally</u>. At this time the water was on land not owned by HS2, nor did they have the right to close the road. 22.5.20

With Looming eviction from the HS2 Rebellion Harvil Road Protection Camp, HS2 closed Dews Lane denying the protectors the right to water. Larch Maxey again peacefully watches his son get choked and assaulted by HS2 bailiffs – himself also assaulted and laying here on the ground.
https://vimeo.com/421671629

https://vimeo.com/419930316

<u>Harvil Road – Illegal eviction.</u>

Protestor describes being attacked by NET - NET bailiffs assault a peaceful protestor at Harvil Road Stop HS2 camp.

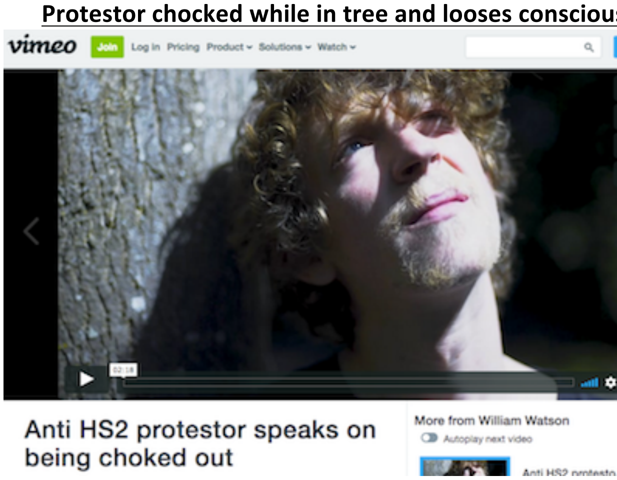
Uploaded/recorded 12.5.20

https://vimeo.com/417640198

See also supporting material1 and:

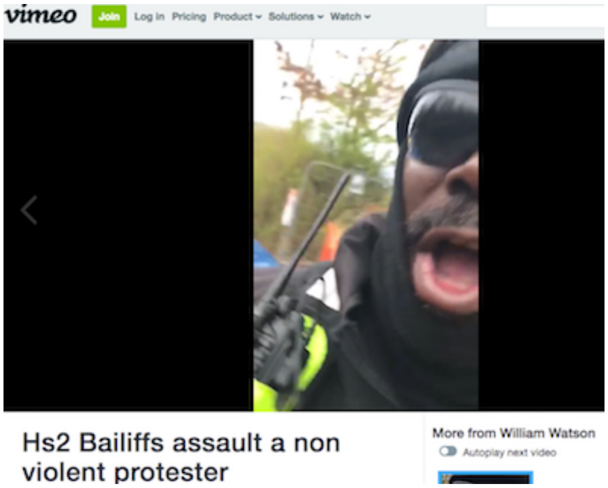
https://vimeo.com/417504558

<u>Protestor chocked while in tree and looses consciousness – he and his father speak about the attack.</u>



https://vimeo.com/416868476

<u>**Hs2 Bailiffs – NET – assault a non violent protester -** 6.4.20 7.17</u>

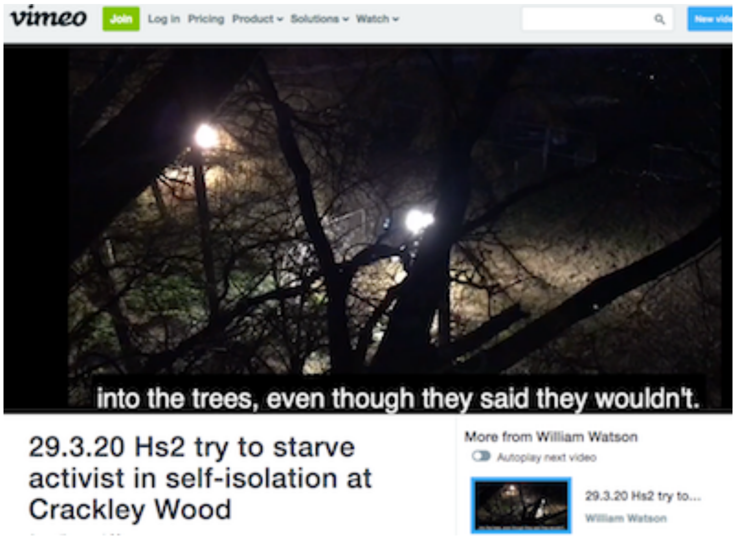


Crackley Wood 6.4.20 7.17 am A Hs2 bailiffs assaults a non violent protestor on a public roadway and also endangers her life by not observing the 2 meter distance
https://vimeo.com/404505061

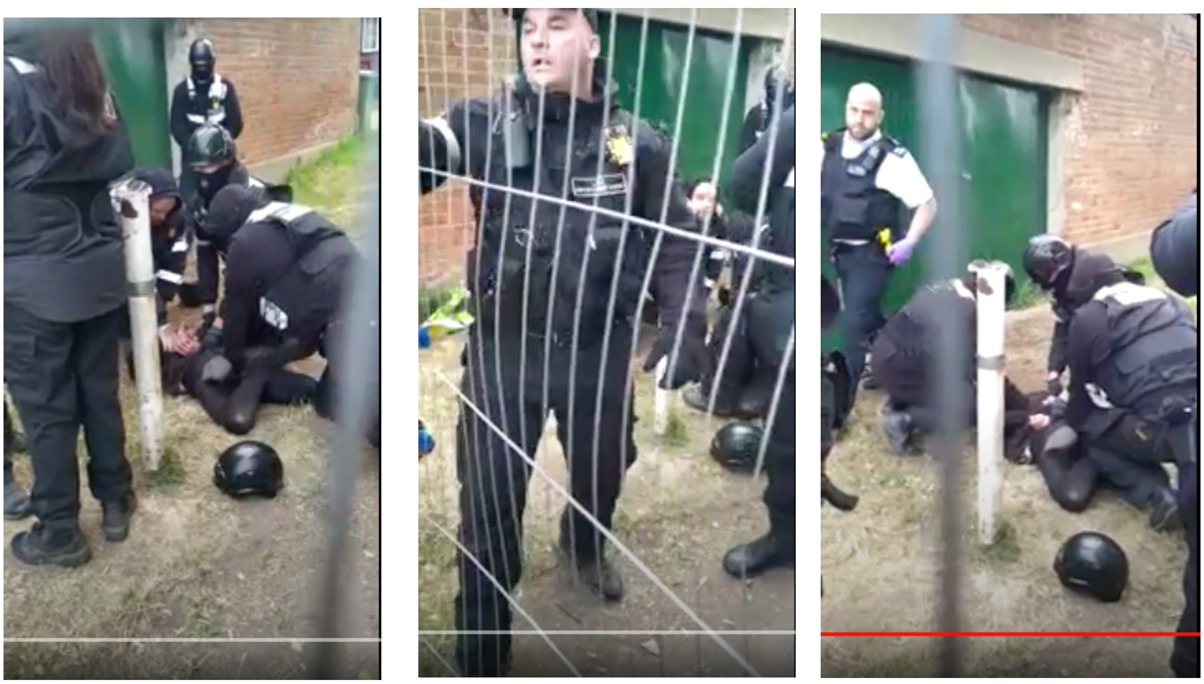
HS2 put lives at risk - 28.3.20

28.3.20 Extinction Rebellion activist Larch Maxey on day 4 of the eviction attempt by the Nation Eviction Team speaks about his health being put at risk where HS2 bailiffs are trying to starve him out of his treehouse residence at Crackley Wood during his COVID-19 self-isolation.
https://vimeo.com/401617128

Connected to the above video
Withholding food and water and shinning bright lights and using noise/generator to keep the protestors awake at night.



Extinction Rebellion Activist Larch Maxey speaks about Hs2 bailiffs bring to get to him to leave his treehouse where he is self-isolating during the UK corona virus Lockdown. Hs2 bailiffs are denying the four in isolation food and water.
https://vimeo.com/401912496



NET restrain a protestor for around 25 minutes, face down on the ground. Dews Lane.
Facebook – StoppingHS2 (Date to be checked)

#STOPPINGHS2

Hayley Marie shared a **live video**.
17 May ·

Hayley Marie was live.
17 May ·

25 10 comments 5 shares

Stalking Protestors - HS2 security and NET follow protestors along a public road for no reason. Facebook – stoppingHS2 : 17 May 2020.

<u>Environmental Damage – see also supporting image document 1 – and for a comprehensive forecast of HS2's impact see – Wildlife Trusts, *What's the Damage?* Report (Jan 2020)</u>

water contamination Harvil Road - accessed 10.8.20
(see also supporting material-images 1.)
https://hs2rebellion.earth/2020/07/30/water-contaminated-by-hs2-drilling-activities-at-harvil-road/?fbclid=IwAR2PLybkxWbhhUid8ixW9If_wjiUYxpN1ck5Actv7bsTGuJfafIggYcss9o

Since the end of July, HS2 works at Harvil Road, Uxbridge, has turned stream water white showing evidence of the harm that is being inflicted upon an important water bearing aquifer. What can't be seen, yet, is the result of the irreparable damage that HS2's reckless disrespect for this vital water source will have, on us all.

<u>Wendover 1.5.20</u>

https://vimeo.com/417688871

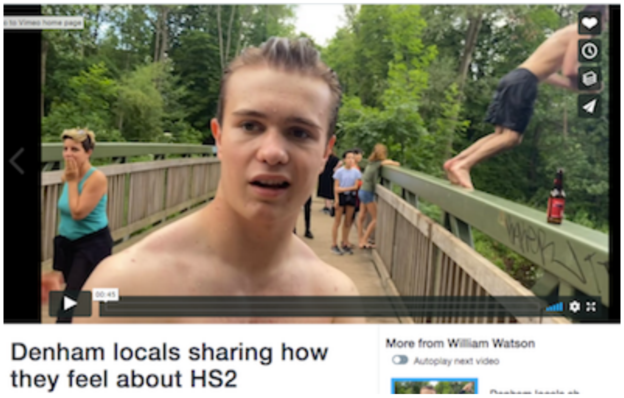
Facebook – StoppingHS2 - Blocking animal burrows. 28 April 2020

<u>Public Responses to HS2</u>

<u>Amanda - 17.7.20</u>

Local North Acton Resident who lives adjacent to HS2 Old OakCommon Station speaks about her medical illness and how she believes she got it by air pollution that was produced by HS2. 17.7.20
https://vimeo.com/439785122

<u>**Denham locals sharing how they feel about HS2 -** 13.6.20</u>

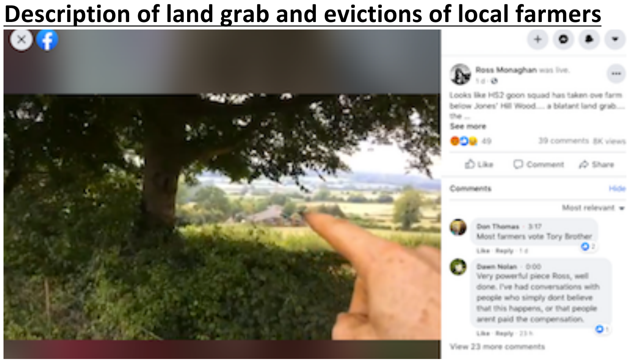


13.6.20 Denham Country Park. Local Denham youth take a short break from jumping off a bridge to share how they feel about the HS2 train project.
https://vimeo.com/428943673

6.4.20 James Brown at Broadwell Wood – concerns about HS2 social distancing and NHS.

6.4.20 James Brown at Broadwell Wood where he voice his concerns for the NHS and how HS2 is disregarding the 2 meter rule. NHS ICU nurse Shirley Watts intimately share how the NHS is 'on our knees.' https://vimeo.com/404662848

Description of land grab and evictions of local farmers

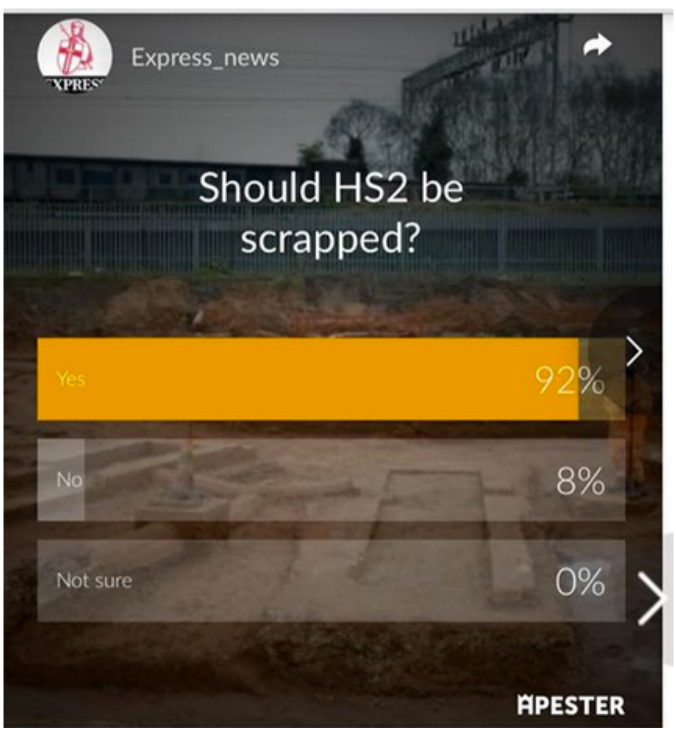


https://www.facebook.com/ross.monaghan.35/videos/10160096278209992/

Couple lose seven year battle to save their dream home from HS2 bulldozers – 29.7.20

Ron Ryall at the period farmhouse he tried to save

A couple facing eviction because of HS2 have lost a seven year battle to save their dream home from the bulldozers.
Anne and Ron Ryall, who spent years restoring a period farmhouse at Harefield, west London, have been told they must leave on Friday.
The 400-year-old red brick house in the picturesque Colne Valley is on the route of the £106bn high speed railway.
https://www.itv.com/news/london/2020-07-28/harefield-couple-lose-seven-year-battle-to-save-their-dream-home-from-hs2-bulldozers?fbclid=IwAR1sKhoC0K_XsMyEW96JqqDD88pGBo7NfNYLLfq3E-rTvPXhfNkEdXHYjVg



Express Newspaper poll – May 2020
https://www.express.co.uk/news/uk/1283375/hs2-cost-price-high-speed-rail-coronavirus-cost-to-the-economy-commuters-working-from-home

D2691

Seven Arguments against HS2

This memo advances several arguments for scrapping HS2, and in particular takes issue with its claims to save CO2. It draws partly on the dissenting report published by Lord Berkeley, who was Deputy Chair of the Oakervee Review on which the Government relied in deciding to approve HS2. It is worth noting the misgivings of many about the Oakervee Review. For example Lord Berkeley states 'Given the noted specific areas of interest of the panel, and that the Chair was a former Chair of HS2, with the secretariat drawn largely from DfT officials, some of whom were previously working on HS2, it is difficult to argue that the Review was "independent".[1]' In December 2020 he added: 'on 14 December, Doug Oakervee explained what drove the panel to reach its conclusions earlier this year. His revelation is shocking … stripped down to its bones Mr Oakervee says the needs of the Construction Industry were a major driver for proceeding[2].'

Lord Berkeley also states **'I believe that Parliament has been seriously misled by the failure of HS2 Ltd and by ministers to report objectively and fairly on costs and programme changes.[3] '**

1 There is no CO2 benefit to HS2

HS2 has been presented as saving CO2 as it would carry people who would otherwise fly or drive and would free up capacity elsewhere on the rail network. The claim is 'HS2 will provide a cleaner, greener way to travel.' In practise however the project is predicated on speed, not CO2 saving, and you can't do both.

Supporters of HS2 point to the hope that it will enable freight and passengers to shift from road and plane to rail. HS2 Ltd has put a figure on this saving, stating that over 120 years it will save 307,000 tonnes of CO2. However HS2 has put the CO2 cost of construction as 1,451,000 tonnes of CO2, a figure 4.7 times greater than all the CO2 savings they hope to achieve[4].

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[1] Berkeley para 1.3

[2] https://www.tonyberkeley.co.uk/#xl_xr_page_hs2

[3] Berkeley p7, Summary and conclusions

[4] High Speed Two Phase 2a Information Paper E27: Carbon, Last updated 2 September 2019, Table 2: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/828986/E27_Carbon_v1.2.pdf

The footnotes to this table are these:
10 The use stage is a net carbon emission figure, which includes a carbon sequestration benefit from tree planting estimated to be -144,000 tCO2e over 60 years and -174,000 tCO2e over 120 years.
11 The benefits and loads stage is the net carbon emission figure, which includes loads (i.e. increase in carbon emissions) from additional surface access journeys to access the Proposed Scheme, and benefits (i.e. reduction in carbon emissions) from freight and passenger modal shift

D2692

That should be the end of the argument about HS2's claim to be "a cleaner, greener way to travel" – and yet HS2 and its supporters still make that claim.

HS2 also admits that running HS2 over 120 years generates 315,000 tonnes of CO2 - which itself exceeds the 307,000 tonnes saved by modal shift from road to rail.

Here are some reasons why HS2 does not save CO2:

(a) High speed needs enormous amounts of electricity, estimated by HS2 as an extra 67% of the energy consumption of the entire existing UK railway network[5].

(b) A high speed line on new land needs massive engineering: a massive concrete slab base, extensive tunnelling, huge concrete bridges.

(c) Research shows only 4% of HS2 passengers would otherwise make that journey by car, and only 1% of HS2 passengers would have flown. In fact it will actually facilitate air travel rather than replacing it, as it will serve Birmingham and Manchester airports, and will run very close to East Midlands Airport. It is actively being lobbied for by those airports, along with Leeds Bradford Airport, who all state that HS2 is 'essential' for their plans to expand international aviation.

(d) HS2 does little or nothing to ameliorate one major failing of the rail network – the lack of connectivity across Britain. Lord Berkeley states 'Large journey time reductions… only apply to those cities served by HS2, and not others, such as Nottingham and Derby… because of poor locations of HS2 stations.'[6] For example Birmingham New Street is an important modern rail hub not just for the Midlands but with direct trains to cities including Southampton, Plymouth, Cardiff, Liverpool, Glasgow, Edinburgh, Newcastle, Manchester, York and London…but HS2 will not stop there but at its own new station, Curzon Street, about a mile away.

(e) As many HS2 stops will be in 'parkway' locations, more car journeys will be required to access them.

(f) It has been argued HS2 would enable the expansion of rail freight. The suggested benefit is that if the West Coast Main Line (WCML) ran fewer express trains (those passengers being served by HS2), then the WCML could put more freight trains in its schedule without affecting passenger trains. This is strongly disputed[7]. Lord Berkeley's dissenting report states: 'HS2 Ltd claims to free up capacity for rail freight,

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[5] A 2018 KPMG report called HS2 Electricity Strategy (https://www.whatdotheyknow.com/request/487395/response/1177578/attach/4/FOI18%202020%20Annex%20A.pdf?cookie_passthrough=1) includes this graph:

[6] Berkeley para 5.6

[7] http://stophs2.org/news/18285-nearly-no-modal-shift-hs2

but DfT's actions to date mean that this may be just an illusion, as there is no firm policy evidence of what any freed-up capacity will be used for and the extent to which this will be allocated for rail freight'.[8] Moreover, as there are 15 stations along the WCML between London and Birmingham, including Watford, Northampton, Rugby and Coventry, all needing fast services and none of them served by HS2, there are doubts whether the provision of fast trains can be reduced enough to enable a significant expansion of freight at all.

(g) In fact there is a requirement in the HS2 business case for £11.1bn of cuts to existing services. So building HS2 means losing existing trains and potentially losing connectivity for towns and cities not along the HS2 route. (For example when HS2 was first announced, official documents showed it was planned that Coventry lose two of its three fast services to London.)[9]

(h) More people are working from home and attending meetings remotely - a trend all major employers are confirming will continue after the Covid pandemic. The capacity problems HS2 was intended to help solve have thus already been greatly reduced.

(i) The most complete answer to the argument that HS2 expands capacity is Lord Berkeley's conclusion:

'HS2 is the wrong and expensive solution to "making it faster and easier to travel for work and leisure" by providing better North South intercity services. Many more people travel to work and leisure on local or regional services, and those in the Northern Power House (NPH) and Midlands Connect (MC) areas are some of the worst in the country. There is strong evidence that the greatest need and demand for improved rail services is within the regions, in particular the NPH and MC areas, since services to and from London are of better quality, and that HS2, apart from its Northern end within the NPH area, does not help this much. Its stated aim of providing better North-South links is just as likely to attract more jobs from the regions to London than the other way round.'

So, in a nutshell, if the aim is to increase capacity and get people out of their cars, HS2 is not the way to do it.

[8] Berkeley para 2.10

[9] Stop HS2 Submission to the Oakervee Review

2 We cannot afford it

Even if we could have afforded HS2 once, we can't afford it now, with the UK in the worst recession for a century and Chancellor Sunak looking for services to cut and taxes to raise.

Recent cost estimates lie between **£106 billion** (leaked report from Oakervee, Feb 2020) and **£170 billion** (press release by Lord Berkeley, 3rd November 2020[10]). Neither of these figures includes the cost of the actual trains. Moreover costs invariably increase during a major project as technically challenging as this. If it comes to £170 billion, that is more than the government's annual spend on the NHS, and more than twice its annual spend on schools. And each taxpayer from Lands End to John O'Groats is chipping in an average £5610 to build it.

Although a huge saving could be made by stopping the project after Phase 1 (London - Birmingham), this would be the most senseless and wasteful outcome of all. Both Oakervee and Berkeley agree the project would make no sense at all if only Phase 1 was completed.[11]

Lord Berkeley is highly critical of the costing and benefit estimates submitted to the Oakervee Review, and concludes 'the Benefit Cost Ratio could fall to 0.6:1, and therefore rank 'poor value for money' when using the Treasury Green Book. This means that the taxpayer would receive only 60p of return for every pound that is spent on the project'.[12]

3 There is no 'jobs' argument for HS2

It appears HS2 will only create 2,500 net jobs (22,000 created[13] minus 19,500 jobs that HS2 admits would be displaced[14]), which means a cost of £40 million per job. At a time when numerous industries need massive government support to avoid collapse, this is insane. Also the 22,000 new jobs are mostly only for the duration of the construction.

[10] https://www.tonyberkeley.co.uk/index_htm_files/rh201103%20Tony%20Berkeleys%20HS2%20Update.pdf: "The HS2 gravy train goes on; whereas DfT ministers try to cut back or delay expenditure on other new rail projects, including those most needed in the Midlands and North, nobody seems to care about the still escalating costs of HS2, the ongoing environmental destruction and whether the demand is still there; and of course whether the country can afford such a vanity project."

[11] 'Phase One as a standalone scheme makes little sense' (Oakervee paragraph 2.8)

[12] Berkeley para 5.2

[13] https://www.bbc.co.uk/news/business-54010727

[14] High Speed Rail Working Draft Environmental Statement Volume 3: Route-wide effects, October 2018, Table 35 (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/746554/HS2_Phase_2b_Working_Draft_ES_Volume_3_Route-wide_effects.pdf)

D2695

4 It can be cancelled now

One of Oakervee's main arguments for continuing with the project was the cost to the country and especially the construction industry if it was cancelled. The jobs the project creates are absurdly expensive. As regards the argument 'we have spent so much on it we might as well finish it', the sums spent so far only seem enormous if you ignore the context of the immensely greater sums yet to be spent. Bearing in mind that not a single tunnel or station has so far been constructed, no signalling installed, not a single piece of track laid, not a single train ordered – the large sums spent so far are a drop in the ocean compared to the sums still to be spent, on a project we do not need and can no longer afford. Berkeley lists a number of schemes to improve the network that 'are being developed in conjunction with Network Rail and former railway people; a number are 'shovel ready' and so could be started at an early date to provide some opportunities to the construction industry in place of building HS2.'[15]

A YouGov poll[16] of May 2020 showed public support for HS2 to have dropped to 28%. The figures are evenly spread across party preferences, and **it is even less popular in the North than in London**. In the present climate it is unlikely support will increase.

5 The most environmentally damaging construction project in European history

Building for high speed requires the line to be straight and undeviating. HS2 goes straight through 693 local wildlife sites, 108 ancient woodlands, 33 SSSIs. To allow trains to travel at 250 mph, the area of felling and clearing required each side of the track is massively wide. The technical specifications prescribe 75 metres from fence to fence. That is about the width of Parliament Square Gardens. In addition the construction access roads for such a project cause as much damage as the line itself.

At a time of climate and ecological breakdown, further degradation of the UK's catastrophic biodiversity loss is unacceptable. There are numerous cases of HS2 felling trees beyond its designated area and ignoring legally required permissions such as bat licences before destroying habitats. The network of species making up essential ecologies is destroyed even when only parts of a protected area are damaged. HS2's careless planting of saplings is no substitute, and the saplings frequently do not survive as HS2 pays no attention to them after planting.

Not surprisingly HS2 has been called out by environmentalists such as Chris Packham and environmental charities including CPRE, RSPB, The Woodland Trust and BBOWT.

[15] Berkeley para 6.7

[16] https://yougov.co.uk/topics/politics/survey-results/daily/2020/05/18/31266/2

6 UK does not need high-speed trains

Compared with continental high-speed trains, the distance from London to Birmingham does not justify a high-speed line. Continental high-speed trains often go 300 miles without stops, which reduces overall timings and makes them worth it.

7 HS2 is not the answer

The billions spent on HS2 at a time of financial crisis will make it far less likely money will be found for the two things the UK really needs to meet its climate change obligations: a coherent national public transport network to reduce dependency on cars, and high-speed broadband to reduce the need to travel at all. If HS2 is scrapped, a smaller expenditure properly directed could achieve a far greater benefit, and far less damage.

Further Reading

Lord Berkeley's dissenting report (5th January 2020) and the press releases on his website www.tonyberkeley.co.uk are very useful. For example it goes into detail on cheaper, far more effective alternative strategies to building HS2: https://www.tonyberkeley.co.uk/index_htm_files/rh200105%20Dissenting%20report.pdf

The http://stophs2.org/ website

Account by Simon Jenkins of the project's political background (7th June 2016): https://www.theguardian.com/uk-news/2016/jun/07/hs2-the-zombie-train-that-refuses-to-die

George Monbiot article (17th May 2010): https://www.monbiot.com/2010/05/17/fast-train-to-nowhere/

My Statement in support of the defence against the claim.
QB-2022-BHM-00044,HS2 Ltd & SOS For TransportVPersons
Unknown and Ors

My name is Brenda Bateman .
My address is 120 Rowland Way
,Aylesbury Bucks .

I am a retired HLTA at Secondary School
I have lived in Aylesbury all my life.
Really care about nature and the environment
Love all animals

1) My first grievance against HS2 is despite going to their meeting at our local community centre we were given incorrect information.We were told that footpaths would not be closed and we would still be able to walk there. This was particularly important during lockdown.We were able to go out on walks and this helped people with their mental health.Then the fences were put up every week more and more We were told we would be trespassing and could be arrested.More footpaths closed nowhere to walk .We were told they would be closed till 2024 Locals very angry nowhere to take children walk dogs for peace and quiet.

2) Having lived and worked here all my life I am devastated on a daily basis by the destruction HS2 is causing. So many trees and hedges ripped out and felled some of them hundreds of years old.These are replaced by huge concrete compounds .These can not be replaced by saplings.So many areas destroyed.Breaks my heart seeing wildlife displaced and trapped by huge fencing.Hs2 are supposed to survey trees and hedges for wildlife but they do miss things.If I wouldn't have been able to observe we wouldn't have found the red kite nest in the tree and I fear it could have been felled.We reported it and made sure it was safe until the chicks had fledged.This route injunction would have prevented this. Things do get missed.I think it is so important we are allowed to do this.

3) I am really shocked that so many people have lost their homes and land Compulsory purchase.They have lost their land and homes they have worked so hard for So Wrong .Even if land is taken temporary it will be never returned to what it was.I think they have a right to have their voices heard in protecting what is theirs and totally give them my support.

4) In Buckinghamshire the traffic is often gridlocked. Often road closures pop up without warning.This Affected my daughter's business as she couldn't get to her clients in the villages as both points of entry blocked by Hs2 traffic lights could be sitting there for fifty minutes or more so she had to give up that part as couldn't. get there.

5) I personally feel it is important that we should have the right to peaceful protest and observe .This is important as we should have our concerns heard as it affects our lives.It is heartbreaking to stand watch the devastation happening and helpless to do anything .I think have to here to see for themselves .I have personally stood watched,heard the awful noise as the trees go down.When they fall no empathy for the people protecting the trees the Hs2 workers have cheered.Total lack of respect cheering while people are reduced to tears.The .amount of ancient woodland wildlife areas being destroyed for these concrete compounds is

tragic.We should be protecting and preserving them for our future .Ancient woodlands can not be replaced by saplings.We need to protect our environment .This is especially urgent now in view of our climate emergency.This will probably not affect me .I fear for my grandchildren their children.Hs2is supposed to take traffic of the roads.In my opinion we have more traffic and pollution building it.The damage is irreversible by the time it is built the damage will be done.

6) My last point is If Hs2 are allowed this Route wide injunction where does it stop   ?.We will have lost our right to protect our property,voice our concerns.We will have lost our right to be heard.What will be the point anymore we will lose the right to have a say in our futures. It is our world too, surely we have a right to protect it too.

Brenda Bateman

D2699

Statement in support of the Defence Against the Claim QB-2022-BHM-000044

HS2 Ltd and SoS for Transport v Persons Unknown

Councillor Carolyne Culver, 1 Forge Cottages, Abingdon Road, East Ilsley RG20 7LQ

Green Party councillor and Group Leader, West Berkshire Council and Green Party parliamentary candidate for Chesham and Amersham by-election, June 2021

I believe the following to be a true and honest account:

1.) I supported the protest camp at Jones Hill Wood, near Great Missenden in Buckinghamshire, and visited frequently between June 2020 and June 2021. Having spent much of my career in media and public relations, I assisted the campaign by securing coverage in the national media. I also delivered donations of food, clothing, bedding and climbing equipment from concerned residents in West Berkshire.
2.) I witnessed the National Eviction Team take control of Jones Hill Wood on 1 October 2020, and the subsequent eviction facilitated by the NET and Thames Valley Police.
3.) I believe it was an illegal eviction because there was no eviction notice issued in advance. I did not see an eviction notice and nobody I have spoken to saw an eviction notice.
4.) To my knowledge there has only been one conviction associated with the eviction, despite more than 20 arrests.
5.) I did not participate in tree occupations or lock-ons and was not arrested.
6.) I met many people at Jones Hill Wood including local residents of all ages and backgrounds, ecologists, and the landowner. They were in full support of the protestors who had come from further afield to support them.
7.) I have photographic evidence of a NET bailiff in uniform wearing a black rucksack with two badges sewn on to it – one said 'In my defense I was left unsupervised' and the other said 'Bad decisions make good stories'. In my view this shines a light on their lack of professionalism, laissez faire attitude towards health and safety, and their arrogant attitude that they can get away with it.
8.) There is clear video evidence of a police eviction team officer in a tree repeatedly punching a protestor in the leg.
9.) On 2 October 2020, I approached police on Bowood Lane – approx. 100 metres from the edge of the wood – to speak to them about my concerns that my friend and colleague, Councillor Steve Masters, was being put in jeopardy in his tree house. The tree house had been dismantled, his belongings scattered on the woodland floor, and he was suffering badly from the cold weather. The police told me there was nothing they could do and I should call 101. It was not clear what purpose they were serving standing on a country road while the eviction was taking place 100 metres away.
10.) There is video evidence during the eviction of a police officer asking a local resident to desist from approaching the wood across land owned by local farmer Mr Kevin Bunce. The police officer attempted to physically block the resident from proceeding and said 'if you carry on you could get arrested for trespass'. Mr Bunce intervened to say it was his land, and she could cross it, which she then proceeded to do.
11.) There is video evidence of police in a cherry picker speaking to a protestor. He asks what he is going to be arrested for and they cannot tell him.
12.) These and other incidents during the week-long eviction led me to the conclusion that the police were present at Jones Hill Wood to take orders from others, and did not attempt to

make their own enquiries and judgements regarding the legality of the eviction, ownership of land, justification for making arrests, and so on.

13.) I have no faith in the police as a result of my experiences. My experiences lead me to the conclusion that they prioritise protection of the interests of the state and private companies over the protection of the rights of the individual – in this case the rights of Mr Bunce over his land, and the rights of people to protest.

14.) The state has seized land for the HS2 project and many landowners still have not received compensation. It would be grotesque for the government to also prevent people from protesting against this.

15.) Prior to the eviction and afterwards the protestors undertook wildlife surveys, guided by advice from professional ecologists. They discovered the presence of the rare and protected Barbastelle bat, which did not deter Natural England from granting a licence to HS2 for their felling work. In my opinion the protestors demonstrated more concern for an evidence-based approach to the protection of wildlife habitat than state agencies did. This underscores how essential it is to protect the right to challenge government decisions and the right to protest in this country.

Signed (electronically):

Councillor Carolyne Culver

Defence against the claim QB-2022-BHM-00044

HS2 Ltd & SoS for Transport V Persons Unknown and Others

Dr Denise L Baker
Flat 20 Bartholomew House
4 Southern Row
London
W10 5AG

I am a photojournalist and documentary photographer working on projects that have a social and environmental impact. I have been photographing and writing about the HS2 construction project and its impact on the environment and individual communities for the past two years.

I believe the following to be a true and honest account to the best of my knowledge and experience.

I am making this submission on behalf of myself, and other colleagues covering the HS2 project, and I am here to state that a route wide injunction against 'persons unknown' has wide ranging consequences for journalists covering the story.

1. I have been covering the Stop HS2 campaign for the past two years. This route wide injunction would be highly likely to impact on my work detrimentally, along with that of other journalists.

2. I strongly believe that it will limit our abilities to report fairly on issues related to environmental and community impact and will place HS2 Ltd beyond scrutiny.

3. It also places journalists at risk of arrest and aggressive removal from sites if we are perceived as breaking an injunction. Aggressive responses from HS2 security are already an issue and this would further increase the risk.

4. I have my own experiences of being assaulted by HS2 security employees (either the NET – National Eviction Team, Black Onyx, or Incident Response Team) and have a case against an IRT employee. I have also witnessed assaults on others. A young man who had his jaw broken, young women dragged across the ground by the hair, people kicked on the ground during evictions and the targeting of people of colour and young women).

5. Article 10 of the Human Rights Act: Freedom of Expression states that everyone has the right to freedom of expression. This right shall include the freedom to hold

opinions and to receive and impart information and ideas without interference by public authority and regardless of frontiers.

6. In addition, the government champions the freedom of the press. This was debated in parliament when Extinction Rebellion blockaded the printing presses and stopped national newspaper distribution in September 2020.

7. Since billions of pounds of taxpayer's money is being used to build HS2 and in excess of 250 NDA's (Non-disclosure agreements) are in place[1] it is essential that they be fully accountable to the British taxpayer. A route wide injunction will contravene our rights as journalists to report to the public, will interfere with journalistic integrity, extending an increasingly pervasive 'cloak of secrecy' across the project and outlaw our ability to scrutinise HS2's working practices.

Signed: Dr Denise L Baker

1 https://www.newcivilengineer.com/latest/revealed-the-253-companies-and-public-bodies-to-sign-hs2-gagging-orders-16-11-2020/

Garry's statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd SoS for Transport V persons unknown & Ors

Name : Garry Welch
Address: 18 Bearbrook Place
Aylesbury
HP19 8RN

I believe the following to be a true and honest account to the best of my knowledge.

1. Our environment and economy are in peril. HS2 is destroying nature and inflicting suffering on businesses and property owners. Government is investing in an inept and recklessly run project, offering poor value for money. HS2 will not reach Net Zero by 2050, the pandemic has changed how we work forever and invalidated the business case.

2. The Wildlife Trust claimed in a recent report that "the deep cut HS2 will make across the landscape could stop nature's recovery in its tracks."

3. A number of popular public foot paths have been closed due to work on HS2 with no alternative offered

4. The project has had numerous budget revisions that ever increase which has no benefit to the people it is supposed to be helping only the very few will use this means of transport with fares being unaffordable for the majority of people.

5. Mitigation that has taken place so far has been poorly done & not to a professional standard.

6. The wildlife that has been displaced has had tremendous impact on local habitats across the country which won't be reversed any time soon with HS2 not doing the surveys required on the land before any work has begun.

In conclusion HS2 either needs to be revised or ended all together, from what I have witnessed they have no care for the environment or the local residents & treat us with contempt. These projects have no place in UK especially considering we could have improved much needed infrastructure costing massively less & improving the majority of lives & not just the few percent of people that would use this vanity project.

Signed by (Printed Name)
Garry Welch

D2704

This statement is in support of the Defence against the Claim Q8-2022-BHM-00044, HS2 Lts & Sos for Transport v Persons Unknown and Others.

My name is Sally Brooks of 4 Shepherds Croft, Stroud GL5 1US
I am a self employed Ceramic Artist and Architectural Designer.

I believe the following to be a true and honest account to be best of my knowledge

I became involved with protest campaign against HS2 in 2019 when I realised that over 108 ancient woodlands were going to be partially, or completely felled, for a train line that only took 20 minutes off the journey times from London to Birmingham and would cost Billions of tax payers money. The fact that normally protected species of plants and insects are not mitigated for at all I found very disturbing, at a time of climate emergency when we need to preserve as much wildlife as possible.

I have been actively surveying protected wildlife for the last 2 years, which started when I lived at Jones' Hill Woods in Buckinghamshire in May 2020. There I worked with other protectors to monitor the bats and later on the badger setts, of which there were large numbers north and south of the woods that would be affected by HS2. I became familiar with laws protecting bats and badgers when an ecologist, Eileen Robley, visited Jones' Hill woods in September 2020, and did an induction into surveying for badgers, bats and dormouse. She gave me a signed certificate to say I had undertaken this training. (see document attached). My main concern with the HS2 project was the detrimental affect on the environment and the wildlife. It was, and still is important to try and save the wildlife that HS2 are destroying, by holding them to account and reporting wildlife crimes to the police. This injunction will completely stop any independent surveying to take place and allow HS2 to continue destroying wildlife areas that would normally be highly protected, such as SSSI, bio-diverse active sites and ancient woodlands, with no one able to check if they are carrying out the correct licence mitigations, or any surveys. Natural England (NE) have made it clear that it is not their job to check that ecologists are carrying out work correctly to the letter of the licences that NE issue. So who will be checking, who will be reporting on any illegal felling if 'persons named or unnamed' are not allowed to go into any of the woodlands or SSSI sites without fear of getting arrested. Hypothetically, evidence given to the police showing a wildlife crime taking place on an HS2 site, would then allow the police to arrest the person who has submitted it, as they had been on injuncted land?

Here are five of the many examples of Wildlife crimes and potential wildlife crimes that I helped to stop, that I was a first hand witness to:

1. Incident on HS2 site, close to Rocky Lane, near Jones' Hill Wood, Buckinghamshire.
This took place on the 15th March 2021 Police log number 532 150321

I was able to prevent a wildlife crime taking place on an HS2 site by HS2 workers:
As a preliminary to this episode these are the current laws protecting badgers:
Badgers are protected under the Protection of Badgers Act 1992 that consolidates past badger legislation and, in addition to protecting the badger itself from being killed, persecuted or trapped, makes it an offence to damage, destroy or obstruct badger setts. Where badgers pose a problem, licences

D2705

can be issued to permit certain activities:

HS2 have an organisational licence from Natural England that is route wide and allows qualified Ecologists working for HS2, between 1st July and 30th November to:

-Have construction work no closer than 10 meters away. In normal practice this would be a 30 meter exclusion zone.

-Remove vegetation with hand tools, this includes chainsaws and strimmers.

-Install one-way gates on sett entrances and install chain link mesh over the sett mounds to prevent badgers entering and digging new holes.

-These gates have to remain open for first 3 days then monitored for 21 days before the setts entrances can be filled and covered with chain link mesh if no badgers have been able to return.

On the 7th March 2021 I found an active badger sett close to Rocky lane. I then went back on the 12th March and set up a wildlife cam to capture any badger footage.
While there I saw that HS2 had felled a hedge line, with a heavy tree grabber machine within 5metres of un-gated badger setts we had been monitoring. We had been taking photos with w3w of the sett entrances showing they were open and therefore potentially in use.
On the 13th March I returned to collect the wildlife cam I had put out the evening before and found footage of a badger/badgers entering/ exiting the sett.
On the 14th I logged a wildlife crime onto the police website and have an email as evidence, (see attached) I described the badger sett positions and that the tree grabber had been too close. (This was for the setts further towards the London road not the sett where I had put the badger cam)

-On the 15th March I went back to Rocky Lane to see if they were continuing the felling. When I arrived there around 10am I saw the ecologist walking very quickly along the other side of one of the hedgerows from me. I could also see about 4 men in orange following behind her. As she walked she glanced into the hedgerow, which I presumed was a very quick check for bird's nests. My attention was then drawn to HS2 workers with chainsaws moving towards the hedge with the new badger sett I have discovered. I managed to get to the sett position before them, after a lot of walking back and forth with the security trying to stop me, and sat down and called Thames Valley police. I asked the HS2 security if they could ask if the ecologist could come over and speak to me, but they said they couldn't do that. They asked me to move away and then they would go and ask her. I refused on the grounds that they would simply carry on working if I did and I would then not be able to stop a wildlife crime. On my 2nd call to the police I was given log number 532 150321 and reassured me they took wildlife crime seriously and would have officers there shortly.
On the 3rd time of calling I was concerned for my safety as the tree grabber was very close by, within 5 meters, and HS2 were threatening to remove me- I told them if they touched me that would be assault. I relayed this on the 999 call and soon after the police turned up. As soon as the Police were on site all work stopped and the machinery was moved away, as the HS2 workers knew that working with heavy machinery so close to a member of the public was illegal.
When the Police arrived I was so relieved that I didn't ask them if they were going to talk to the workers about their bad health and safety practices. I was more concerned with proving that there was indeed an active badger sett. I showed the police a W3W photo on my phone that showed the wildlife camera set up, pointing at the sett entrance, and they were able to locate the sett. I said I had footage from just one night before and they agreed it did appear to be active. Then I asked them if I could speak to the ecologist on site as I had been denied that. They went away briefly and came back with the ecologist who was happy to talk as long as I didn't video our conversation. She looked at the sett entrance and agreed to mark an area around the sett that could not be felled.

My conversation with the ecologist was helpful and I felt I could finally speak to someone who seemed to listen to my concerns. She said that the Durham farm bridleway was out of bounds to

D2706

HS2 because of the badger setts located there, until the beginning of July 2021. I also spoke to her about the fact that we had found a very rare species of bat, the Barbastelle at Jones' Hill woods and HS2 were looking to fell half of it without carrying out surveys over the next summer season or putting in any kind of mitigation. She seemed genuinely surprised, and said she was not working in that area. However she would pass on my concerns. She appeared genuinely to care about the wildlife and wanted to keep HS2 within the law, but she had not seen the badger sett that I had found without difficulty, and her inspection of the hedgerows for nesting birds was very hurried, and she could easily have missed them.
I was dismayed to see her 2 weeks later in Jones' Hill woods directing HS2 workers in marking of trees to be felled.

After that I told the police about the other wildlife crime I had reported online on the 14th March and they went to look at it with the ecologist. I was not allowed to go with them, and I was never informed about the outcome.
The Police didn't ask me for the evidence at the time, although I still have it. In retrospect I should have insisted that I send it to them, as now they probably have very little on their records about the incident. I was so pleased to have actually stopped HS2 from destroying a badger sett and a hedgerow, that I was in shock. Of course, the police 'Rocket team' would not have wanted evidence of a potential crime, they didn't contact me for a statement about the incident and I was so concerned about the imminent felling at JHW that I didn't follow it up. I did video this incident on a Facebook live stream (see attached) although some of the footage is missing. This account I wrote in an email to our legal team for JHW at that time (see attached).

2. October 2020 Barbastelle Bats at Jones's Hill Woods (JHW)

During the summer of 2020, when I was living at JHW I started bat surveys at dusk, with another protector, and we identified Barbastelle bat calls. This was very exciting because they are so rare. Kevin Hand, a professional ecologist, witnessed these bats fly out from a tree at JHW 2 nights before the illegal eviction of protestors on the 1st of October 2020.
HS2 deliberately had strong spotlights directly pointing at the oak tree where Kevin Hand had seen/heard the Barbastelle bat leave from. These lights were put up on the 1st October 2020, and those lights stayed there until the Chiltern Conservation Board sent and open letter to Mark Thurston CEO HS2 (see attached) on the 30th October, complaining about these lights, and the disturbance to the bats and other wildlife, that the lights were finally removed. We had previously made numerous complaints about this to HS2 and nothing had been done.

A case against Natural England (NE) taken out by wildlife protestors at JHW, which protesters won, was overturned when HS2 appealed the judgement a week later. However HS2 were forced to carry out far more mitigation measures for roosting bats, than if there had been no one there to challenge them about the lack of survey in this ancient woodland!

3. 30th October 2020, Grims Ditch, Kings Lane, Buckinghamshire

Val Saunders and I were arrested for sitting on top of a chipper outside the gates of a HS2 compound for Grims Ditch. We ended up there in frustration, trying to get the police to take notice of the fact that HS2 did not have a class 4 bat licence which we believed they needed in order to be able to fell the woodland at Grims ditch, which they were doing that day. We had a reply from NE to Eileen Robley, who had asked if HS2 had carried out any surveys or had a class 4 licence. The answer to both of these questions was no they didn't. The police refused to contact Natural England or stop the felling. Previous to this incident protesters, including myself had walked into Grim's Ditch on the 15th October. I sent Eileen Robley Photographs taken with the What3words app on the

D2707

16th October via a link set up for ecology evidence at Jones' Hill Wood. These were photos of badger setts and possible bat roost trees within Grim's ditch, so I believed that there were potential bat roost trees and that HS2 were acting illegally.
When our case came to court we were found guilty of stopping work under the Trades Union Act 241, and our belief that HS2 had committed wildlife crimes was not taken into consideration. I later went on to appeal this judgement, after the successful appeal case taken out by **Sebastian Roblyn,** by way of case stated against a decision of District Judge DJ Dodds (DJ) sitting at High Wycombe Magistrates' Court on 16 March 2021.
The Judgement (Case No: CO/1869/2021)
can be found here -https://www.bailii.org/ew/cases/EWHC/Admin/2021/3055.html

Discussion

15. An essential element of the alleged offence under s241(1) of the 1992 was that HS2 ltd and its contractors were acting lawfully and had a lawful right to fell the tree. To make out their case, the prosecution had to prove that the activity was lawful (compare *Richardson v DPP* [2014] UKSC 8; [2014] AC 635.)

16. As is apparent from the first question posed in the stated case, the DJ found that the felling of the tree might lead to the commission of a specified offence. That finding meant that the prosecution had failed to establish that the activity was lawful. Nonetheless, the judge held that the possibility of the commission of these offences did not mean that the workman did not have a legal right to fell the tree. He relied on the fact that this was a lawful construction project that had been approved by central and local government.

17. At paragraph 16 in *Packham v Secretary of State for Transport* [2020] EWHC 828 (admin) this court held that the HS2 Act does not

> "relieve the … nominated undertaker (or its appointed contractors) of the duty to comply with, for example, the requirements of Parts 3 and 4 of the Conservation of Species and Habitats Regulations 2017 (SI2017No.1012)("the Habitats Regulations") in respect of the protection of species and habitats. As the Respondent properly concedes, this is also self-evident from the terms of the CoCP cited above, compliance with which is mandatory under the EMRs for the construction of Phase 1."

18. It follows that, as a matter of law, it is possible for HS2 appointed contractors to commit wildlife offences. Indeed, at paragraph 6 (dd) of the Stated Case the DJ acknowledged that the HS2 project and scheme did not provide immunity from prosecution.

19. That being so, if, as the DJ had found to be the case, there was evidence that the construction scheme, including the felling of the tree in question, "may have resulted in" wildlife offences then it cannot be said that contractors were acting lawfully or had a lawful right to fell the tree.

The Judgements concusion was that:
'The DJ was wrong to conclude that the felling of the tree was an act that the contractors had a legal right to do and it was not open to him to convict the Appellant.'

The appeal trial (43SP045120) against my conviction at Aylesbury Crown Court took place on 5th May 2022. As part of that appeal case, the Crown served evidence of Stuart Pankhurst, an ecologist. He provided evidence that on 26th August 2020 a tree was found to have moderate roost potential and therefore required further surveys before it could be felled. Mr Pankhurst confirmed this tree was felled without these further checks and without a license from Natural England.
When my appeal case appeared before Aylesbury Crown Court for mention on 11th May 2022 the Crown stated that they no longer resisted the appeal. The Judge ordered the Crown to review all cases that this new evidence was likely to effect. He was critical that the Crown had been in possession of this evidence since the conviction of Ms Saunders and I in the Magistrates Court but it had not been disclosed.

I am now going to put in a complaint against Stuart Pankhurst for poor professional conduct in essentially misleading the court in his first witness statement, via the professional body CIEEM.

4. May 2021 Red Kite Fairford Lys, Aylesbury, Buckinghamshire

I would also like to give another example of wildlife crime prevention on a HS2 site near Fairford Lys, Aylesbury. A woman, living locally in that area had contacted me to say that HS2 were felling trees near the A418 Oxford road and that she and her husband had spotted a Red Kite's nesting in one of the trees that would be felled. I gave them advice to film the birds on the nest (without disturbing them) and then inform HS2 enquires about the nest.
The Red Kite is a schedule 1 listed bird and so both the bird and the nest are protected. Best practice is to leave the birds alone until after the bird nesting season at the end of August. HS2 said they were not aware of the nest so therefore they would have likely continued to fell that tree and destroy a protected bird's nest and their eggs. Luckily the local woman kept monitoring the nest and made sure the birds were not disturbed. The tree was felled as soon as the Red Kite chicks had fledged.

5. June 2021 Bats at Fairford Lys, Aylesbury, Buckinghamshire

A small group of protectors carried out bat monitoring (02/06/21) and we were able to identify and video Soprano Pipistrelle bats flying out of a roost (probably a maternity roost as there were so many) and used an echo bat monitor with GPS location to gather evidence, which I sent to PC Underwood of Thames Valley police and I informed HS2 enquiries. Within the next few days we went to the area being felled on the A418, there were ecologists present, the majority of the trees in the area were felled but the bat roost tree we had identified was left for sometime. I would argue this would not have happened if we had not been there and sent the police evidence.

Cash's Pit (Bluebell woods)

In the spring/summer of 2021 I visited Cash's Pit (Bluebell woods). Initially I went there to meet up with professional ecologist Kevin Hand, an ecologist I had first met at JHW. Kevin led some wildlife walks to identify any protect species in Bluebell woods and other wildlife areas that were going to be affected by HS2. We saw a whole variety of woodland birds. Some were nesting in Bluebell woods, and nearby Clifford's wood where we saw buzzard nests and a large Badger sett, that will be disturbed by HS2 when they come to fell part or all of these woodlands. While there I was able to carry out dusk surveys, using an Echo touch bat monitor, heterodyne bat monitor and Anabat Express monitor. These various monitors record bat's ultrasonic calls and location. The Anabat Express was left out over night at various locations, within Bluebell woods, where we had seen bats on previous evenings and the zero crossing files show a variety of different species of bats and I have evidence of potential bat roost trees and badger sett locations using the What 3 Words application which gives the GPS location of where the photograph was taken and when. All this evidence can be provided, if required. Now that Cash's Pit has been fenced and protesters will soon be evicted by the NET and no more wildlife evidence can be gathered. This is in the full breeding season for birds, bats, badgers and other unprotected animals, and therefore I fear HS2, if they so wish, can fell this woodland with no bat licences or any independent ecology surveys, so wildlife crimes will go unnoticed.

In Summary

In my experience over the last 2 years as an activist protesting about HS2, there simply are not enough ecology surveys being carried out at HS2 sites, and when ecologists are present they are not being rigorous enough in their surveys, resulting in protected species being lost. Where activists or people living locally have been able to inform police or HS2 by being able to witness potential wildlife crimes, through access to an un-fenced HS2 site, have been prevented, but what about the countless areas that are being destroyed where there is no one there to prevent these crimes?
With this injunction there will be no one left to protest against this horrendous project and there will be no witnesses to any wildlife crimes.

I, Sally Brooks, to the best of my knowledge I believe that the facts in this witness statement are true.

Signed

Sally Brooks

D2710

Witness statement

Statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

Witness Name and Address:
Lord Tony Berkeley, House of Lords, Westminster, London SW1A 0PW

Date of Statement 12th May 2022

I believe the following to be a true and honest account to the best of my knowledge

1.
I am making this Witness Statement in support of those currently raising concerns and protesting against the construction of the HS2 train line, as well as raising my own concerns, noted here and as stated in my recent reports and letters to Parliament (see link below).

2.
Personal background
My career started in the construction industry, in which I have worked for many years, involved with major projects around the world. Since becoming the Public Affairs Manager of the Channel Tunnel/Eurotunnel from 1981 until the end of construction of the Channel Tunnel in 1994, my work has been tied up with rail – following closely the design and construction of HS1 and the TGV Nord in France connecting to the Channel Tunnel during this period. From 1995 until I retired (2020), I was Chairman of the Rail Freight Group, and fully involved in policy matters for both passenger and freight issues. I was a Board member and past President of the European Rail Freight Association, and am an Honorary Board Member of Allrail, the European representative body of private rail passenger operators and other companies. I am a Member of the Institution of Civil Engineers, Fellow of the Chartered Institute of Transport and Honorary Fellow of the Institution of Mechanical Engineers in the UK.

3.
I am a Labour member of the House of Lords and have been an opposition Transport Spokesperson. I regularly speak in the Lords on transport and related matters, challenging governments on policies and investment decisions. I am currently a member of a House of Lords Sub-Committee on the Built Environment. I am enthusiastic for more rail infrastructure and improvements to services, but recognise the necessity to challenge costs and processes of particular solutions. With regard this, I submitted the *HS2-Dissenting Report*[1] to Parliament in January 2020, raising serious concerns relating to the *Oakervee Review*[2] (2019) which I was initially Deputy

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[1] **Dissenting Report, Lord Tony Berkeley**, 5 January 2020:
https://documentcloud.adobe.com/link/review/?pageNum=1&uri=urn%3Aaaid%3Ascds%3AUS%3A8e9c8f87-2650-4aa0-8e0f-0eaf6e709640
[2] **Oakervee Review of HS2**, December 2019:
https://www.gov.uk/government/publications/oakervee-review-of-hs2

D2711

Chair until I resigned when it became clear that there was no intention to produce an independent report. I subsequently proposed alternatives to the HS2 project.

4.

HS2 Phase 1 Route Wide Injunction

In the Injunction in question (Claim QB-2022-BHM-00044), HS2 have issued two sets of maps relating to this Claim. The first set of maps (Maps1, dated:21/03/22), were submitted on 28th March 2022 with the initial Claim. These were withdrawn one month later and new maps (Maps2, dated:22/04/22) submitted.

5.

The major difference in the 2 sets of maps, is the initial failure to accurately inform the Court of the land acquired for the HS2 project in Maps1 – leading the court to believe HS2 had control (ownership or possession) over all the land for which it was seeking a route-wide Injunction. The second revised set – Maps2, we can only assume are more accurate, giving HS2's current, actual land ownership/control of.

6.

There are 2 areas of concern, which the second, current set, Maps2, raise:

1. HS2 does not have ownership or control (lease) of all the land it wishes to impose an injunction upon (not to mention build a railway across).

2. HS2 should have, by 23rd February 2022, acquired all the land it needed for Phase 1 of the project. From these maps we can see this is not the case – there are many areas of land along the route which HS2 does not own or lease. In this context, we assume that the 'word' acquire means full ownership or lease, and transfer of all the related funding.   <is this true>   My understanding is that they are very very late with payments.

7.

As noted, I can only assume HS2 has ownership/control of the land it says it has but, given HS2's initial submission to Court of areas to be injuncted (Maps1), as well as, from my own experience - HS2 failure to inform, and knowingly withholding information from Parliament on many occasions – I do not take HS2 word at face value, and therefore it is reasonable to demand proof of all property and land ownership or lease.

8.

Taking into consideration that the land acquisition date has passed (23.02.22), HS2 is not in a position to serve any injunction on land it doesn't have rights to or own. It follows that HS2 will need to return to Parliament to ask for an extension to enable more land acquisition. Given the serious failings of HS2, the impact of Covid-19 on live/work patterns, the spiralling costs, and the national outcry against the project, this may not be easy.

9.

This particular information, regarding HS2's land control and ownership, and lack of, has only come to light because of the route wide injunction that HS2 are trying to enforce on its critics.

10.

D2712

What is interesting in this situation is that the Injunction is aimed at controlling and limiting the movement of those (local residents, environmental groups and organisations, wildlife organisations, climate activists, and local businesses) who are concerned about the impact of HS2 on issues such as: health and wellbeing of their communities, local environments, local businesses, natural environments and climate change. These groups and individuals, in light of HS2's failure to oversee itself and its contractors, have tried to bring the unnecessary destruction and illegality of HS2 to the public's attention, and as well as raising concerns in local and national media, have helped to inform local councils, Parliament, police, local communities and the general public of the negative and dangerous activities and impact of HS2.

11.
HS2 wishes to silence and limit criticism. Through this Injunction, and all previous Injunctions, it wants to remove any external oversight of its actions and any criticism of its work. It is essential that HS2 at all times complies and is seen to comply with the assurances and commitments given during parliamentary hearing or other means, and for parliamentarians and others to hold them to account.

12.
I, as a Member of the Lords, have used my position to bring to the attention of the House of Lords, the Houses of Parliament and the Prime Ministers, the failures of HS2, including: HS2 and the Department for Transport's false accounting, Misconduct in Public Office, and breaches of the Ministerial Code; as well as also bringing to their attention cheaper, more useful and less environmentally destructive alternatives to HS2. (See link to my website below for more information).

13.
In July 2020, for an earlier HS2 injunction in Hillingdon, I wrote a statement in support of Mark Keir and other protestors. I again give my support to those listed and not named in this injunction. It is extremely important that the public have a voice and are listened to, otherwise our democracy fails. This Injunction is an abuse of Rights, and as with the whole HS2 project, an abuse of the laws of the country and the HS2 Bill, which brought it into being. I take this opportunity to repeat my final paragraph from the 2020 statement:

> In such a case as HS2, where an agreed national infrastructure project is now recognised to have no financial benefit, has serious negative environmental and health impacts, but is allowed to continue, then peaceful protest, as a Human Right and necessity, needs to not be limited or infringed, but encouraged and where possible supported by all means available, and especially through the Legal System.

14.
And I would like to add to this – where we in public office, whether in local government, Parliament or the Lords, are not listened to, then the voice of the people should not be silenced, particularly in such a case as HS2 - currently the biggest deforestation and most unnecessary infrastructure project in Europe - which

is having a dramatic negative impact on climate change, and is set to continue for 20+years.

14.
The concerns I have raised with Parliament and refer to in this statement can be found on my website: https://www.tonyberkeley.co.uk/#xl_xr_page_hs2

Signed

Lord Tony Berkeley
Date

D2714

My statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors

Dr Jessica Upton
46 Chester Street
Oxford

I am a veterinary surgeon, mother of 2, relief foster carer, tax payer and active member of my community.

I believe the following to be a true and honest account to the best of my knowledge.

My objections to HS2 are based on what I have read / researched on line and witnessed for myself.

There is no longer any debate about the existence of climate change and the role that environmental destruction and fossil fuels play in it.

"We are on a fast track to climate disaster. Major cities under water. Unprecedented heatwaves. Terrifying storms. Widespread water shortages. The extinction of a million species of plants and animals. This is not fiction or exaggeration." - UN Secretary-General António Guterres, April 2022.

"What we do I believe in the next three to four years will determine the future of humanity." - Sir David King, former chief scientific advisor to the UK government, February 2021

With this as a basis huge construction projects such as HS2 should only be going ahead if they
1. will be carbon saving in a very short period of time.
2. cause the least environmental destruction on the way.

HS2 clearly fails on both these grounds -
1. Published calculations state HS2 will not be carbon neutral within the next 120 years and it is currently churning out vast amounts of CO2 during it's construction.
2. I have witnessed trees felled during nesting season with visible nests in. I've seen the new plantations of dead saplings that supposedly replace ancient woodlands. I've seen the stumps of trees in abandoned areas felled in haste by HS2. There are documented incidents of police removing protestors from trees that aren't in the area to be felled and those trees being felled only to discover the protestors were right that they shouldn't have been. There are multiple reliable witness accounts of wanton, unnecessary vegetation removal. A protestor won her appeal against HS2 because it was proven HS2 had committed a wildlife crime by felling a tree illegally that had been identified as a potential bat roost and needed further investigation before it could be cut down.

HS2 promises on its web site :
- HS2 is mitigating the environmental impact of the project, and delivering many miles of ecological and landscape investments alongside the construction of the new railway.

- All our ecological work is carried out in accordance with the relevant laws and regulations, and is guided by the HS2 Phase One Act of Parliament and its Environmental Minimum Requirements.

The protestors and members of public on the ground are showing these statements to be mere window dressing. The public need to be able to hold HS2 to account without being criminalised for it and the defendants mentioned should be applauded not harassed.

"We are on a pathway to global warming of more than double the 1.5°C limit agreed in Paris. Some Government and business leaders are saying one thing, but doing another. Simply put, they are lying. And the results will be catastrophic. This is a climate emergency. Climate scientists warn that we are already perilously close to tipping points that could lead to cascading and irreversible climate impacts. But, high-emitting Governments and corporations are not just turning a blind eye, they are adding fuel to the flames." - UN Secretary-General António Guterres, April 2022.

Protest against HS2 is valid and the oversight of it is vital. A route wide injunction should not be put in place to prevent this.

Jessica Upton

My Statement in Support of the Defence against the Claim QB-2022-BHM-00044
HS2 Ltd & SoS for Transport V Persons Unknown and Ors

From Kevin Hand MSc MCIEEM,
7 Bermuda Rd Cambridge CB4 3JX

I have been a professional Ecologist for38 years. I have run the government's UK-wide National Tree Week and other campaigns for the Tree Council, of which I was Director. I was a Higher Scientific Officer at ADAS, Ministry of Agriculture. I was President of Cambridge Natural History Society. I am currently a Course Director at the Association for Cultural Exchange. I have run and directed many other environmental projects, and been a trustee for a number of wildlife charities.

I believe the following to be an honest and true account, to the best of my knowledge.

1. From 2020 to 2022 I have given a number of environmental training courses to activists and protesters against the HS2 route. I have trained over 100 people, from all walks of life, many of whom have gone on to train others. Colleagues have run similar training courses. All have taken place in situ, along the route of HS2.
2. I did this because I became aware that HS2 staff and contractors employed by them were reportedly breaking the law, specifically the Wildlife and Countryside Act 1981 and associated legislation.
3. I trained protesters to monitor protected wildlife species, including bats, badgers and nesting birds, some of which were on Schedule 1 due to their rarity.
4. We became aware of numerous occasions when UK wildlife law appeared to be broken as a result of the development of HS2. With legal colleagues such as members of Lawyers for Nature, we learnt how to document these probable breaches of the law, using photography and video recordings in particular.
5. I strongly believe that without this monitoring by protesters, often at great risk to their personal well-being and safety, a large number of offences would have been committed.
6. As more and more people living near the route became aware of the impacts of HS2, more of them came to support and help the protesters.
7. As a result of this, I believe HS2 Ltd were more effectively held to account, and forced or obliged to follow the letter of the law, particularly relating to the above Act and associated legislation.
8. As a useful example volunteers trained by me and others, in bat monitoring techniques, became aware of a number of protected species at Jones Hill Wood, near Wendover, Buckinghamshire. These included the very rare Barbastelle bat, Barbastella barbastellus. Very few colonies of this species are known in the UK. HS2 planned to destroy the wood and the bat colony, as their own ecologists had found no evidence of it. The destruction of the wood was halted, temporarily, following publicity in the national press. Ultimately it was still destroyed, but some extra mitigation measures were put in place, and an even wider audience was made aware of the deleterious effects of the HS2 development.

D2717

9. Another example of the value of protesters' overview of the HS2 project, covered by the BBC and others, concerned occupied badger setts at a number of sites along the route, including Jones Hill Wood and woodland near Cubbington, Leamington Spa. I was running a training day here, and those involved and I became aware of netting covering occupied badger sett openings. The Protection of Badgers Act 1992 provides strict guidelines on treatment of badger setts. Natural England, the government body tasked with protecting wildlife, was giving licences to HS2 to block and destroy setts, which very few members of the public were aware of at the time. NE set guidelines for sett destruction, which protesters living along the HS2 route were able to monitor, and highlight when the guidelines were broken. The awareness raised of this by the protesters led to widespread public condemnation of badger sett destruction, and could lead to a change in the law in future.

10. There are many more examples of this sort uncovered by protesters along the route, including the destruction of nesting bird sites and other bat and badger colonies. In some cases protesters have been able to prevent wildlife laws being broken by informing HS2 in advance. In other cases HS2 are now obliged to monitor their own work more carefully, knowing that any breaches of the law will be seen and recorded by protesters and the many members of the public who help them. With greater scrutiny by protesters at least other bat colonies and other protected wildlife may have a greater chance of survival.

11. It is self evident that if protesters and the public were prevented from overseeing the work of HS2 by this injunction, more laws would have been and will be broken, and more rare and protected wildlife destroyed.

12. Indeed, it would set a precedent that would suggest that any large and /or government led projects could not be overseen by observers. This is obviously not desirable in a fair and democratic society.

13. To end, I should like to commend Mark Keir, and all the other defendants who stand to lose so much as a result of these proceedings, many of whom I know personally as a result of the work detailed above. I have known Mark since the start of my involvement, and he has always been inspirational and a true gentleman with whoever he deals with, be it a security guard or the head of a company. His diplomacy and tact have diffused many difficult situations. I sincerely hope he and his colleagues are spared any further hardship and allowed to continue with their pursuit of truth and justice on behalf of us all.

Signed,

Kevin Hand

Kevin Hand MSc MCIEEM
9 May 2022

D2718

Statement in support of the Defence against the claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

Mark Browning
52 Skip Lane,
Walsall
West Midlands
WS5 3LP

The following is true and honest.

1.0

My partners brother is renting a property that HS2 has compulsorily purchased near Hopwas in the Tamworth area. It has substantial pasture that needs managing;
I am concerned that I may be criminalised if working on this land or in the vicinity of HS2 compounds; from what I hear HS2 maps are frequently misinterpreted by security staff.
I request an exemption from this injunction.

D2719

Witness statement

Statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

Witness Name and Address:
Lord Tony Berkeley, House of Lords, Westminster, London SW1A 0PW

Date of Statement 12th May 2022

I believe the following to be a true and honest account to the best of my knowledge

1.
I am making this Witness Statement in support of those currently raising concerns and protesting against the construction of the HS2 train line, as well as raising my own concerns, noted here and as stated in my recent reports and letters to Parliament (see link below).

2.
Personal background
My career started in the construction industry, in which I have worked for many years, involved with major projects around the world. Since becoming the Public Affairs Manager of the Channel Tunnel/Eurotunnel from 1981 until the end of construction of the Channel Tunnel in 1994, my work has been tied up with rail – following closely the design and construction of HS1 and the TGV Nord in France connecting to the Channel Tunnel during this period. From 1995 until I retired (2020), I was Chairman of the Rail Freight Group, and fully involved in policy matters for both passenger and freight issues. I was a Board member and past President of the European Rail Freight Association, and am an Honorary Board Member of Allrail, the European representative body of private rail passenger operators and other companies. I am a Member of the Institution of Civil Engineers, Fellow of the Chartered Institute of Transport and Honorary Fellow of the Institution of Mechanical Engineers in the UK.

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I am a Labour member of the House of Lords and have been an opposition Transport Spokesperson. I regularly speak in the Lords on transport and related matters, challenging governments on policies and investment decisions. I am currently a member of a House of Lords Sub-Committee on the Built Environment. I am enthusiastic for more rail infrastructure and improvements to services, but recognise the necessity to challenge costs and processes of particular solutions. With regard this, I submitted the *HS2-Dissenting Report*[1] to Parliament in January 2020, raising serious concerns relating to the *Oakervee Review*[2] (2019) which I was initially Deputy

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[2] **Oakervee Review of HS2**, December 2019: https://www.gov.uk/government/publications/oakervee-review-of-hs2

D2720

Chair until I resigned when it became clear that there was no intention to produce an independent report. I subsequently proposed alternatives to the HS2 project.

4.

HS2 Phase 1 Route Wide Injunction

In the Injunction in question (Claim QB-2022-BHM-00044), HS2 have issued two sets of maps relating to this Claim. The first set of maps (Maps1, dated:21/03/22), were submitted on 28th March 2022 with the initial Claim. These were withdrawn one month later and new maps (Maps2, dated:22/04/22) submitted.

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The major difference in the 2 sets of maps, is the initial failure to accurately inform the Court of the land acquired for the HS2 project in Maps1 – leading the court to believe HS2 had control (ownership or possession) over all the land for which it was seeking a route-wide Injunction. The second revised set – Maps2, we can only assume are more accurate, giving HS2's current, actual land ownership/control of.

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1. HS2 does not have ownership or control (lease) of all the land it wishes to impose an injunction upon (not to mention build a railway across).

2. HS2 should have, by 23rd February 2022, acquired all the land it needed for Phase 1 of the project. From these maps we can see this is not the case – there are many areas of land along the route which HS2 does not own or lease. In this context, we assume that the 'word' acquire means full ownership or lease, and transfer of all the related funding.   My understanding is that they are very very late with payments.

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9.

This particular information, regarding HS2's land control and ownership, and lack of, has only come to light because of the route wide injunction that HS2 are trying to enforce on its critics.

10.

What is interesting in this situation is that the Injunction is aimed at controlling and limiting the movement of those (local residents, environmental groups and organisations, wildlife organisations, climate activists, and local businesses) who are concerned about the impact of HS2 on issues such as: health and wellbeing of their communities, local environments, local businesses, natural environments and climate change. These groups and individuals, in light of HS2's failure to oversee itself and its contractors, have tried to bring the unnecessary destruction and illegality of HS2 to the public's attention, and as well as raising concerns in local and national media, have helped to inform local councils, Parliament, police, local communities and the general public of the negative and dangerous activities and impact of HS2.

11.
HS2 wishes to silence and limit criticism. Through this Injunction, and all previous Injunctions, it wants to remove any external oversight of its actions and any criticism of its work. It is essential that HS2 at all times complies and is seen to comply with the assurances and commitments given during parliamentary hearing or other means, and for parliamentarians and others to hold them to account.

12.
I, as a Member of the Lords, have used my position to bring to the attention of the House of Lords, the Houses of Parliament and the Prime Ministers, the failures of HS2, including: HS2 and the Department for Transport's false accounting, Misconduct in Public Office, and breaches of the Ministerial Code; as well as also bringing to their attention cheaper, more useful and less environmentally destructive alternatives to HS2. (See link to my website below for more information).

13.
In July 2020, for an earlier HS2 injunction in Hillingdon, I wrote a statement in support of Mark Keir and other protestors. I again give my support to those listed and not named in this injunction. It is extremely important that the public have a voice and are listened to, otherwise our democracy fails. This Injunction is an abuse of Rights, and as with the whole HS2 project, an abuse of the laws of the country and the HS2 Bill, which brought it into being. I take this opportunity to repeat my final paragraph from the 2020 statement:

> In such a case as HS2, where an agreed national infrastructure project is now recognised to have no financial benefit, has serious negative environmental and health impacts, but is allowed to continue, then peaceful protest, as a Human Right and necessity, needs to not be limited or infringed, but encouraged and where possible supported by all means available, and especially through the Legal System.

14.
And I would like to add to this – where we in public office, whether in local government, Parliament or the Lords, are not listened to, then the voice of the people should not be silenced, particularly in such a case as HS2 - currently the biggest deforestation and most unnecessary infrastructure project in Europe - which

is having a dramatic negative impact on climate change, and is set to continue for 20+years.

14.
The concerns I have raised with Parliament and refer to in this statement can be found on my website: https://www.tonyberkeley.co.uk/#xl_xr_page_hs2

Signed

Lord Tony Berkeley
Date

D2723

Talia Woodin's statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

All evidence cited can be viewed here:
https://drive.google.com/drive/folders/1ebP1Nk-fclif7xpZBD5xaSqrfcDHFtUc

Talia Woodin
1 Camelford Road, Bristol, BS5 6HW
I'm a freelance photographer and filmmaker that has worked within many environmental and climate justice organisations full time over the past 4 years and have been involved with that campaign against HS2 since early 2020.

I believe the following to be a true and honest account to the best of my knowledge.

Throughout my time on the HS2 campaign, in which I spent my time documenting the wildlife crimes and assaults on protesters being committed. I was continually appalled by the extent of injustice and violence enacted by HS2 employees and enablers on every level. Whether that be physical violence, endangerment or just general carelessness on the part of HS2 security and the National Eviction Team (NET), or the enabling of such by Police officers of various constabularies. The following describes a number of examples of these incidents that myself and others documented through the period of May 2020 to February 2021.

The first incident took place on 21st May around 11am near Harvil Road in Uxbridge and is shown in **Evidence Exhibit 8,** which I recorded myself, shows an individual being violently restrained by members of the NET. The individual was violently pulled to the ground in a reckless and poorly coordinated way that resulted in one of the NET themselves falling over. They then proceeded to kneel on the individual and apply unnecessary pressure to his abdomen and throat whilst also twisting his arm at an angle that caused physical pain, evident by the individual's cries and pleading for them to stop. Throughout this the NET failed to give reason as to why they were restraining this individual and wouldn't allow anyone near him to medically aid him despite his clear distress. The violence on the part of the NET shows the extreme retaliation often enacted against protesters whilst peacefully practising their right to protest.

The second incident, which took place on 23rd July 2020 in Denham Country Park, is shown in **Evidence Exhibit 9,** which I did not film myself but did witness. The event involved a NET climber cutting a wire line that was strung between two trees over a river, on which a young individual was standing with no safety attachment, causing them to fall around 20 feet into the shallow River Colne below. In the run up to this those on the scene had been pleading with the NET climber to stop the work they were doing on the tree, initially felling branches, as it was causing the line to become unstable and already risking the safety of those attached. The severity of the situation only increased when the NET climber began cutting the rope above the wire line which had initially been used as a safety line. This resulted in those that had been attached to this line being lowered down into the river below, however it left the final individual standing on the wire and only secured by them holding onto a branch above them. The evidence shows that despite the clear pleading of individuals on scene and the awareness of the NET climber and all of his colleagues of the danger of the situation, the climber cut the line on which the individual was standing causing him to fall the hight into the shallow water below. This was undoubtedly a dangerous and calculated move on the part of the NET climber who would have had extensive training on how to safely handle a situation like this. Instead he made the decision to cut the only apparatus holding up this young individual causing a fall that could have easily broken their neck or killed them. Despite this endangerment to the individual's life he was the one who was subsequently arrested after being taken to hospital because of the extent of the fall and his injuries. The police on site not only failed to intervene when the individual's life was at risk but then allowed the NET climber to avoid any consequence despite causing this threat to someone's life, again a clear example of the police's bias and favour of HS2 above public safety.

The next incident took place the following day on 24th July 2020 also in Denham Country Park, and can be seen in **Evidence Exhibit 10** at around 1 hour 03 minutes on the recording**.** Again, much like the incident the previous day, this event involved the wire on which an individual was sat and attached to, suspended around 20 feet above the shallow River Colne, being cut, causing them to fall and then be suspended by the line they were attached to, resulting in injury to their arm and collar bone. The incident was caused again by the cutting of the individual's safety line and the wire on which they were sitting, being cut by a NET climber. This happened the day after the previous incident despite the severity of the initial incident resulting in the individual needing medical attention in hospital. Once again there were numerous police officers, paramedics and HS2 employees standing by, none of whom intervened whilst another individual's life was endangered.

The incidents that took place on these days, 23rd and 24th July 2020, show some of the more extreme cases in which the NET, in enabling HS2's work, not only enacted violence towards members of the public and peaceful protesters, but also went as far as endangering people's lives. All the while being supported and protected in doing so by various police forces including Thames Valley Police.

The following pieces of evidence were collected by myself, from various sources, after an incident which occured in the Colne River in Denham Country Park on 7th and 8th September 2020. The first video, **Evidence Exhibit 11a**, shows individuals peacefully making their way around a section of fencing on the side of the Colne River, outside of the HS2 compound on the banks of the river. It shows members of the NET pushing and shoving these individuals into the river, and violently restraining one young woman on the ground causing significant injuries. Another young woman had her finger broken by a member of the NET, when she was attempting to provide first aid assistance to another individual, shown in **Evidence Exhibit 11b.** She was later also arrested and has since had all charges dropped. Throughout this incident, the NET and HS2 workers were extremely hostile and violent and showed no concern for the physical injury being enacted on the protesters.

The following day, 8th September, further violence ensued when individuals protested the felling of a tree on the banks of the River Colne, which again was being done so unlawfully due to a lack of correct bat licensing for the area. The extensive video footage shows the violence and aggression again committed by the NET and HS2 security against the individuals present, many of whom were young women and teenagers and all of whom maintained their non-violent protest, often raising their arms so as to clearly show their lack of physical engagement. **Evidence Exhibit 12a to 12f**, shows the NET and HS2 hired security pushing, shoving and grabbing people, forcing and holding people down into the river, tripping people over, restraining people and pulling peoples hair and beards. All the while protesters maintained their non-violence despite the constant assault being committed against them. **Evidence Exhibit 13a to 13h,** shows various resulting injuries to individuals as a result of the NET and HS2 securities violence. This included cuts, scrachest, bruises and head injuries as seen by the A&E report in **Evidence Exhibit 14.** Once again, despite HS2 employees carrying out unlawful work which was enabled by excessive violence by the NET and security as well as police being on scene, various protesters were arrested and detained for over 48 hours.

The next incident happened during the eviction of the protest site in Steeple Claydon on 23rd February 2021. At this point HS2 hadn't taken possession of the land lawfully as they hadn't given the required 28 days notice and all charges of aggravated trespass have since been dropped against protestors. The incident, which I filmed from close proximity, took place as an individual was suspended on a traverse between the tower in the section of the woodland which was being evicted and one in the section of woodland which was not. The individual was on the traverse, attached safely with climbing gear, making their way from one tower to the other in order to collect drinking water for the group of individuals that were in the tower due to be evicted. This was because HS2 workers weren't allowing them to receive water and other essential items after they had run out. As seen in **Evidence Exhibit 15** as the individual was suspended at the centre of the traverse, at least 30 feet above the ground, one of the NET climbers, the same one who cut the individuals off their lines in **Evidence Exhibit 9 and 10**, came up to their level in a cherry picker. On approaching the individual on the traverse, the climber reached out of the cherry picker cradle and attempted to grab the legs of the individual on the traverse. The climber attempted to drag the individual into the cherry picker despite not having the stability or control to do this properly. With one arm holding the individual's legs they then proceeded to take out their climbing knife with the other hand, this was a hugely dangerous manoeuvre for both individuals involved as can be seen by the precarity of the situation in the evidence. Whilst continuing to restrain the legs of the individual on the traverse, maintaining the instability of both individuals, the NET climber began attempting to cut the traverse that the person was still attached to, despite them being still suspended in the air and not secured in the cherry picker. The instability of the cherry picker, as well as the lack of control and precaution on the part of the NET climber, in attempting to hold the legs of the individual and cut the traverse with a large knife at the same time, was hugely dangerous and could have easily resulted in the individual falling or being injured by the knife. When the traverse was cut the NET climber had still not secured the individual into the cherry picker and narrowly avoided dropping them backwards which very likely would have been fatal. Again countless HS2 employees, NET and police were on the scene and yet none intervened. The individual was then arrested and restrained by multiple police officers in a hugely disproportionate way leaving them handcuffed behind their back, face down on the floor, unable to move.

This incident occurred on **24th June 2020** in Denham Country Park, Uxbridge.

At this time I was living at Denham Ford Protection Camp in order to document the wildlife crimes and assaults against protesters being committed by HS2 employees.

Throughout the morning of the 24th, HS2 workers had been felling a section of Ash trees in the compound on the banks of the River Colne, next to Denham Ford Protection Camp. They were carrying out this work unlawfully due to not having the proper bat licensing, a fact that has since been proven in a separate case.

Around midday, an individual, not employed by HS2, climbed into one of the trees on the edge of the compound fence, overhanging the compound itself. Despite their close proximity to the HS2 worker felling branches from the next tree, work continued, endangering the individual's life see **Evidence Exhibit 1a, 1b, 1c and 1d**.

Around this time myself and a small group of others came and stood on the public footpath, which at this point was still open and accessible, and which ran alongside the compound. I began filming the individual in the tree in case they were harmed by felled branches.

At some point between midday and 13:00 a few members of the National Eviction Team (NET) were called to the compound, where they began speaking with the individual in the tree. At this point myself and a few others, including two individuals under the age of 18, were sitting on the public footpath next to the compound.

At around 13:00 the HS2 workers and NET started maneuvering the wood chipper and other pieces of equipment out of the compound onto the footpath that we were sitting on. This was done in a hugely disorganised and dangerous way, with the equipment being driven up onto a grass verge where it almost fell over, endangering both the HS2 workers and myself and the other individuals I was with, see **Evidence Exhibit 3a**.

Without warning or caution the NET started violently grabbing and shoving some of the individuals on one side of the footpath. One of them grabbed the breast of a young woman and pushed her to the ground causing an injury to her back and ripping her shirt open as seen in **Evidence Exhibit 2a and 2b**. This assault was later reported to the police and to HS2.

At this time myself and another young woman, who at the time was only 17 years old, were sat separately apart from the other individuals who were being violently removed from the publicly accessible footpath. Abruptly, again without warning or being asked to move, two members of the NET appeared from behind myself and the other young woman. They proceeded to grab us each by the upper arm and drag us backwards along the gravel path for a few metres, before throwing us into a bed of stinging nettles on the side of the path, as seen in **Evidence Exhibit 3a and 3b.**

This resulted in both myself and the other young woman gaining injuries across our backs, both from the gravel and the stinging nettles and also extensive bruising across our arms from being physically grabbed, see **Evidence Exhibit 4a, 4b and 4c**.

After we were removed from the path the HS2 workers accompanied by the NET moved the equipment further along the public footpath towards the public footbridge crossing the Colne River. On approaching the footbridge, individuals that I was accompanied by halted the moving of the equipment by sitting on it peacefully. To which no arrests or charges were made at any point. This was again met by disproportionate violence from the NET who pulled, pushed and shoved the individuals to remove them, as can be seen in **Evidence Exhibit 5.** One member of the NET even went so far as to push his own colleagues aside in order to target a young woman, who he then lifted off the ground and body slammed her to the floor causing her to develop a concussion and later be hospitalised. Again all shown in **Evidence Exhibit 5**.

All of these assaults were reported to Thames Valley Police as well as to HS2 itself, yet nothing came of it. The whole event left myself and others physically and emotionally harmed and to feel that there was no accountability when it came to the actions of HS2, even when it involves endangerment to members of the public.

<u>This incident took place on **8th July 2020**, also in Denham Country Park.</u>

In the early hours of the morning those of us camping in Denham Protection Camp were awoken by the sound of machinery working in the compound next to the site. Once again HS2 workers were unlawfully felling trees as they still didn't have the correct bat licencing. Some individuals from the encampment were already at the compound fence filming the felling and requesting that the workers show the correct paperwork to prove they are able to fell the trees. As often happens no paperwork was shown.

At around midday I made my way along the river from the encampment, past the compound and onto the public footbridge crossing the Colne River. A few individuals from the protest site were already on this footbridge playing a game. On one side of the bridge was an HS2 buggy full of wood chips and several HS2 workers waiting to cross.

The previous night, on July 7th, I had suffered several seizures and had been hospitalised. Despite being well enough to be discharged I was still very physically weak and so sat down on the side of the footbridge to rest whilst the other individuals continued to play the game.

Throughout this time the HS2 workers at the end of the bridge were threatening to call the police, claiming we were breaking the law by being on a public footbridge.

At around 13:00 a Thames Valley Police Officer arrived at the scene to enquire about what was going on. We informed them that we were simply playing a game on a public footpath which we rightfully had access to be on. They suggested that we may be breaking a law as the HS2 buggy hadn't been able to cross the bridge, however the officers were unable to tell us what law exactly we were breaking.

After a few minutes a second officer joined and after some deliberation with his colleague, they informed us we were in breach of Section 241 of the Trade Union Act. We were told we had to move off the footbridge to which we agreed to once we'd finished our game. After a few minutes we all moved off the bridge and the HS2 workers and buggy continued across to their destination. The TVP officers oversaw the whole procedure and then left with no further issues.

Myself and the other individuals on the bridge then made our way back to the protest site where we got on with our day. Less than an hour passed when we were alerted by another person on the site that a few dozen Thames Valley Police Officers had come onto the site. By doing so they were in breach of Section 6 on the area and so we all went to inform them of this.

When approaching the officers they began arresting two individuals that they claimed had been on the footbridge earlier. When I enquired under what power they were arresting them, an officer pointed at me and said that I was also under arrest, as can be seen in **Evidence Exhibit 6a**. Two male officers then proceeded to grab my arms and handcuff me behind my back informing me I was under arrest for breach of Section 241 of the Trade Union Act. They also detained 5 other individuals they claimed had also broken the Section. Despite informing them that I had just come out of hospital and wasn't well and not resisting in any way, they insisted on putting me in handcuffs. All of this can be seen in **Evidence Exhibit 6b**.

We were led along and across the river past the compound where all the HS2 workers who had previously been on the footbridge as well, stood watching. One worker, who I later found out to be named Michael Bower made an intimidating and derogatory comment as I passed, clearly amused by the events.

Once on the other side of the river we were led to the car park of the Country Park. Here I was placed by my arresting officers in an unmarked car separately from the other detained individuals who were put in separate police vans and cars. Despite asking where we were being taken, the officers would not tell us. At this point I was hugely distressed as I was essentially being taken to an unknown location by two men in an unmarked car.

The proceeding arrest and detainment by Thames Valley Police included various breaches of mine and the other arrested individuals fundamental rights as well as unlawful strip searches, one of which was committed against a minor with no appropriate adult present. We are currently all pressing charges against Thames Valley Police for False Imprisonment and Assault.

The case against us for breaching Section 241 has since been proven not to be true and all charges dropped. The whole event was a clear example of Thames Valley Police unquestioningly enabling and protecting the unlawful activities of HS2 through intimidation and violence.

The next incident took place on the 8th September 2020 in Denham Country Park.

At the time I recorded a testimony of what happened which can be seen in **Evidence Exhibit 7a, 7b, 7c and 7d.**

Again the incident began with HS2 workers unlawfully felling sections of ancient woodland in Denham Country Park, which they did not have the appropriate bat licensing for. Myself and a few others had made our way to the section of woodland between the Colne River and the Grand Union Canal where this felling was taking place, in order to document it. On walking down a section of public footpath in the country park a group of HS2 employees all in orange high vis walked past us in the opposite direction. On passing me, HS2 engineer Michael Bower, who had been named as a witness on the case involving my arrest at Denham on July 8th, called my name and then proceeded to wink and make an inappropriate gesture with his tongue towards me. This made me feel hugely uncomfortable and threatened as he was surrounded by his colleagues, all of whom were men, and I was by myself on the path as the others I was with were further behind. As well as this he was a named witness on my case, which was still open at the time and therefore shouldn't have been engaging with me in any way.

At this point we decided to walk back towards Denham Ford Protection Camp as I felt quite alarmed by the incident. This was in the direction that Bower and his colleagues were walking so I stayed a few paces behind. During this time they continued to make gestures at me and call my name, which only added to my distress. On approaching the footbridge over the Colne River I decided to continue across the bridge in the direction the workers were going in order to express my upset at their behaviour and show that I was not intimidated.

On the other side of the footbridge the group of workers stopped and turned to face me, with Bower in the centre of the group. He came right up to where I was standing and began making various threats to me claiming he would 'get me arrested again if I wasn't careful'. He also made various inappropriate comments and gestures including saying "that's disgusting language to come out of such a pretty mouth", when I verbally protested his behaviour. This interaction continued until Bower's supervisor came out of the nearest compound and physically removed Bower from the scene.

The event caused me to feel extremely unsafe and that I could easily be harmed by HS2 employees. This was also not the first time that an HS2 employee had made sexually inappropriate and threatening gestures, remarks and actions towards myself and other young women.

Every incident recounted here is an example of the ongoing violence and danger enacted by those employed by HS2 at every level. This not only poses a threat to those practising their right to protest, but also any member of the public that comes into contact with HS2 employees. I have witnessed every form of assault, injury and harassment enacted by HS2 employees and the resulting physical, emotional and mental harm done to myself and countless others is extensive. This is all on top of the broader injustice of HS2 as a completely undemocratic, unnecessary and extortionately expensive project. By allowing this injunction, it would not only disable our right to protest, enshrined by international human rights, but would also allow for even greater harm to be committed against anyone that might oppose HS2 and for even less accountability and justice in response.

My statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors

Timothy Chantler
6 Sultan Croft
Shenley Brook End
Milton Keynes
MK57FD

I believe the following to be a true and honest account.

I am a computer systems architect for a major financial services provider by profession. I am not an environmental activist, I am a concerned taxpayer and member of the public.

On Friday the 13th May 2022, at a time between 11am and 12am, I was walking along the A51 near Swynnerton in Staffordshire.

I was seriously concerned for the welfare for a number of individuals who were effectively unable to obtain food and water, due to HS2 surrounding their home with a temporary purchase order and a metal fence, having seen footage on the news. I was visiting the site on this day with the intention of ensuring the health and safety of those in the fenced off area, and assisting with any vital supplies or care they might need.

Taking great care to avoid the HS2 land, even though there were no markings or signs whatsoever to indicate which land was owned by HS2, and which was not, I walked along the public highway to a point level with a fenced area of woodland to the South of the A51.

I explained to the HS2 staff present that I was concerned for the welfare of various individuals, and explained clearly to the HS2 staff present that I was not intending to step onto their land at all, that I was not intending to enter the fenced area, and that I was only there to speak to the people behind the fence.

At this point I was surrounded by approximately 8-12 HS2 employees wearing NET badges, black uniforms and whole face coverings. They formed a line between me and the fenced area, and stood to my sides and behind me. I was still on public land, and this made me feel extremely intimidated being completely surrounded. The NET staff filmed me constantly, took photos of me throughout the encounter, and took photos of and loitered around my car (which I had spoken to the police liaison about and they had confirmed it was fine to park in the location I had parked)

I asked the HS2 / NET staff if I could pass water to the people behind the fence, approx. 3-4 metres away from my position. The HS2 / NET staff refused to allow me to do so.

I asked HS2 / NET staff if I could pass water to the HS2 / NET staff to pass to the people behind the fence. The HS2 / NET staff refused to do so.

I asked why HS2 / NET staff were effectively denying people the ability to obtain water and food on a sunny day where the temperature hit approximately 20c, and was given no answer.

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One member of HS2 / NET staffed asked me to leave the location. I asked why, and declined to do so unless asked to do so by the police, as I was on a clearly marked public highway and believed I had every right to be there. The HS2 / NET demand to move was made in a seemingly official capacity, and no mention was made by HS2 / NET that I would not have to comply. The police community liaison officer also confirmed later that I was completely within my right to be where I was.

I slowly and carefully moved myself a metre or so away from the HS2 / NET members directly between myself and the fence, so I could clearly see the people the other side of the fence, in order to talk to them. I remained on the public highway at all times.

After I had moved myself fractionally away from the HS2 / NET staff, approximately 4 of them moved directly between me and the fence again, blocking my visibility, preventing effective communication with the people behind the fence.

One member of HS2 / NET staff moved himself to a point where his chest was touching my arms, which were folded in front of me. He then immediately and repeatedly asked if I could move myself to provide him with 'personal space' as we were now touching. I politely refused, as I had been in plenty of clear space, and he had chosen to move himself to a positon where he was touching me, against my will. This was extremely threatening and intimidating, and occurred while I was entirely on public land. Not HS2 land. The police community liaison present conformed this at the time.

After an extremely stressful and intimidating few minutes with an HS2 NET employee pressed physically against me, against my will, while I was on public land, one of his colleagues called him away and he was replaced in the line in front of me by another NET member, who thankfully made no attempt to touch me, and did maintain at least a few inches of space away from my body.

Despite the wall of NET employee's blocking my view and ability to communicate with the residents of the fenced are, I managed to talk loudly enough to speak to the people the other side of the fence, and establish that they did indeed need water, and food. At this point I returned to my car, remaining on public land the entire time, and shortly thereafter departed to the nearest supermarket for water and food.

I returned from the shops to the same location on the A51 just after lunchtime on the 13th May 2022, and carried the water and food from my car, parked some way away on public land, back to the fenced area. I again remained on public land at all times.

The HS2 / NET staff once again followed me the entire time, formed a line between myself and the fenced area, filmed me, and took photos of me.

The HS2 / NET staff again refused to allow me to pass the water over the fence myself

The HS2 / NET staff again refused to pass the water and food over the fence on my behalf

At this point, the only option left to me was to throw the items of food over the fence. This was a difficult proposition due to the line of HS2 / NET employees in front of me.

I informed the NET employees of my intentions to throw the food and bottles of water over, and moved myself onto public land with a clear view of the fence and no NET staff obstructing me to avoid any potential injury to anyone.

Once again, the NET staff formed a line between me and the fence, placing themselves deliberately in a position obstructing my throwing of the food and water.

I informed the NET staff that I was about to throw the items, and took great care to throw the food and water over their heads without causing any injury, despite the difficult position the NET staff had put me in, and their constant obstruction.

This process of water and food delivery took some time, but I delivered approximately 30 litres of water and a substantial amount of fruit and other food stuffs and supplies to the people behind the fence. Despite the determined efforts by NET staff to prevent me from doing so.

This was an extremely stressful situation for me. I was intimidated constantly by NET staff. I was actively prevented from delivering water to people in need on a hot day by NET staff. I was followed by NET staff. I was photographed by NET staff. I was filmed by NET staff. I was asked to leave a location where I had every legal right to be by NET staff. I was physically touched against my will by NET staff.

At no point in the entire encounter did I step foot on HS2 land.

As the entire encounter was filmed by HS2, There is video evidence to corroborate my story. At one point a man with a camera walked past, and took several photos of the HS2 staff intimidating me, providing photographic evidence.

If this is how HS2 and NET behave on land they do not own, I can only imagine the distress or potential harm they will cause to untold numbers of members of the public if this injunction is allowed to go ahead. HS2 / NET staff clearly have no qualms making physical contact with members of the public on public land. HS2 / NET do not follow any of the same independent oversight procedures as the Police, nor are they as well trained or vetted. The potential for serious injury or harm to members of the public if the injunction goes ahead is, in my opinion, and based on my experience with the apparently unprofessional and intimidating NET staff, significant.

If the right to protest against HS2 is removed, the HS2 / NET staff who physically touched/assaulted and intimidated me on public land in Staffordshire, will be effectively free to do the same to any member of the public who either knowingly or unknowingly strays close to or onto HS2 land. HS2 / NET staff clearly have no respect for the boundaries of public land. HS2 / NET staff operate without oversight, without recourse. As a law-abiding citizen I find this idea abhorrent. The right to protest is the fundamental core of democracy – even if we do not like the protesters message or actions. We must not allow this injunction to proceed.

Timothy Chantler

My statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors

Victoria Tindall
Blackfield Cottage,
Blackfield Lane
Ballinger
Bucks
HP16 9LL

I believe the following to be a true and honest account.

I am a resident of a small hamlet close to the Lee and South Heath.

On Thursday 24 March at just after 3pm I was walking with my dog and 7 year old daughter across our local fields.

As we are concerned about what is happening to our natural environment we walked across Potter Row coming from the fields to the East and down the driveway of a friend who borders onto the earthworks adjacent to Leather Lane to take a look.

Having watched for a few minutes we returned up the driveway and turned South away from Leather Lane down Potter Row towards South Heath.

We stopped at a stile as my daughter had a stone in her welly.

At 15.26 a HS2 security van drove past us going in the same direction at no more than 5 mph which I thought was odd as they usually travel at the normal speed - 30mph on Potter Row. I was waved at by the driver.

A minute later the same van drove back past me towards Leather Lane having obviously turned around in front of us.

I felt intimidated and spied upon as at no point had we approached Leather Lane itself - having crossed the field behind Potter Row. I am aware that our friend is adjacent to an HS2 site with security cameras and I feel as though we must have been watched on her driveway - private property. I was with my young daughter and feel as though our privacy was invaded.

Corporations should not be allowed to intimidate and invade the privacy of local residents. The people who protest against HS2 and other businesses ensure that such businesses cannot act without scrutiny of their behaviour and actions. Without the right to protest and occupy space, ordinary residents and people will be at the mercy of these businesses who seem to act above the law. The protestors I have encountered care far more for our beautiful countryside than the businesses who prioritise profit above the environment and they are certainly more peaceable and less threatening than the paid 'security' employed by EKFB.

Victoria Tindall

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STATEMENT FROM:

Mr and Mrs Phil Wall, of Elmtree Cottage, Bottom House Farm Lane, Chalfont St Giles, Bucks HP8 4EE regarding their experience of HS2.

We live on what was once a rural single track farm lane, where HS2 have now destroyed almost a mile of hedgerow to widen it and build a parallel haul road for construction of the Chalfont St. Giles ventilation shaft.

Our experience of HS2 is of a pattern of misinformation, deception and obfuscation, as far back as 2015 and 2016, when Mrs Wall attended HS2 Select Committees hearings in Westminster as a petitioner. She argued then that our lane was unsuitable because of listed buildings, residential buildings, the River Misbourne flood plain and the steepness of the lane where it meets the A413. She proposed an alternative route across fields from the A355. HS2's QCs dismissed her concerns, and both a Chalfont St Giles Parish Council petition, for which Mrs Wall gave a witness statement in 2015, and her own petition in 2016 were ignored.

HS2 and its contractors have repeatedly failed to be truthful, open and accountable on issues including:

1. **A haul road embankment built immediately opposite our house to mitigate the steepness.** There was no mention of this in the 2013 Environmental Statement, which stated that there would be a "permanent widening of Bottom House Farm Lane generally along the south side, to achieve a 4m wide road, including the provision of passing bays". We were only informed of plans for an embankment in 2019. Construction of this involved months of noise, dust and vibrations yards from our front door, along with a total loss of privacy, with construction vehicles and workmen at a height that rose to be level with our bedrooms. The work also led to severe traffic disruption on the A413, adding up to half an hour to car journeys, including our return from work.
   We had been told the embankment would be 1.2 metres above the level of the existing field, only for it to be built far higher, meaning the total loss of our view of the Misbourne Valley from the ground floor. We are now overlooked by construction traffic, other traffic and pedestrians on a level with our upstairs windows, including that of our teenage daughter. HS2 have not given us any explanation of when and by whom the decision was taken to raise the height of the embankment and why we were not informed until it was built. HS2's contractors Fusion refused to answer questions on the subject once construction started.

2. **Vibration damage to our home.** During construction of the embankment, HS2 used 'vibrating compactors' to pack down the earth and road base, which caused our whole house to shake and radiators, door frames and the contents of the kitchen cupboards to rattle. It made working from home impossible and led to Mrs Wall feeling nauseous. Cracks subsequently became evident in a number of rooms, including one which had been newly plastered. When we raised this with HS2, they refused to accept any responsibility. They offered us a structural survey but as the damage had already been done it would be impossible for a survey to prove it was caused by HS2 construction. They eventually admitted that we should have been offered a structural survey prior to beginning such work.

3. **The volume of construction traffic using the haul road.** HS2 documents, prior to construction, showed 22 predicted HGV movements in either direction using our lane in 2021. This has proved to be a vast underestimate according to Align's own figures. For example, Mr Wall's weekday counts for October 2021 frequently registered in excess of 130 total HGV movements. HS2 have refused to provide figures of the total number of HGVs

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going to and from the Bottom House Farm Lane vent shaft site.

4. **Closure of much of Bottom House Farm Lane for an extended period**. In May 2020, we were advised of a three-month closure of a short stretch of the lane near the vent shaft compound. In fact, a much longer section of the lane was closed for virtually the whole of 2021, apparently for drainage installation. There was no mitigation for residents, making us trespassers on our own lane. Our children could no longer cycle a safe way to Chalfont St Giles, avoiding the busy A413, nor could we walk or run on the lane. HS2 indicated that we should use detour footpaths, which became overgrown and impassable in the summer.
   On one occasion Mrs Wall attempted to cycle home along the haul road from Bottrells Lane, as the existing lane was fenced off. She found her route blocked by gates manned by a security guard 200 yards from the house. The guard refused to let her through and she was forced to take a 3-mile detour to get home.

5. **Access to our home.** We were assured by HS2 that access would be maintained throughout construction. However, once the haul road was completed, our end of the existing lane was turned into a cul-de-sac and HS2 then carried out resurfacing at the other end of the cul-de-sac, cutting us off entirely between 08:00 and 16:00 for seven days. We had to request permission to leave our home, including to go to work. Any deliveries, such as courier or shopping deliveries, were impossible.
   The result of turning our end of the lane into a cul-de-sac is that we have since had to take a detour of approximately a quarter of a mile every time we go out or return.
   Poor and confusing signage by HS2 has, at times, resulted in parcels failing to arrive. This problem was particularly acute before Christmas 2020, when numerous packages did not arrive, with members of the family receiving emails saying they had been "undeliverable".

6. **Working hours.** The HS2 Environmental Statement states: "Core site operating hours will be 08:00 to 18:00 on weekdays and 08:00 to 13:00 on Saturdays." However, throughout construction, there have been many HGV movements outside these hours; eg on 21 October 2021, six unladen earth-moving trucks went past our house towards the vent shaft site by 0713 and seven fully laden trucks left the site before 07:45.
   Then on 20 December 2021 we were informed via a "Construction Update" from Align that the working hours had been extended at the vent shaft to 07:00 to 22:00 with one hour's start up and shut down outside of those hours. The HS2 update stated: "For HGV movements, apart from concrete deliveries or abnormal loads, all deliveries to and from the site, as far as reasonably practicable, will be between 7am and 10pm." However, HGVs often begin arriving before 06:00.
   We learnt that the extension of the working hours had begun in September 2021. During that period, we were having regular meetings with members of Align, the HS2 contractors building the vent shaft, aimed at 'consulting' us. But they did not inform us of this change.
   Traffic lights installed at the junction with the A413 mean additional noise and pollution from vehicles stopping and starting, including the many HGVs. The noise early in the morning is particularly problematic for Mrs Wall, who is a shift worker, sometimes finishing at midnight.

7. **Night work**. Despite earlier assurances to us from HS2's contractors that no night work would be required, in March 2021, overnight works were carried out at the junction of Bottom House Farm Lane and the A413.
   We obtained the "Control of Pollution Act 1974, Section 61, Prior Consent for Work" notice for this from Buckinghamshire County Council. This showed that HS2 had originally sought permission for five nights of overnight works. When they could see they wouldn't manage to finish in that time, they requested a further two nights, which the Council approved with one

day of notice rather than the required two weeks. This work continued until after 3am some nights but HS2 only carried out noise monitoring until midnight. We know from reports submitted by Goodhand Acoustics to Buckinghamshire County Council that noise insulation levels were repeatedly triggered during the hours before midnight, when the noise frequently exceeded 90 decibels. We asked at the time and subsequently why noise monitoring stopped at midnight but have never received an explanation. This period of HS2 overnight works showed total disregard for the wellbeing of all residents around the junction.

8. **Uncertainty about permanent lane.** Under the HS2 Hybrid Bill, the haul road is temporary and must be removed. There has long been concern among residents on the lane that this will not in fact happen and the haul road will be permanent, meaning permanent blight to our home, with the loss of our view and privacy and consequent diminution of value.
   HS2 have for many months been promising us designs for rebuilding the junction of Bottom House Farm Lane and the A413 once the haul road has been removed. The lane is to be widened, with its height past our house raised in order to lessen the gradient where it meets the A413. Until these designs are forthcoming we are in limbo, with no idea as to how our drive will meet the re-profiled lane and how far the permanent outcome will blight our property.
   The above work, including breaking up the tarmac, will obviously mean many more months of noise, vibrations, disruption and difficulty accessing our home.

9. **Failure to provide statutory notice.** HS2 claims to be committed to providing two weeks' notice to those affected by its works, as set out in the Code of Construction Practice. Yet on numerous occasions, as in point 7. above, it has failed to do so. Indeed, a letter from Roger Mountford, Chairman Special Cases Panel, stated that a "revision of works timings to provide you with 14-days' notice" was among "enhanced measures", which HS2 claim to have granted us. So HS2 appeared to say that compliance with the commitment to providing two weeks' notice was a special favour to us.

10. **Responses to complaints.** Any complaint made to HS2 has been whitewashed and no liability ever admitted, even when it's plain that they are in the wrong. On occasions when we have complained about questions not being answered, the complaint still has not resulted in proper answers being provided. The Public Response Team that addresses complaints rarely meets its own timescales for responses.
    While we have at times had meetings with HS2's contractors, these have rarely resulted in our complaints being addressed or questions being answered. We have often felt that the meetings have been little more than a tickbox exercise, allowing HS2 to claim that they were "engaging" with us.

Over the years since HS2 arrived in our lane, there have been many absurdities, which HS2 have stubbornly refused to acknowledge or act upon. For example, while the embankment was being built, all HS2 traffic had to use the existing Bottom House Farm Lane, next to our house. HS2 insisted on erecting unnecessary national speed limit signs at the entrance to the lane, at a time when the speed limit on the A413 had been reduced to 40mph. This, in effect, encouraged HGVs to drive faster on the single-track farm lane than the main road, past our house with its children and pets. There had never been a national speed limit sign on the lane prior to the works beginning.
Mrs Wall had to write to our then MP, Dame Cheryl Gillan, and Buckinghamshire County Council for any action to be taken on this.

On one occasion an HS2 security guard told Mrs Wall she was not allowed to film, as she photographed trees being felled in Bottom House Farm Lane during bird nesting season. Yet it is illegal to intentionally damage or destroy wild birds' nests while they are being used or built.

When a handful of lane residents had the temerity to stage a small, peaceful protest in May 2021 against the ongoing closure of the lane, a police patrol car arrived, and the officer questioned us. We concluded that only HS2 could have requested the police presence, as if in an attempt to intimidate us.

HS2's construction of the haul road and embankment has radically changed the peaceful nature of the rural farm lane we previously lived on. Since the haul road is much wider and straighter than the lane, some car drivers have tried to use it as a race track. We have video of a convoy of cars speeding down it off the A413. HS2 at one point removed the security barrier on the haul road. We and other residents argued that this was against the agreement initially made and would be an invitation to some drivers to use the full length of the haul road as a race track. HS2 finally reinstated the security barrier.

There has been fly-tipping, of a mattress and other items. a hundred yards or so from our home, which never happened before the arrival of HS2. There was also a massive increase in the level of littering, on roads, verges and in fields. Items we have picked up include numerous pieces of soft plastic packaging from construction materials, cable ties, paint cans used for marking roads, laminated signs, electrical wiring, cups, bottles, cigarette packets, snack and other food wrappers, and even plastic packaging with the label "Considerate Constructors" on it.

HS2 construction work on our doorstep and along the length of our once quiet rural lane, has taken a toll on the peaceful enjoyment of our home, our ability to access our property and our mental wellbeing. It has been a frustrating and challenging period for our entire family, with Mrs Wall seeking stress counselling. We have spent hundreds if not thousands of hours on HS2 correspondence and meetings, going back to 2015, mostly in attempts to get information or to try and make HS2 carry out actions they had agreed to.

We loved our home and its location and our children attend a local grammar school, so we would not otherwise be considering moving house. However, the stress, blight and uncertainty over future works and the value of our house have driven us to conclude that our only option is to leave.

For years, HS2 refused to discuss compensation for the blight to our home and the impact on our quality of life. They directed us to the "Need to Sell" scheme, under which we could have applied for HS2 to buy our house for their idea of an "unblighted" valuation. The "Need to Sell" scheme would have resulted in a considerable financial loss for us, because even if HS2 had offered us a fair unblighted valuation, we would have to have paid our moving costs and stamp duty on a new property.

Only after we involved our current MP, Sarah Green, and the Residents' Commissioner, did HS2 offer us the equivalent of compulsory purchase terms in March 2022. Two months later the process of valuations has not yet begun because HS2 proposed appointing a surveyor from the Valuations Office Agency (who already represented them) to do an 'independent' valuation, despite the VOA not even being on the approved list of valuers they provided.


D2741

In support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

from
Dr.Susan M. Arnott, 171 Brook Drive, London SE11 4TG
A former research biologist (U.Minnesota, then University College London) and documentary film-maker (Channel 4, BBC, Channel 5; Govt.s Papua New Guinea & Kenya; UN/FAO, European Commission, British Council, DfID, Oxfam *inter alia*).

I believe the following to be a true and honest account to the best of my knowledge.

1. The proposed train line will increase, not decrease, our cumulative carbon emissions over the coming century.
   This seemed counter-intuitive, until I examined the hard sums involving 'carbon footprints' of steel and concrete production, and the embedded carbon costs in construction work, labour etc. These are not remotely 'off-set' by likely savings incurred by modal shift or other changes in travel&transport.
   The Phase2 information paper indicates net emissions of 1.49megatonnes of CO_2e (carbon dioxide equivalent), over the proposed 120-year lifespan. A small proportion of the UK's total current 'travel&transport' emissions, but we should be reducing these, not adding to them.
2. The 'opportunity costs' of HS2 are many, and substantial. They include:
   a) Financial: costs are massive, and this investment is very badly needed elsewhere. For example, insulation of housing and other building stock would do far more to reduce our collective carbon emissions. Likewise, renewable energy production and storage.
   b) Ideological: the project serves a misguided notion that spending, consuming and travelling as much or more as before, just in 'greener ways', is a viable response to the Climate Emergency.
   c) Sector-wide 'goodwill' and 'head-space': full electrification of our existing railway system is dreadfully overdue. The sector is in any case handicapped by the awkwardnesses of privatisation and franchising; no efforts should be wasted on an illogical project like HS2.
3. The construction of the proposed lines would continue savage destruction of long-established ecosystems.
   Even well-intentioned tree-planting and 're-wilding' cannot replace ancient woodlands; waterways are being damaged with un-knowable knock-on effects; complex soil systems can't be 'bought and replaced'.

I've had no direct dealings with HS2, beyond mourning loss of woodlands I wandered as a child growing up in Wendover (the family moved away in 1989). A recent funeral in Amersham took me walking from the train station to the crematorium, past one of the construction sites; having only read about the project until then, the extent and scale horrified me.
The protests seem not only valid but brave and commendable. I'm in my sixties, but many of those putting themselves in danger to resist this project are decades younger, with so much more at stake.
Yours sincerely,

Susi Arnott

Dated: 6 May 2022

To whom it may concern:

Regarding: HS2 Route Wide Injunction QB-2022-BHM-00044 HS2 Ltd and SoS v Persons Unknown and Ors.

1. I am Ann Hayward, a retired Children's Guardian and Court Advisor.

2. I am a resident of Halton Lane, Wendover, Bucks, HP22 6AR.

3. I make this statement as a local who has witnessed first hand the arrival in, and taking over and dismantling of, my village and surrounding countryside by HS2 for the past two years

4. I am a local who enjoyed walking her dog and taking family for walks into the countryside around Wendover. This has been severely restricted and in some areas curtailed for good, since the arrival of HS2 in the village.

5.HS2 maps are notoriously difficult to read/interpret it is often difficult to know if one is trespassing on HS2 land or not. HS2 expands it's compounds and land take without a moments notice so it becomes difficult to know where one can or cannot walk. My experience has been that any approach to me by HS2 has usually been accompanied by hostility and an uncaring and beligerent attitude that lacks any hint of engagement with the locals.

6.I have experienced first hand HS2s bullying and intimidating tactics. These tactics, used by HS2 employees, (and includes Thames Valley Police (TVP), National Eviction Team (NET) and Incident Response Team (IRT) all working with HS2) included following me (making me feel uncomfortable and threatened), taunting me for my age and for being sympathetic to the woodland Protectors, bringing aggressive guard dogs on to the public highway to intimidate and frighten me, and threatening me with arrest for trespass.

8.It is therefore with some concern that I have learned that HS2 wish to obtain a Route Wide Injunction against named people and 'persons unknown'. This is a sweeping order that would allow HS2 the right to 'pick and chose' who they target or indeed to target ANYONE being in the vicinity of their works. They could treat everyone with the same beligerence, disrespect and intimidation that I have experienced.

9.In my view, this goes against democracry, to a persons right to protest, object or challenge. I believe that, as service of the injunction will be difficult and, indeed may well be insufficient everyone within the vicinity of HS2 works could, in a worse case scenario, be at risk of arrest and this potentially risks criminalising locals and communities along the route who object to the project for whatever reason.

10.It became apparent to me, as I walked the Wendover lanes, that HS2 displayed no accountability to anyone for the deep flaws in the project around their Environmental statement, carbon equations etc. I established that Hs2 often 'marked it's own homework' in regards to meeting environmental standards and assessment of it's environmental 'worthiness'. There appeared no valid oversight of

D2743

HS2s environmental care other than by the woodland protectors, independent ecologists and environmentalists and in my view, it was their right to do so. It was and still is, absolutely necessary.

11. I fully supported the woodland protection camps in Wendover as they were one of the few valiantly holding HS2 to account for their environmental misdemeanors, something, which it appeared to me, HS2 clearly did not want to be highlighted and yet which clearly needed to be challenged.

12. It is my opinion that HS2s Route Wide Injunction would be used to protect itself from such scrutiny. They have the money to shield their possibly unlawful behaviour. This is an abuse of power and a missue of injunctions.

13.Wendover has lost miles of mature hedgerows to HS2,as well as ancient trees and woodlands, several small spinneys and medieval woodland and meadows. Agricultural land with footpaths, farm houses and buildings, many of which were heritage buildings and long established homes to owls, bats, some very rare, and other birds and wildlife which are now gone for good because of HS2 lax environmental oversight. Wendover is now about to lose to HS2, it's heritage high street cottages, a street where people walk everyday.

14. It is vital,therefore, in my view, that people need to know if an injunction exists on or near property and land for their safety and well being. It could be that every person on the route could find themselves potentially at risk of arrest under the HS2 injunction, HS2 does not offer well defined maps or show a duty of care or engagement to anyone.

15. It is my belief that it would be difficult to apply the order, difficult to abide by it and difficult to police it. It is confusing where the injunction starts and ends but importantly the Injunction is being used to stop Protest and challenge, which is a Human Right guarranteed under the Human Rights Act 1998, any interference with non-violent/peaceful protest risks undermining these Convention rights.

I believe this statement to be a true and honest account to the best of my knowledge and I am happy for it to be forwarded as evidence.

Signed

Ann Hayward

Dated. 6 May 2022.

This is a statement in support of the Defence against QB-2022-BHM-00044,HS2 Ltd & SoS for Transport v Persons Unknown and Ors.

Written on 15th May 2022

I am Annie Thurgarland of Box 60, Medway Bridge Marina, Manor Lane, Rochester. Kent. ME 1 3HS

I grew up on a small Nottinghamshire farm and have always spent a lot of time observing and reading about wildlife. I have worked in species ecology/ habitat restoration for the last 15 years in various habitats across the country. I have watched the decline of our biodiversity throughout my lifetime, and it saddens me that now, that our biodiversity levels are so low, we are in the bottom 10 percent Internationally.

I believe the following to be a true and honest account to the best of my knowledge.

From an ecological point of view, with our severely declining biodiversity, HS2 works are a danger we cannot afford.

Habitats and the ecosystems that rely on these habitats do not just develop overnight. Species need to be present that are the links in an ecosystem, these are finely balanced systems, struggling already through habitat fragmentation, nutrient enrichment and other pollutants, loss of habitat and climate change. There are in theory actions developed to ensure there isn't damage – through mitigation – you can't replace mature trees with new trees and expect them to support the same communities – for a long time. Mitigation relies on species surviving the initial loss of yet more of their fragile habitat. They are already vulnerable.

Biodiversity is an essential part of a healthy human ecosystem – ensuring resilience in food supplies/ healthy soils/ clean water/ removal of pollutants/ transforming waste/ not to mention the social and mental wellbeing of the presence of biodiversity – the huge decline in many of our migrant birds such as swallows and swifts – dependant on the many invertebrates present in a health ecosystem – is not to be understated as just one of many obvious declines impacting negatively on peoples wellbeing.

Our rivers are in serious trouble in many areas due to pollutants and low flows. I work on a chalk river – the idea of some one putting a tunnel through the chalk bedrock in these areas is madness. We have the majority of this rare habitat in the world and its already suffering and no one knows how we are going to restore them – just look at Nutrient Neutrality requirements across the country, imposed by Natural England – the mitigation still can't be agreed, because it's an attempt to stop pollutants and the answers are so unresearched/ ill thought out. And our rivers aren't just for biodiversity, they are a natural ecoservice, protecting us from flooding and ensuring clean water, they need more space and more protection.

Look at the loss of bentonite reported last year where HS2 works in Buckinghamshire have taken place by an aquifer – this work makes no sense in our era of water stress/ droughts and floods.

The removal of ancient woodland isn't condoned in any planning system, as it is recognised that with just over 2% of this irreplaceable habitat left, it shouldn't be touched – but this has been allowed for HS2 because this project is of national importance. Given the current economic climate and the serious climate change currently occurring, and the need to do some serious changes to our lives, now, it is difficult to see this project as of national importance. Local public transport and creating sustainable communities where people currently live, with worthwhile employment, local food sources and green space, in the locality is what is required – I would refer you to any work written by

D2745

Dr Noel Flay Cass of Lancaster University who has spent many years researching climate change and what we need to do – we need to reduce our emissions now. – see the paper – Climate scientists: concept of net zero is a dangerous trap – written by J. Dyke, university of Exeter, Robert Watson, university of east Anglia and Wolfgang Knorr, Lund university – published online by The Conversation

Even where habitats are not removed, but are heavily disturbed, as has happened in a number of areas where work has involved ancient woodland along the HS2 route, fragile, fragmented species are disturbed and made more vulnerable, at a time when recovery is harder. There have been many bats disturbed during HS2 work, all bat species are heavily protected. Research shows an impact of disturbance on paleotropical bats – Habitat disturbance results in chronic stress and impaired health status in forest – dwelling paleotropical bats – A. Seltmann, G.A. Czirjak, A Courtiol, H, Bernard, M.J. Struebig and C.C. Voigt – 2017. Conservation Physiology. Vol 5. – Research on such topics needs to be taken from a global context due to the lack of resources to fund effective projects closer to home – The Precautionary principle would surely state that if there was a likelihood of damage to a rare species and this cannot be disproved, then that damage should be avoided.

I can see no justification for HS2. I can also fully understand the need people have to express their disagreement for this travesty against the natural world through peaceful protest. I commend each and every individual who has stood up and said this is wrong, their determination in collecting the environmental data – (which should have been collected thoroughly, including species above and below ground and all seasons – well before this project and its mitigation was agreed) – to demonstrate the devastation that is being undertaken – they are doing the work that should have been done for years throughout all seasons – with something that is requiring so much mitigation. Every habitat, its size, its quality, its ecology should have been recorded. These people have fought long and hard through the appropriate channels – but the laws have been overwritten to allow this work to go ahead through the use of the words National Infrastructure. We all have a moral duty to stand up and say when something is wrong – and peaceful direct action, especially in the form of monitoring and ensuring correct procedure during works, is the last bastion for those who have not been listened to by an unhearing/ uncaring group of people who are doing immeasurable damage to the natural world and peoples lives through their actions.

These people have every right to stand up and defend the land against short-term thinking and plain lack of recognition of reality in the face of scientific research, driven by ignorance of what is being destroyed and the inability of people to accept the need for major changes is now, and its through stopping using more resources/ destroying land and rethinking how the system can work for all and the natural environment, we could possibly have a chance.

This is my statement

Annie Thurgarland

Annie Thurgarland

15th May 2022

D2746

Claim: QB -2022-BHM-00044, HS" Ltd & SoS for Transport V Persons Unknown and Ors.

Statement from [redacted]

To whom it may concern

Please note that I have chosen to submit this report anonymously for two reasons. Both are because I have been intimidated so much in the past 15 months by security/subcontractors working on behalf of HS2.

Firstly, I do not want to jeopardise the immediate quality of life for myself and my family any further whilst living at our current home.

Secondly, if this route-wide injunction is granted to HS2, it will have a direct impact on the tenancy contractual agreement of my home; being that it lies within the Act Boundary and is in fact owned by HS2. My husband and I are tenants at the property, with HS2 as our landlords, and would then be entirely at the mercy of HS2 (and their subcontractors) to interpret the contractual agreement in any way they chose. My fears are not unfounded; they are based on the series of intimidation that we have suffered over the last 15 months and the intimidation that we have witnessed our former next-door neighbours enduring, to the point that they actually left their home.

It is in fact this second point that has prompted me to write this report to the court. I write this on behalf of all the residents who live along the HS2 route and within the Act Boundary. But particularly for those who are renting their homes and have HS2 as their landlord.

1. I am extremely concerned that we were not notified of this route-wide injunction, given the enormity of the impact on residents like ourselves. None of my neighbours have been notified of this injunction either.
2. The vague term 'un-named defendants' could extend to include anyone who is deemed as 'trespassing' on HS2 land, (the Act boundary), as defined by the maps attached to the injunction application.
3. Therefore, all homes and gardens that fall within that boundary become subject to the injunction.
4. All land that falls within that boundary could therefore be subject to constant surveillance.
5. Therefore, all Human Rights to privacy and an entitlement to enjoy our home and garden (that all residents are entitled to) would be completely undermined and put at risk.
6. All tenant's family, friends or visitors to their homes (or even gardens) that fall within the Act Boundary, will also be subject to surveillance, (which must be against their Human Rights) and therefore, they too could be unwittingly deemed as 'trespassers' by HS2.
7. **Very importantly** - There is no definition in the injunction of any particular actions that 'un-named' defendants could make, albeit accidentally, that would be classed as 'trespass', other than just entering onto HS2 land. This leaves all tenants, their friends and family completely vulnerable to mis- interpretation of the injunction. This must be addressed with clarity of intent in the wording.
8. Based on all the above - Everyone who lives or visits homes or gardens within the Act Boundary is at risk of being arrested or evicted by HS2 in true **Kafkaesque** style; if they are given this indiscriminate power.
9. Any resident who lives within the Act Boundary would be so threatened by the injunction, that they would feel too intimated to complain, or legitimately object or petition to any actions taken by HS2 or their security staff or the HS2 subcontractors that they feel strongly

D2747

about **(please refer to my notes below for examples of this).** This would be another violation of their Human Rights.

10. All of the above points should be made known to all residents that live within the Act Boundary, before any 'route-wide' injunction is given consideration.

Please be aware that the points I have made above are based on my historical experience of HS2 security and intimidation, which I outline below:

The majority of residents, Councillors and MPs who live anywhere within the HS2 route-wide project Act boundary, are understandably unhappy with the devastation it has caused to their local countryside and wildlife. They would all prefer it wasn't happening but have come to accept accept that it is.

However, they continue to monitor HS2 very closely and hold them accountable for every single misdemeanour. They have the legitimate right to complain, object and petition.

I am no different to any of these residents or councillors and last March started a legitimate local resident's campaign**.**

Note: We have over 1000 local signatories on this petition now, and counting, including nearly every single tenant currently renting HS2 owned property that les within the Act Boundary and who would be directly impacted by this injunction in the ways I have outlined above.

Our campaign is to protect a 1km line oak trees that form a vital wildlife and bat corridor from needless felling by HS2. We have been successful in our campaign to a great extent and are still currently engaged in discussion with their subcontractors EKFB with regards further mitigation measures.

Last March, our intervention as a campaign, actually prevented HS2 from illegally felling these trees: given that they have subsequently agreed to redesign their over-road alignment in order that these trees may be retained. It is evident from this that they would have felled this large number of veteran oak trees last March needlessly; which breaches the Precautionary Principle and their own Environmental Statement.

However, since the start of this legal and legitimate campaign, my family and I have been subjected to the following:

1. Verbal threat during a visit from EKFB representatives that my 18 year old daughter (who is not the tenant) should stop her FB campaign, as it may affect our (my husband and my) tenancy agreement. My husband made our feeling of threat known to the EKFB representative at the time.
2. A 3 metre high security fencing which was placed beyond the permitted Construction Site boundary that actually touched our garden fence all the way around our house. With Security guards on duty all the way along, every few metres. We made our complaint known to EKFB and HS2. As well as stationary security guards, there were others, all in black, who walked along the fence line continuously, sometimes with dogs and torches. It was oppressive and distressing to me; it felt like living in a prison. This fencing was only removed after continual complaint from us to the Dept of transport, who told HS2 it was beyond their construction site boundaries .

D2748

3. 24 hour surveillance by security guards, facing our home, right up against our garden fencing, looking into our downstairs bathroom and living rooms and kitchen. Extremely intimidating as they wear full face balaclavas all night and with security lights behind them. Try to imagine silhouettes of men with just their eyes showing, facing your home at all hours of night. (Evidenced by video 1). Again I made our complaint known to EKFB and HS2.
4. Security guards would stand right next to the fence beside our cars! Wearing balaclavas! Can ypu imagine walking out of your front door to go to your car or arriving home and having to park your car and get out of it right next to one of these security men? Every single day? They would never speak but take photos of us on their personal mobile phones.Again I complained to EKFB about this. I asked how are they allowed to use their personal phones to photograph or video us?
(see video)
5. Several times I caught the security guards on my garden side of the security fencing, beyond their boundaries. So much so that my daughter and I were terrified. We had heard that many of these security employees do not have DSB checks, in fact whether true or not, we had heard that some are ex-prisoners and we felt that we had no knowledge about who these men were 'surveilling' our home 24 hours a day. I could not sleep and would often get up at early hours and find them on our side pf their security fencing. One night I filmed them and when I called out about DBS checks, they ran off pretty quickly. (see video evidence)

6. Again I complained to EKFB and HS2 and it was within days of this complaint that the security fencing was moved back to its correct placing around the correction site and I was assured by EKFB verbally that the next security team that came in were ex-soldiers. I checked this out to be true and felt more comfortable with the new distance between the security fencing and my home.

7. However, the security teams are constantly changing and we have suffered continued violations of our Human Rights. Sometimes when we return home at night in the dark or I let the dog out into the garden late, flashing torches are shone onto our faces.

8. Rotational cameras have been erected on a pole that can clearly 'see' into our home and garden and up our drive.

9. Security guards, sometimes with dogs, walk along the security fencing and shine their torches out and 'pan' them across the land to our garden. We now close our curtains every night at the back of the house (we never used to before as we are unoverlooked) and only use one tiny part of our garden now to sit out in, that we believe is completely private from surveillance. This is a complete change in our behaviour as a family.

10. Friends have reported being slowly followed by security men as they walk up our drive or security vans waiting at the bottom of the drive to film them and follow them as they leave.

11. For most of the past year, security men have sat in the dark under the trees, facing towards our home all night. Facing directly towards our downstairs and upstairs bathrooms. We do not turn on the bathroom lights any more. So intimidated are we within our own home.

12. Security vans sit and watch the front door and driveway of our home from the road. Recently (see video) I approached them from walking out of the back way of my home and hopped

over the farmers field next door, to walk along the road towards the back of their security van. As I approached their van, they saw me in their rear view mirrors and drove off. This is a blatant breach of our human rights to privacy. (I have submitted 2 videos to witness this incident.)

13. **Perhaps the most shocking incident is this:**In October last year, my husband and I were using a spa pool in our garden, that was obviously positioned in a part of the garden that we felt afforded us reasonable privacy (in a secluded corner in the 'L' shape of the house which is behind trees too). On this particular night, heavy earth moving machinery was parked just behind the security fencing, giving us what we believed to be even more privacy. However, when I left the spa and went indoors, I heard my husband shouting out. When I ran outside, we caught two security guards hiding between the machinery, positioning themselves in such a way, in order to watch us. They didn't realise that their clothing would reflect the light and tried to stand still and hide but when I shone on my torch on them and walked towards them with my camera, at first they tried to hide and then they separated and walked off quickly in separate directions. I made complaint to EKFB about this incident and even sent the video, which most people would consider outrageous. We also wrote to Sarah Green MP. In response, Sarah Green MP received not an apology for me , but a list of excuses from Andrew Stephenson as Minister of Stae for Transport on behalf of HS2 for their behaviour. He even went so far as to imply that the action was justified because of alleged security issues that had occurred 'in the area'. My husband and I were outraged by this suggestion that we had anything to do with any breaches of security and so contacted Thames Valley Police to report it as a 'peeping Tom' crime.
14. I have been given a crime reference number for this incident and, as I was advised that repeated surveillance would suggest a pattern, I intend to add the security van incident (recorded above) to that crime reference.
15. I suffer from severe anxiety and this is all too much to bear. EKFB know I suffer from severe anxiety ; I had made them aware of this from early March 2021.
16. Added to the above numerous incidents, I have witnessed first hand the terror that my former next-door neighbours suffered at the hands of HS2 security:
    Their young daughters were filmed playing in their paddock by security men who were peering at them through the hedgerow from the roadside, not behind security fencing. These young girls have been raised with home-schooling and are very naieve for their ages; 13 and 15 at that time.
    On another occasion, security guards were actually video-recorded as gesturing towards the girls and calling them 'jailbait'. I can confirm that I saw that video and can witness the fact that two EKFB security men made no attempt to hide the fact that they were watching the girls and were gesturing to the girls when they made this comment.
    Those neighbours left their home in June 2021 as a direct result of the intimidation by HS2 security. They moved back to Poland; so are unable to witness these events themselves.

Based on all the above - I respectfully request that the Court carefully consider the implication that the 'route-wide injunction' would have to all residents that live within the Act Boundary, particularly those who are living as tenants of HS2.

If residents like myself and my husband are treated as badly as we have been over the last 15 months, what protection would anyone have from worse intimidation and threats from HS2 and their subcontractors with an injunction in place?

Residents will be living in fear and this injunction will take away their human right to make objection or to petition legitimately against any action that they feel threatens their rights to privacy or security and furthermore, will prevent them from openly and legitimately objecting to any action (or lack of it) that they observe HS2 or their subcontractors taking that they believe is a breach of the Precautionary Principle or a danger to wildlife.

Yours sincerely,

[redacted] 16th May 2022

D2751

Claim: QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

My name is [redacted]

I am a local resident to both the HS2 works compound, and the Bluebell Wood Protection Camp (located on Cash's Pit on the A51).

The statement I provide is to the best of my knowledge a true and honest account related to the impact of HS2.

I regularly walk and sometimes cycle around much of the area which will be directly affected by the proposed HS2 train route - now classified as HS2 land. i am dissatisfied with the way in which HS2 generally provides very limited information when asked direct questions.

Having attended a 1:1 meeting in Madeley last year, myself and another neighbour asked a lot of questions concerning the following topics:

- Ecology monitoring
- How wildlife was going to be protected where works were scheduled
- How would safe relocation be carried out
- Traffic management systems
- Dirt / dust / noise generated

The reason I chose to live in this rural location was to walk and cycle, interact with nature and generally get away from the pollution & noise in towns / cities.

Once HS2 begins its works programme, I won't be able to continue to pursue these activities and my quality of life will be massively affected and my commute time to work will also be increased...I may even be effectively "landlocked" and unable to leave my home between certain times of day. This is not acceptable for transport project.

I also believe in the fundamental right to have an opinion and be able to voice that opinion - through peaceful protest. This is a basic fundamental human right in the UK, which certain fractions of the population / government are seeking to erode with this Injunction.

Since I have been supporting the Bluebell Wood Protection Camp, I have been photographed by members of the security team and been followed numerous times when I left Bluebell Wood Protection Camp in my vehicle - this is unlawful and very intimidating...which is probably what is intended !

HS2 did not provide the local residents with details of the injunction / proceedings - one has to ask the question: why is that ?

Regards

[redacted]

[redacted] statement in support of the Defence against the Claim QB-2022-BHM-00044, HS2 Ltd & SoS for Transport V Persons Unknown and Ors.

[redacted]

I was previously working in the care sector, before becoming ill and disabled myself. I used to live in an area that will be affected by HS2, and now live in Scotland. HS2 is a concern for people in Scotland just as much as those in England as it degrades and causes irreversible damage to precious ecosystems and the environmental richness and biodiversity of the UK

I believe the following to be a true and honest account to the best of my knowledge.

I'm sure you will be aware of much of the evidence against HS2, but I will list some of my grievances here:

1 Biodiversity loss - Wildlife is already under extreme pressures and in crisis. HS2 will add to this, causing fragmentation of some of the last patches of sanctuary for wildlife to find a home in the UK. Sites at risk include 18 Wildlife Trust nature reserves, 5 internationally designated wildlife sites, 33 Sites of Special Scientific Interest and 21 Local Nature Reserves. The designation of these areas of land as environmentally and socially important ought to have offered some protection, but HS2 has been given total priority above environmental concerns.

2 Destruction of Ancient woodland - I can't help but be angered by seeing photos of the destruction of the UK's last few remaining patches of precious areas of ancient woodland - it is heartbreaking and intolerable to witness this. The vast array of flora and fauna that the woodland supports is left without a home. Ancient woodland only now covers a mere 2% of land in the UK. Yet still the HS2 development is managing to flatten and destruct some of these few remaining areas, with 108 ancient woodlands at risk from the HS2 construction. At a time of climate emergency when we need to be valuing our trees more than ever - due to the carbon sequestration provided by these habitats, and their ability to provide alternatives to fossil fuels that are low in carbon - this makes no environmental or economic sense at all. These woodlands provide a vital resource that is irreplaceable. As the Woodland Trust states, *'no amount of replanting can replace these habitats'*. Leading Ecologists say that the proposal that ancient woodland can be relocated, is completely flawed. As Doctor Mark Everard from the University of West of England states, translocation is "essentially a smokescreen for destruction and recreation". "You can't create ancient, you can't instantly create ecosystems." This and future generations will be denied the vital role that these ancient woodlands provide.

3 Species at risk - the HS2 development will put the following species under risk of local extinction: the Willow Tit, the White-Clawed Crayfish, which is globally endangered and European-protected and the Dingy Skipper Butterfly which is considered to be a 'conservation priority'. The Wildlife Trust say that in putting these species at risk, the HS2 development will be acting in contrary to European Law as well as this Government's own biodiversity policies, and international obligations.

4 The HS2 construction is carbon intensive - Far from the argument that HS2 will help the UK cut it's carbon emissions, according to HS2's own forecasts, the overall construction and operation of HS2 over 120 years, will cause carbon emissions of 1.49m tonnes of carbon dioxide equivalent. Over the railway's projected 120-year lifetime, the government's own calculations for HS2 suggest its carbon emissions could exceed potential savings.

Those who protest against HS2 in the areas affected by this development, have sacrificed a lot to be here and have the most to lose in order to make this stand on behalf of us all. They should not need to be doing this, and have my whole hearted support, respect and gratitude. The protest is totally valid as I have always felt that those protesting are speaking for myself and so many

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others, who like me, are unable to go and be there ourselves. It is important that their protest must be able to continue as they represent so many unheard voices, who are unable to be present on the route of HS2. They are also an important independent witness of what is happening. They have voiced the exact same objections to the development as myself. The reasons they have given as to why they feel so strongly that it should not go ahead, are the very same reasons that I have voiced myself to those around me all along and in correspondence I have written or signed in objection to the development at the planning stage. The reasons are scientific and form a solid statement of all the many sane, economic, environmental, social reasons why the construction of HS2 needs to be prevented from continuing. It is an injustice to the environment, to wildlife, to future generations, and to ourselves. Those defending themselves today are only resorting to the measures they are using because the stark evidence against this project has been ignored by HS2 Ltd, and ignored by those who have permitted the development to go ahead.

Yours sincerely,

[redacted]

[redacted]

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Summary for Policymakers

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SPM

Summary for Policymakers

Drafting Authors:
Myles Allen (UK), Mustafa Babiker (Sudan), Yang Chen (China), Heleen de Coninck (Netherlands/EU), Sarah Connors (UK), Renée van Diemen (Netherlands), Opha Pauline Dube (Botswana), Kristie L. Ebi (USA), Francois Engelbrecht (South Africa), Marion Ferrat (UK/France), James Ford (UK/Canada), Piers Forster (UK), Sabine Fuss (Germany), Tania Guillén Bolaños (Germany/Nicaragua), Jordan Harold (UK), Ove Hoegh-Guldberg (Australia), Jean-Charles Hourcade (France), Daniel Huppmann (Austria), Daniela Jacob (Germany), Kejun Jiang (China), Tom Gabriel Johansen (Norway), Mikiko Kainuma (Japan), Kiane de Kleijne (Netherlands/EU), Elmar Kriegler (Germany), Debora Ley (Guatemala/Mexico), Diana Liverman (USA), Natalie Mahowald (USA), Valérie Masson-Delmotte (France), J. B. Robin Matthews (UK), Richard Millar (UK), Katja Mintenbeck (Germany), Angela Morelli (Norway/Italy), Wilfran Moufouma-Okia (France/Congo), Luis Mundaca (Sweden/Chile), Maike Nicolai (Germany), Chukwumerije Okereke (UK/Nigeria), Minal Pathak (India), Antony Payne (UK), Roz Pidcock (UK), Anna Pirani (Italy), Elvira Poloczanska (UK/Australia), Hans-Otto Pörtner (Germany), Aromar Revi (India), Keywan Riahi (Austria), Debra C. Roberts (South Africa), Joeri Rogelj (Austria/Belgium), Joyashree Roy (India), Sonia I. Seneviratne (Switzerland), Priyadarshi R. Shukla (India), James Skea (UK), Raphael Slade (UK), Drew Shindell (USA), Chandni Singh (India), William Solecki (USA), Linda Steg (Netherlands), Michael Taylor (Jamaica), Petra Tschakert (Australia/Austria), Henri Waisman (France), Rachel Warren (UK), Panmao Zhai (China), Kirsten Zickfeld (Canada).

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SPM

Introduction

This Report responds to the invitation for IPCC '... to provide a Special Report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways' contained in the Decision of the 21st Conference of Parties of the United Nations Framework Convention on Climate Change to adopt the Paris Agreement.[1]

The IPCC accepted the invitation in April 2016, deciding to prepare this Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

This Summary for Policymakers (SPM) presents the key findings of the Special Report, based on the assessment of the available scientific, technical and socio-economic literature[2] relevant to global warming of 1.5°C and for the comparison between global warming of 1.5°C and 2°C above pre-industrial levels. The level of confidence associated with each key finding is reported using the IPCC calibrated language.[3] The underlying scientific basis of each key finding is indicated by references provided to chapter elements. In the SPM, knowledge gaps are identified associated with the underlying chapters of the Report.

A. Understanding Global Warming of 1.5°C[4]

A.1 Human activities are estimated to have caused approximately 1.0°C of global warming[5] above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) (Figure SPM.1) {1.2}

A.1.1 Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (*likely* between 0.75°C and 0.99°C)[6] higher than the average over the 1850–1900 period (*very high confidence*). Estimated anthropogenic global warming matches the level of observed warming to within ±20% (*likely range*). Estimated anthropogenic global warming is currently increasing at 0.2°C (*likely* between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (*high confidence*). {1.2.1, Table 1.1, 1.2.4}

A.1.2 Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic. Warming is generally higher over land than over the ocean. (*high confidence*) {1.2.1, 1.2.2, Figure 1.1, Figure 1.3, 3.3.1, 3.3.2}

A.1.3 Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred (*medium confidence*). This assessment is based on several lines of evidence, including attribution studies for changes in extremes since 1950. {3.3.1, 3.3.2, 3.3.3}

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1 Decision 1/CP.21, paragraph 21.

2 The assessment covers literature accepted for publication by 15 May 2018.

3 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5.

4 See also Box SPM.1: Core Concepts Central to this Special Report.

5 Present level of global warming is defined as the average of a 30-year period centred on 2017 assuming the recent rate of warming continues.

6 This range spans the four available peer-reviewed estimates of the observed GMST change and also accounts for additional uncertainty due to possible short-term natural variability. {1.2.1, Table 1.1}

A.2 Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*), but these emissions alone are *unlikely* to cause global warming of 1.5°C (*medium confidence*). (Figure SPM.1) {1.2, 3.3, Figure 1.5}

A.2.1 Anthropogenic emissions (including greenhouse gases, aerosols and their precursors) up to the present are *unlikely* to cause further warming of more than 0.5°C over the next two to three decades (*high confidence*) or on a century time scale (*medium confidence*). {1.2.4, Figure 1.5}

A.2.2 Reaching and sustaining net zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing would halt anthropogenic global warming on multi-decadal time scales (*high confidence*). The maximum temperature reached is then determined by cumulative net global anthropogenic CO_2 emissions up to the time of net zero CO_2 emissions (*high confidence*) and the level of non-CO_2 radiative forcing in the decades prior to the time that maximum temperatures are reached (*medium confidence*). On longer time scales, sustained net negative global anthropogenic CO_2 emissions and/or further reductions in non-CO_2 radiative forcing may still be required to prevent further warming due to Earth system feedbacks and to reverse ocean acidification (*medium confidence*) and will be required to minimize sea level rise (*high confidence*). {Cross-Chapter Box 2 in Chapter 1, 1.2.3, 1.2.4, Figure 1.4, 2.2.1, 2.2.2, 3.4.4.8, 3.4.5.1, 3.6.3.2}

A.3 Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*). (Figure SPM.2) {1.3, 3.3, 3.4, 5.6}

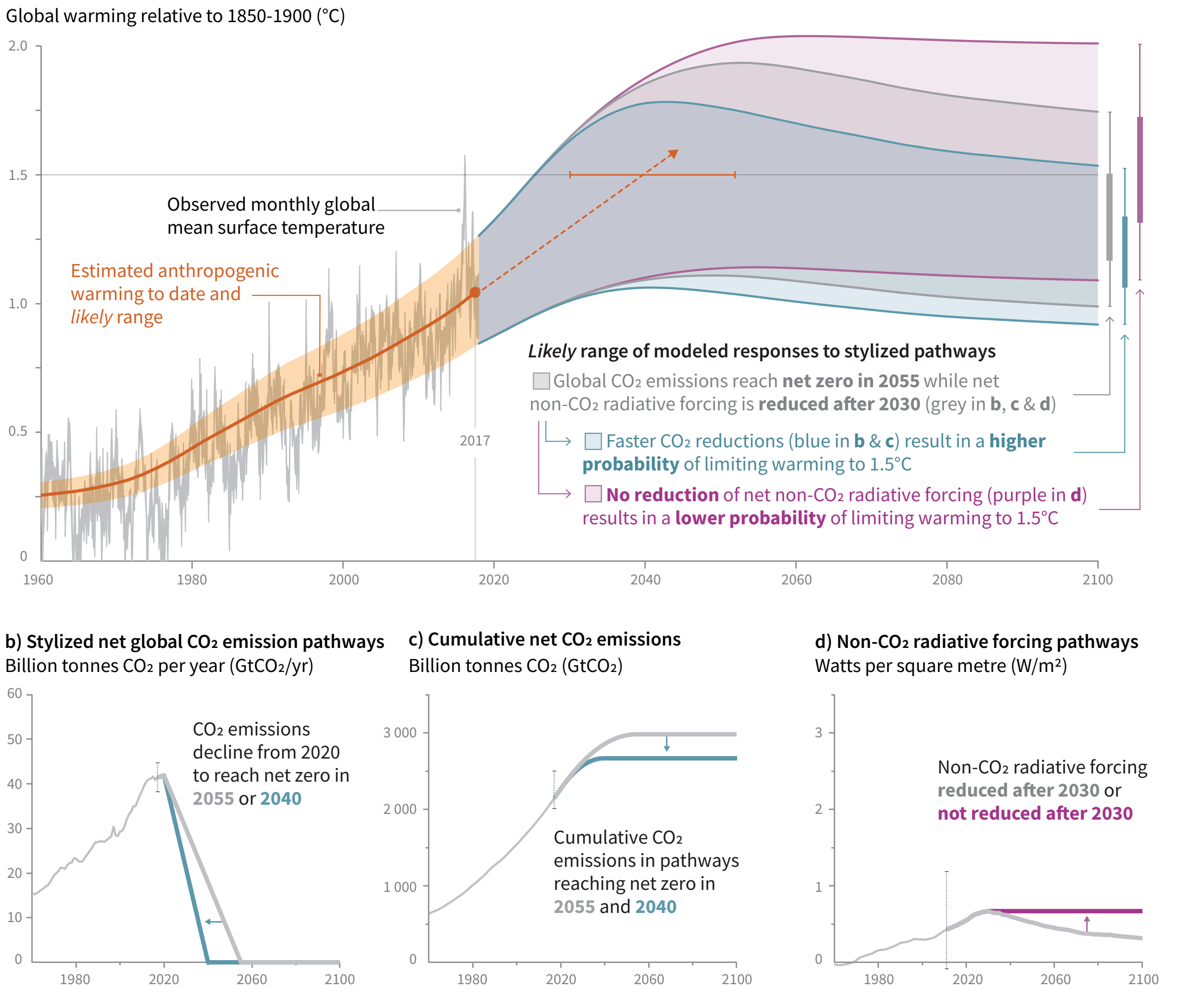
A.3.1 Impacts on natural and human systems from global warming have already been observed (*high confidence*). Many land and ocean ecosystems and some of the services they provide have already changed due to global warming (*high confidence*). (Figure SPM.2) {1.4, 3.4, 3.5}

A.3.2 Future climate-related risks depend on the rate, peak and duration of warming. In the aggregate, they are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (e.g., about 2°C) (*high confidence*). Some impacts may be long-lasting or irreversible, such as the loss of some ecosystems (*high confidence*). {3.2, 3.4.4, 3.6.3, Cross-Chapter Box 8 in Chapter 3}

A.3.3 Adaptation and mitigation are already occurring (*high confidence*). Future climate-related risks would be reduced by the upscaling and acceleration of far-reaching, multilevel and cross-sectoral climate mitigation and by both incremental and transformational adaptation (*high confidence*). {1.2, 1.3, Table 3.5, 4.2.2, Cross-Chapter Box 9 in Chapter 4, Box 4.2, Box 4.3, Box 4.6, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.4.1, 4.4.4, 4.4.5, 4.5.3}

Cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the probability of limiting warming to 1.5°C

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways



Faster immediate CO_2 emission reductions limit cumulative CO_2 emissions shown in panel **(c)**.

Maximum temperature rise is determined by cumulative net CO_2 emissions and net non-CO_2 radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

Figure SPM.1 | Panel a: Observed monthly global mean surface temperature (GMST, grey line up to 2017, from the HadCRUT4, GISTEMP, Cowtan–Way, and NOAA datasets) change and estimated anthropogenic global warming (solid orange line up to 2017, with orange shading indicating assessed *likely* range). Orange dashed arrow and horizontal orange error bar show respectively the central estimate and *likely* range of the time at which 1.5°C is reached if the current rate of warming continues. The grey plume on the right of panel a shows the *likely* range of warming responses, computed with a simple climate model, to a stylized pathway (hypothetical future) in which net CO_2 emissions (grey line in panels b and c) decline in a straight line from 2020 to reach net zero in 2055 and net non-CO_2 radiative forcing (grey line in panel d) increases to 2030 and then declines. The blue plume in panel a) shows the response to faster CO_2 emissions reductions (blue line in panel b), reaching net zero in 2040, reducing cumulative CO_2 emissions (panel c). The purple plume shows the response to net CO_2 emissions declining to zero in 2055, with net non-CO_2 forcing remaining constant after 2030. The vertical error bars on right of panel a) show the *likely* ranges (thin lines) and central terciles (33rd – 66th percentiles, thick lines) of the estimated distribution of warming in 2100 under these three stylized pathways. Vertical dotted error bars in panels b, c and d show the *likely* range of historical annual and cumulative global net CO_2 emissions in 2017 (data from the Global Carbon Project) and of net non-CO_2 radiative forcing in 2011 from AR5, respectively. Vertical axes in panels c and d are scaled to represent approximately equal effects on GMST. {1.2.1, 1.2.3, 1.2.4, 2.3, Figure 1.2 and Chapter 1 Supplementary Material, Cross-Chapter Box 2 in Chapter 1}

B. Projected Climate Change, Potential Impacts and Associated Risks

B.1 Climate models project robust[7] differences in regional climate characteristics between present-day and global warming of 1.5°C,[8] and between 1.5°C and 2°C.[8] These differences include increases in: mean temperature in most land and ocean regions (*high confidence*), hot extremes in most inhabited regions (*high confidence*), heavy precipitation in several regions *(medium confidence*), and the probability of drought and precipitation deficits in some regions (*medium confidence*). {3.3}

B.1.1 Evidence from attributed changes in some climate and weather extremes for a global warming of about 0.5°C supports the assessment that an additional 0.5°C of warming compared to present is associated with further detectable changes in these extremes (*medium confidence*). Several regional changes in climate are assessed to occur with global warming up to 1.5°C compared to pre-industrial levels, including warming of extreme temperatures in many regions (*high confidence*), increases in frequency, intensity, and/or amount of heavy precipitation in several regions (*high confidence*), and an increase in intensity or frequency of droughts in some regions (*medium confidence*). {3.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4, Table 3.2}

B.1.2 Temperature extremes on land are projected to warm more than GMST (*high confidence*): extreme hot days in mid-latitudes warm by up to about 3°C at global warming of 1.5°C and about 4°C at 2°C, and extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C and about 6°C at 2°C (*high confidence*). The number of hot days is projected to increase in most land regions, with highest increases in the tropics (*high confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in Chapter 3}

B.1.3 Risks from droughts and precipitation deficits are projected to be higher at 2°C compared to 1.5°C of global warming in some regions (*medium confidence*). Risks from heavy precipitation events are projected to be higher at 2°C compared to 1.5°C of global warming in several northern hemisphere high-latitude and/or high-elevation regions, eastern Asia and eastern North America (*medium confidence)*. Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C global warming (*medium confidence*). There is generally *low confidence* in projected changes in heavy precipitation at 2°C compared to 1.5°C in other regions. Heavy precipitation when aggregated at global scale is projected to be higher at 2°C than at 1.5°C of global warming (*medium confidence*). As a consequence of heavy precipitation, the fraction of the global land area affected by flood hazards is projected to be larger at 2°C compared to 1.5°C of global warming (*medium confidence*). {3.3.1, 3.3.3, 3.3.4, 3.3.5, 3.3.6}

B.2 By 2100, global mean sea level rise is projected to be around 0.1 metre lower with global warming of 1.5°C compared to 2°C (*medium confidence*). Sea level will continue to rise well beyond 2100 (*high confidence*), and the magnitude and rate of this rise depend on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas and deltas (*medium confidence*). {3.3, 3.4, 3.6}

B.2.1 Model-based projections of global mean sea level rise (relative to 1986–2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C of global warming, 0.1 m (0.04–0.16 m) less than for a global warming of 2°C (*medium confidence*). A reduction of 0.1 m in global sea level rise implies that up to 10 million fewer people would be exposed to related risks, based on population in the year 2010 and assuming no adaptation (*medium confidence*). {3.4.4, 3.4.5, 4.3.2}

B.2.2 Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (*high confidence*). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5°C to 2°C of global warming (*medium confidence*). (Figure SPM.2) {3.3.9, 3.4.5, 3.5.2, 3.6.3, Box 3.3}

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7 Robust is here used to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

8 Projected changes in impacts between different levels of global warming are determined with respect to changes in global mean surface air temperature.

B.2.3 Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and damage to infrastructure (*high confidence*). Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems and infrastructure reinforcement (*medium confidence*). (Figure SPM.2) {3.4.5, Box 3.5}

B.3 On land, impacts on biodiversity and ecosystems, including species loss and extinction, are projected to be lower at 1.5°C of global warming compared to 2°C. Limiting global warming to 1.5°C compared to 2°C is projected to lower the impacts on terrestrial, freshwater and coastal ecosystems and to retain more of their services to humans (*high confidence*). (Figure SPM.2) {3.4, 3.5, Box 3.4, Box 4.2, Cross-Chapter Box 8 in Chapter 3}

B.3.1 Of 105,000 species studied,[9] 6% of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5°C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C (*medium confidence*). Impacts associated with other biodiversity-related risks such as forest fires and the spread of invasive species are lower at 1.5°C compared to 2°C of global warming (*high confidence*). {3.4.3, 3.5.2}

B.3.2 Approximately 4% (interquartile range 2–7%) of the global terrestrial land area is projected to undergo a transformation of ecosystems from one type to another at 1°C of global warming, compared with 13% (interquartile range 8–20%) at 2°C (*medium confidence*). This indicates that the area at risk is projected to be approximately 50% lower at 1.5°C compared to 2°C (*medium confidence*). {3.4.3.1, 3.4.3.5}

B.3.3 High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss, with woody shrubs already encroaching into the tundra (*high confidence*) and this will proceed with further warming. Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km^2 (*medium confidence*). {3.3.2, 3.4.3, 3.5.5}

B.4 Limiting global warming to 1.5°C compared to 2°C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm-water coral reef ecosystems (*high confidence*). {3.3, 3.4, 3.5, Box 3.4, Box 3.5}

B.4.1 There is *high confidence* that the probability of a sea ice-free Arctic Ocean during summer is substantially lower at global warming of 1.5°C when compared to 2°C. With 1.5°C of global warming, one sea ice-free Arctic summer is projected per century. This likelihood is increased to at least one per decade with 2°C global warming. Effects of a temperature overshoot are reversible for Arctic sea ice cover on decadal time scales (*high confidence*). {3.3.8, 3.4.4.7}

B.4.2 Global warming of 1.5°C is projected to shift the ranges of many marine species to higher latitudes as well as increase the amount of damage to many ecosystems. It is also expected to drive the loss of coastal resources and reduce the productivity of fisheries and aquaculture (especially at low latitudes). The risks of climate-induced impacts are projected to be higher at 2°C than those at global warming of 1.5°C (*high confidence*). Coral reefs, for example, are projected to decline by a further 70–90% at 1.5°C (*high confidence*) with larger losses (>99%) at 2°C (*very high confidence*). The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2°C or more (*high confidence*). {3.4.4, Box 3.4}

9 Consistent with earlier studies, illustrative numbers were adopted from one recent meta-study.

B.4.3 The level of ocean acidification due to increasing CO_2 concentrations associated with global warming of 1.5°C is projected to amplify the adverse effects of warming, and even further at 2°C, impacting the growth, development, calcification, survival, and thus abundance of a broad range of species, for example, from algae to fish (*high confidence*). {3.3.10, 3.4.4}

B.4.4 Impacts of climate change in the ocean are increasing risks to fisheries and aquaculture via impacts on the physiology, survivorship, habitat, reproduction, disease incidence, and risk of invasive species (*medium confidence*) but are projected to be less at 1.5°C of global warming than at 2°C. One global fishery model, for example, projected a decrease in global annual catch for marine fisheries of about 1.5 million tonnes for 1.5°C of global warming compared to a loss of more than 3 million tonnes for 2°C of global warming (*medium confidence*). {3.4.4, Box 3.4}

B.5 Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C. (Figure SPM.2) {3.4, 3.5, 5.2, Box 3.2, Box 3.3, Box 3.5, Box 3.6, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 5.2}

B.5.1 Populations at disproportionately higher risk of adverse consequences with global warming of 1.5°C and beyond include disadvantaged and vulnerable populations, some indigenous peoples, and local communities dependent on agricultural or coastal livelihoods (*high confidence*). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island developing states, and Least Developed Countries (*high confidence*). Poverty and disadvantage are expected to increase in some populations as global warming increases; limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050 (*medium confidence*). {3.4.10, 3.4.11, Box 3.5, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 4.2.2.2, 5.2.1, 5.2.2, 5.2.3, 5.6.3}

B.5.2 Any increase in global warming is projected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*) and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence*). Urban heat islands often amplify the impacts of heatwaves in cities (*high confidence*). Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*). {3.4.7, 3.4.8, 3.5.5.8}

B.5.3 Limiting warming to 1.5°C compared with 2°C is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America, and in the CO_2-dependent nutritional quality of rice and wheat (*high confidence*). Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon (*medium confidence*). Livestock are projected to be adversely affected with rising temperatures, depending on the extent of changes in feed quality, spread of diseases, and water resource availability (*high confidence*). {3.4.6, 3.5.4, 3.5.5, Box 3.1, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4}

B.5.4 Depending on future socio-economic conditions, limiting global warming to 1.5°C compared to 2°C may reduce the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%, although there is considerable variability between regions (*medium confidence*). Many small island developing states could experience lower water stress as a result of projected changes in aridity when global warming is limited to 1.5°C, as compared to 2°C (*medium confidence*). {3.3.5, 3.4.2, 3.4.8, 3.5.5, Box 3.2, Box 3.5, Cross-Chapter Box 9 in Chapter 4}

B.5.5 Risks to global aggregated economic growth due to climate change impacts are projected to be lower at 1.5°C than at 2°C by the end of this century[10] (*medium confidence*). This excludes the costs of mitigation, adaptation investments and the benefits of adaptation. Countries in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change should global warming increase from 1.5°C to 2°C (*medium confidence*). {3.5.2, 3.5.3}

10 Here, impacts on economic growth refer to changes in gross domestic product (GDP). Many impacts, such as loss of human lives, cultural heritage and ecosystem services, are difficult to value and monetize.

B.5.6 Exposure to multiple and compound climate-related risks increases between 1.5°C and 2°C of global warming, with greater proportions of people both so exposed and susceptible to poverty in Africa and Asia (*high confidence*). For global warming from 1.5°C to 2°C, risks across energy, food, and water sectors could overlap spatially and temporally, creating new and exacerbating current hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions (*medium confidence*). {Box 3.5, 3.3.1, 3.4.5.3, 3.4.5.6, 3.4.11, 3.5.4.9}

B.5.7 There are multiple lines of evidence that since AR5 the assessed levels of risk increased for four of the five Reasons for Concern (RFCs) for global warming to 2°C (*high confidence*). The risk transitions by degrees of global warming are now: from high to very high risk between 1.5°C and 2°C for RFC1 (Unique and threatened systems) (*high confidence*); from moderate to high risk between 1°C and 1.5°C for RFC2 (Extreme weather events) (*medium confidence*); from moderate to high risk between 1.5°C and 2°C for RFC3 (Distribution of impacts) (*high confidence*); from moderate to high risk between 1.5°C and 2.5°C for RFC4 (Global aggregate impacts) (*medium confidence*); and from moderate to high risk between 1°C and 2.5°C for RFC5 (Large-scale singular events) (*medium confidence*). (Figure SPM.2) {3.4.13; 3.5, 3.5.2}

B.6 Most adaptation needs will be lower for global warming of 1.5°C compared to 2°C (*high confidence*). There are a wide range of adaptation options that can reduce the risks of climate change (*high confidence*). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, with associated losses (*medium confidence*). The number and availability of adaptation options vary by sector (*medium confidence*). {Table 3.5, 4.3, 4.5, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5}

B.6.1 A wide range of adaptation options are available to reduce the risks to natural and managed ecosystems (e.g., ecosystem-based adaptation, ecosystem restoration and avoided degradation and deforestation, biodiversity management, sustainable aquaculture, and local knowledge and indigenous knowledge), the risks of sea level rise (e.g., coastal defence and hardening), and the risks to health, livelihoods, food, water, and economic growth, especially in rural landscapes (e.g., efficient irrigation, social safety nets, disaster risk management, risk spreading and sharing, and community-based adaptation) and urban areas (e.g., green infrastructure, sustainable land use and planning, and sustainable water management) (*medium confidence*). {4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.5.3, 4.5.4, 5.3.2, Box 4.2, Box 4.3, Box 4.6, Cross-Chapter Box 9 in Chapter 4}.

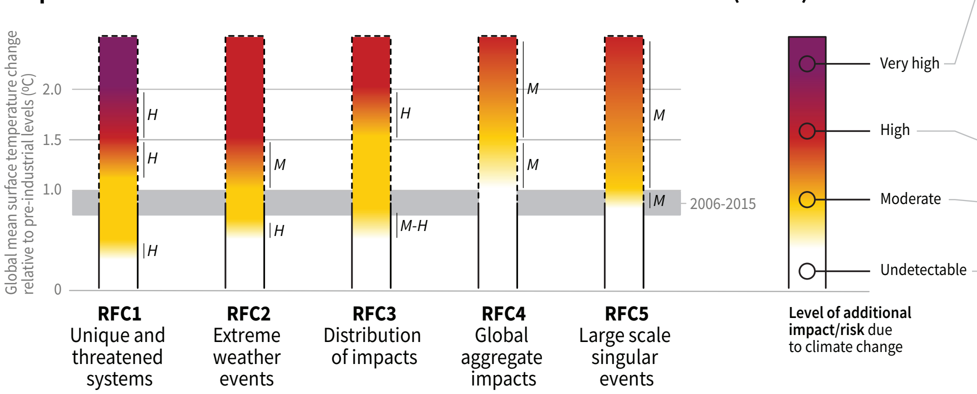
B.6.2 Adaptation is expected to be more challenging for ecosystems, food and health systems at 2°C of global warming than for 1.5°C (*medium confidence*). Some vulnerable regions, including small islands and Least Developed Countries, are projected to experience high multiple interrelated climate risks even at global warming of 1.5°C (*high confidence*). {3.3.1, 3.4.5, Box 3.5, Table 3.5, Cross-Chapter Box 9 in Chapter 4, 5.6, Cross-Chapter Box 12 in Chapter 5, Box 5.3}

B.6.3 Limits to adaptive capacity exist at 1.5°C of global warming, become more pronounced at higher levels of warming and vary by sector, with site-specific implications for vulnerable regions, ecosystems and human health (*medium confidence*). {Cross-Chapter Box 12 in Chapter 5, Box 3.5, Table 3.5}

How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



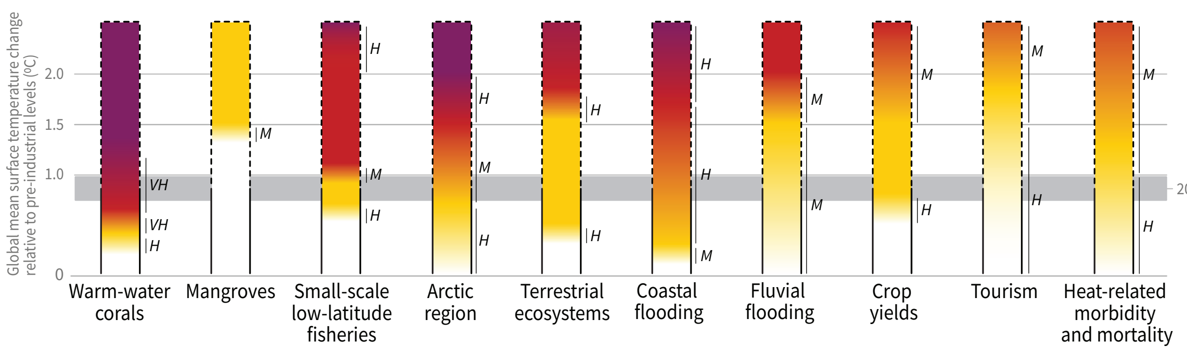
Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.

Red indicates severe and widespread impacts/risks.

Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.

White indicates that no impacts are detectable and attributable to climate change.

Impacts and risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Figure SPM.2 | Five integrative reasons for concern (RFCs) provide a framework for summarizing key impacts and risks across sectors and regions, and were introduced in the IPCC Third Assessment Report. RFCs illustrate the implications of global warming for people, economies and ecosystems. Impacts and/or risks for each RFC are based on assessment of the new literature that has appeared. As in AR5, this literature was used to make expert judgments to assess the levels of global warming at which levels of impact and/or risk are undetectable, moderate, high or very high. The selection of impacts and risks to natural, managed and human systems in the lower panel is illustrative and is not intended to be fully comprehensive. {3.4, 3.5, 3.5.2.1, 3.5.2.2, 3.5.2.3, 3.5.2.4, 3.5.2.5, 5.4.1, 5.5.3, 5.6.1, Box 3.4}

RFC1 Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its indigenous people, mountain glaciers and biodiversity hotspots.

RFC2 Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heat waves, heavy rain, drought and associated wildfires, and coastal flooding.

RFC3 Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability.

RFC4 Global aggregate impacts: global monetary damage, global-scale degradation and loss of ecosystems and biodiversity.

RFC5 Large-scale singular events: are relatively large, abrupt and sometimes irreversible changes in systems that are caused by global warming. Examples include disintegration of the Greenland and Antarctic ice sheets.

SPM

C. Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

C.1 In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range). For limiting global warming to below 2°C[11] CO_2 emissions are projected to decline by about 25% by 2030 in most pathways (10–30% interquartile range) and reach net zero around 2070 (2065–2080 interquartile range). Non-CO_2 emissions in pathways that limit global warming to 1.5°C show deep reductions that are similar to those in pathways limiting warming to 2°C. (*high confidence*) (Figure SPM.3a) {2.1, 2.3, Table 2.4}

C.1.1 CO_2 emissions reductions that limit global warming to 1.5°C with no or limited overshoot can involve different portfolios of mitigation measures, striking different balances between lowering energy and resource intensity, rate of decarbonization, and the reliance on carbon dioxide removal. Different portfolios face different implementation challenges and potential synergies and trade-offs with sustainable development. (*high confidence*) (Figure SPM.3b) {2.3.2, 2.3.4, 2.4, 2.5.3}

C.1.2 Modelled pathways that limit global warming to 1.5°C with no or limited overshoot involve deep reductions in emissions of methane and black carbon (35% or more of both by 2050 relative to 2010). These pathways also reduce most of the cooling aerosols, which partially offsets mitigation effects for two to three decades. Non-CO_2 emissions[12] can be reduced as a result of broad mitigation measures in the energy sector. In addition, targeted non-CO_2 mitigation measures can reduce nitrous oxide and methane from agriculture, methane from the waste sector, some sources of black carbon, and hydrofluorocarbons. High bioenergy demand can increase emissions of nitrous oxide in some 1.5°C pathways, highlighting the importance of appropriate management approaches. Improved air quality resulting from projected reductions in many non-CO_2 emissions provide direct and immediate population health benefits in all 1.5°C model pathways. (*high confidence*) (Figure SPM.3a) {2.2.1, 2.3.3, 2.4.4, 2.5.3, 4.3.6, 5.4.2}

C.1.3 Limiting global warming requires limiting the total cumulative global anthropogenic emissions of CO_2 since the pre-industrial period, that is, staying within a total carbon budget (*high confidence*).[13] By the end of 2017, anthropogenic CO_2 emissions since the pre-industrial period are estimated to have reduced the total carbon budget for 1.5°C by approximately 2200 ± 320 $GtCO_2$ (*medium confidence*). The associated remaining budget is being depleted by current emissions of 42 ± 3 $GtCO_2$ per year (*high confidence*). The choice of the measure of global temperature affects the estimated remaining carbon budget. Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 $GtCO_2$ for a 50% probability of limiting warming to 1.5°C, and 420 $GtCO_2$ for a 66% probability (*medium confidence*).[14] Alternatively, using GMST gives estimates of 770 and 570 $GtCO_2$, for 50% and 66% probabilities,[15] respectively (*medium confidence*). Uncertainties in the size of these estimated remaining carbon budgets are substantial and depend on several factors. Uncertainties in the climate response to CO_2 and non-CO_2 emissions contribute ±400 $GtCO_2$ and the level of historic warming contributes ±250 $GtCO_2$ (*medium confidence*). Potential additional carbon release from future permafrost thawing and methane release from wetlands would reduce budgets by up to 100 $GtCO_2$ over the course of this century and more thereafter (*medium confidence*). In addition, the level of non-CO_2 mitigation in the future could alter the remaining carbon budget by 250 $GtCO_2$ in either direction (*medium confidence*). {1.2.4, 2.2.2, 2.6.1, Table 2.2, Chapter 2 Supplementary Material}

C.1.4 Solar radiation modification (SRM) measures are not included in any of the available assessed pathways. Although some SRM measures may be theoretically effective in reducing an overshoot, they face large uncertainties and knowledge gaps

11 References to pathways limiting global warming to 2°C are based on a 66% probability of staying below 2°C.

12 Non-CO_2 emissions included in this Report are all anthropogenic emissions other than CO_2 that result in radiative forcing. These include short-lived climate forcers, such as methane, some fluorinated gases, ozone precursors, aerosols or aerosol precursors, such as black carbon and sulphur dioxide, respectively, as well as long-lived greenhouse gases, such as nitrous oxide or some fluorinated gases. The radiative forcing associated with non-CO_2 emissions and changes in surface albedo is referred to as non-CO_2 radiative forcing. {2.2.1}

13 There is a clear scientific basis for a total carbon budget consistent with limiting global warming to 1.5°C. However, neither this total carbon budget nor the fraction of this budget taken up by past emissions were assessed in this Report.

14 Irrespective of the measure of global temperature used, updated understanding and further advances in methods have led to an increase in the estimated remaining carbon budget of about 300 $GtCO_2$ compared to AR5. (*medium confidence*) {2.2.2}

15 These estimates use observed GMST to 2006–2015 and estimate future temperature changes using near surface air temperatures.

as well as substantial risks and institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development. They also do not mitigate ocean acidification. (*medium confidence*) {4.3.8, Cross-Chapter Box 10 in Chapter 4}

Global emissions pathway characteristics

General characteristics of the evolution of anthropogenic net emissions of CO_2, and total emissions of methane, black carbon, and nitrous oxide in model pathways that limit global warming to 1.5°C with no or limited overshoot. Net emissions are defined as anthropogenic emissions reduced by anthropogenic removals. Reductions in net emissions can be achieved through different portfolios of mitigation measures illustrated in Figure SPM.3b.

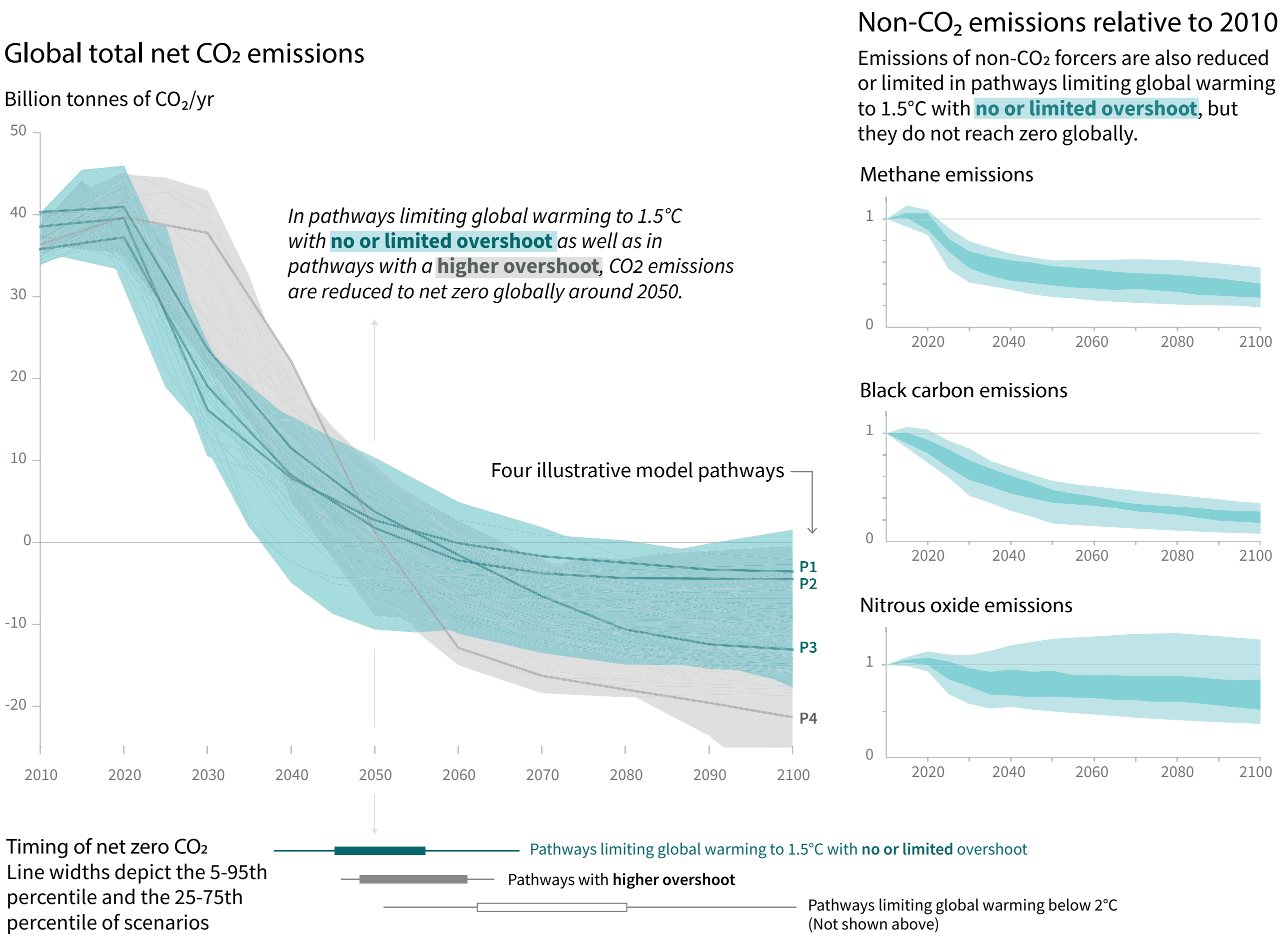
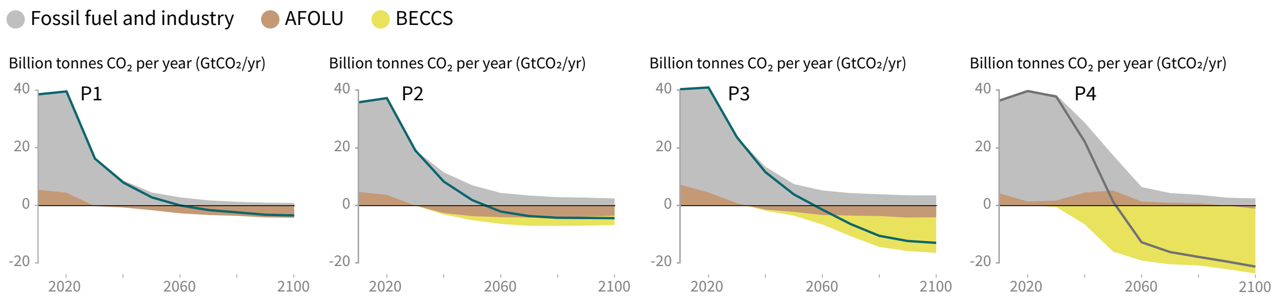


Figure SPM.3a | Global emissions pathway characteristics. The main panel shows global net anthropogenic CO_2 emissions in pathways limiting global warming to 1.5°C with no or limited (less than 0.1°C) overshoot and pathways with higher overshoot. The shaded area shows the full range for pathways analysed in this Report. The panels on the right show non-CO_2 emissions ranges for three compounds with large historical forcing and a substantial portion of emissions coming from sources distinct from those central to CO_2 mitigation. Shaded areas in these panels show the 5–95% (light shading) and interquartile (dark shading) ranges of pathways limiting global warming to 1.5°C with no or limited overshoot. Box and whiskers at the bottom of the figure show the timing of pathways reaching global net zero CO_2 emission levels, and a comparison with pathways limiting global warming to 2°C with at least 66% probability. Four illustrative model pathways are highlighted in the main panel and are labelled P1, P2, P3 and P4, corresponding to the LED, S1, S2, and S5 pathways assessed in Chapter 2. Descriptions and characteristics of these pathways are available in Figure SPM.3b. {2.1, 2.2, 2.3, Figure 2.5, Figure 2.10, Figure 2.11}

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
└ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
└ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
└ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
└ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
└ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
└ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
└ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
└ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
└ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
└ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
└ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km²)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

Figure SPM.3b | Characteristics of four illustrative model pathways in relation to global warming of 1.5°C introduced in Figure SPM.3a. These pathways were selected to show a range of potential mitigation approaches and vary widely in their projected energy and land use, as well as their assumptions about future socio-economic developments, including economic and population growth, equity and sustainability. A breakdown of the global net anthropogenic CO_2 emissions into the contributions in terms of CO_2 emissions from fossil fuel and industry; agriculture, forestry and other land use (AFOLU); and bioenergy with carbon capture and storage (BECCS) is shown. AFOLU estimates reported here are not necessarily comparable with countries' estimates. Further characteristics for each of these pathways are listed below each pathway. These pathways illustrate relative global differences in mitigation strategies, but do not represent central estimates, national strategies, and do not indicate requirements. For comparison, the right-most column shows the interquartile ranges across pathways with no or limited overshoot of 1.5°C. Pathways P1, P2, P3 and P4 correspond to the LED, S1, S2 and S5 pathways assessed in Chapter 2 (Figure SPM.3a). {2.2.1, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.1, 2.4.2, 2.4.4, 2.5.3, Figure 2.5, Figure 2.6, Figure 2.9, Figure 2.10, Figure 2.11, Figure 2.14, Figure 2.15, Figure 2.16, Figure 2.17, Figure 2.24, Figure 2.25, Table 2.4, Table 2.6, Table 2.7, Table 2.9, Table 4.1}

C.2 Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (*high confidence*). These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options (*medium confidence*). {2.3, 2.4, 2.5, 4.2, 4.3, 4.4, 4.5}

C.2.1 Pathways that limit global warming to 1.5°C with no or limited overshoot show system changes that are more rapid and pronounced over the next two decades than in 2°C pathways (*high confidence*). The rates of system changes associated with limiting global warming to 1.5°C with no or limited overshoot have occurred in the past within specific sectors, technologies and spatial contexts, but there is no documented historic precedent for their scale (*medium confidence*). {2.3.3, 2.3.4, 2.4, 2.5, 4.2.1, 4.2.2, Cross-Chapter Box 11 in Chapter 4}

C.2.2 In energy systems, modelled global pathways (considered in the literature) limiting global warming to 1.5°C with no or limited overshoot (for more details see Figure SPM.3b) generally meet energy service demand with lower energy use, including through enhanced energy efficiency, and show faster electrification of energy end use compared to 2°C (*high confidence*). In 1.5°C pathways with no or limited overshoot, low-emission energy sources are projected to have a higher share, compared with 2°C pathways, particularly before 2050 (*high confidence*). In 1.5°C pathways with no or limited overshoot, renewables are projected to supply 70–85% (interquartile range) of electricity in 2050 (*high confidence*). In electricity generation, shares of nuclear and fossil fuels with carbon dioxide capture and storage (CCS) are modelled to increase in most 1.5°C pathways with no or limited overshoot. In modelled 1.5°C pathways with limited or no overshoot, the use of CCS would allow the electricity generation share of gas to be approximately 8% (3–11% interquartile range) of global electricity in 2050, while the use of coal shows a steep reduction in all pathways and would be reduced to close to 0% (0–2% interquartile range) of electricity (*high confidence*). While acknowledging the challenges, and differences between the options and national circumstances, political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies have substantially improved over the past few years (*high confidence*). These improvements signal a potential system transition in electricity generation. (Figure SPM.3b) {2.4.1, 2.4.2, Figure 2.1, Table 2.6, Table 2.7, Cross-Chapter Box 6 in Chapter 3, 4.2.1, 4.3.1, 4.3.3, 4.5.2}

C.2.3 CO_2 emissions from industry in pathways limiting global warming to 1.5°C with no or limited overshoot are projected to be about 65–90% (interquartile range) lower in 2050 relative to 2010, as compared to 50–80% for global warming of 2°C (*medium confidence*). Such reductions can be achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage (CCUS). These options are technically proven at various scales but their large-scale deployment may be limited by economic, financial, human capacity and institutional constraints in specific contexts, and specific characteristics of large-scale industrial installations. In industry, emissions reductions by energy and process efficiency by themselves are insufficient for limiting warming to 1.5°C with no or limited overshoot (*high confidence*). {2.4.3, 4.2.1, Table 4.1, Table 4.3, 4.3.3, 4.3.4, 4.5.2}

C.2.4 The urban and infrastructure system transition consistent with limiting global warming to 1.5°C with no or limited overshoot would imply, for example, changes in land and urban planning practices, as well as deeper emissions reductions in transport and buildings compared to pathways that limit global warming below 2°C (*medium confidence*). Technical measures and practices enabling deep emissions reductions include various energy efficiency options. In pathways limiting global warming to 1.5°C with no or limited overshoot, the electricity share of energy demand in buildings would be about 55–75% in 2050 compared to 50–70% in 2050 for 2°C global warming (*medium confidence*). In the transport sector, the share of low-emission final energy would rise from less than 5% in 2020 to about 35–65% in 2050 compared to 25–45% for 2°C of global warming (*medium confidence*). Economic, institutional and socio-cultural barriers may inhibit these urban and infrastructure system transitions, depending on national, regional and local circumstances, capabilities and the availability of capital (*high confidence*). {2.3.4, 2.4.3, 4.2.1, Table 4.1, 4.3.3, 4.5.2}

C.2.5 Transitions in global and regional land use are found in all pathways limiting global warming to 1.5°C with no or limited overshoot, but their scale depends on the pursued mitigation portfolio. Model pathways that limit global warming to 1.5°C with no or limited overshoot project a 4 million km^2 reduction to a 2.5 million km^2 increase of non-pasture agricultural land for food and feed crops and a 0.5–11 million km^2 reduction of pasture land, to be converted into a 0–6 million km^2 increase of agricultural land for energy crops and a 2 million km^2 reduction to 9.5 million km^2 increase in forests by 2050 relative to 2010 (*medium confidence*).[16] Land-use transitions of similar magnitude can be observed in modelled 2°C pathways (*medium confidence*). Such large transitions pose profound challenges for sustainable management of the various demands on land for human settlements, food, livestock feed, fibre, bioenergy, carbon storage, biodiversity and other ecosystem services (*high confidence*). Mitigation options limiting the demand for land include sustainable intensification of land-use practices, ecosystem restoration and changes towards less resource-intensive diets (*high confidence*). The implementation of land-based mitigation options would require overcoming socio-economic, institutional, technological, financing and environmental barriers that differ across regions (*high confidence*). {2.4.4, Figure 2.24, 4.3.2, 4.3.7, 4.5.2, Cross-Chapter Box 7 in Chapter 3}

C.2.6 Additional annual average energy-related investments for the period 2016 to 2050 in pathways limiting warming to 1.5°C compared to pathways without new climate policies beyond those in place today are estimated to be around 830 billion USD2010 (range of 150 billion to 1700 billion USD2010 across six models[17]). This compares to total annual average energy supply investments in 1.5°C pathways of 1460 to 3510 billion USD2010 and total annual average energy demand investments of 640 to 910 billion USD2010 for the period 2016 to 2050. Total energy-related investments increase by about 12% (range of 3% to 24%) in 1.5°C pathways relative to 2°C pathways. Annual investments in low-carbon energy technologies and energy efficiency are upscaled by roughly a factor of six (range of factor of 4 to 10) by 2050 compared to 2015 (*medium confidence*). {2.5.2, Box 4.8, Figure 2.27}

C.2.7 Modelled pathways limiting global warming to 1.5°C with no or limited overshoot project a wide range of global average discounted marginal abatement costs over the 21st century. They are roughly 3-4 times higher than in pathways limiting global warming to below 2°C (*high confidence*). The economic literature distinguishes marginal abatement costs from total mitigation costs in the economy. The literature on total mitigation costs of 1.5°C mitigation pathways is limited and was not assessed in this Report. Knowledge gaps remain in the integrated assessment of the economy-wide costs and benefits of mitigation in line with pathways limiting warming to 1.5°C. {2.5.2; 2.6; Figure 2.26}

16 The projected land-use changes presented are not deployed to their upper limits simultaneously in a single pathway.

17 Including two pathways limiting warming to 1.5°C with no or limited overshoot and four pathways with higher overshoot.

C.3 All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 $GtCO_2$ over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak (*high confidence*). CDR deployment of several hundreds of $GtCO_2$ is subject to multiple feasibility and sustainability constraints (*high confidence*). Significant near-term emissions reductions and measures to lower energy and land demand can limit CDR deployment to a few hundred $GtCO_2$ without reliance on bioenergy with carbon capture and storage (BECCS) (*high confidence*). {2.3, 2.4, 3.6.2, 4.3, 5.4}

C.3.1 Existing and potential CDR measures include afforestation and reforestation, land restoration and soil carbon sequestration, BECCS, direct air carbon capture and storage (DACCS), enhanced weathering and ocean alkalinization. These differ widely in terms of maturity, potentials, costs, risks, co-benefits and trade-offs (*high confidence*). To date, only a few published pathways include CDR measures other than afforestation and BECCS. {2.3.4, 3.6.2, 4.3.2, 4.3.7}

C.3.2 In pathways limiting global warming to 1.5°C with limited or no overshoot, BECCS deployment is projected to range from 0–1, 0–8, and 0–16 $GtCO_2$ yr^{-1} in 2030, 2050, and 2100, respectively, while agriculture, forestry and land-use (AFOLU) related CDR measures are projected to remove 0–5, 1–11, and 1–5 $GtCO_2$ yr^{-1} in these years (*medium confidence*). The upper end of these deployment ranges by mid-century exceeds the BECCS potential of up to 5 $GtCO_2$ yr^{-1} and afforestation potential of up to 3.6 $GtCO_2$ yr^{-1} assessed based on recent literature (*medium confidence*). Some pathways avoid BECCS deployment completely through demand-side measures and greater reliance on AFOLU-related CDR measures (*medium confidence*). The use of bioenergy can be as high or even higher when BECCS is excluded compared to when it is included due to its potential for replacing fossil fuels across sectors (*high confidence*). (Figure SPM.3b) {2.3.3, 2.3.4, 2.4.2, 3.6.2, 4.3.1, 4.2.3, 4.3.2, 4.3.7, 4.4.3, Table 2.4}

C.3.3 Pathways that overshoot 1.5°C of global warming rely on CDR exceeding residual CO_2 emissions later in the century to return to below 1.5°C by 2100, with larger overshoots requiring greater amounts of CDR (Figure SPM.3b) (*high confidence*). Limitations on the speed, scale, and societal acceptability of CDR deployment hence determine the ability to return global warming to below 1.5°C following an overshoot. Carbon cycle and climate system understanding is still limited about the effectiveness of net negative emissions to reduce temperatures after they peak (*high confidence*). {2.2, 2.3.4, 2.3.5, 2.6, 4.3.7, 4.5.2, Table 4.11}

C.3.4 Most current and potential CDR measures could have significant impacts on land, energy, water or nutrients if deployed at large scale (*high confidence*). Afforestation and bioenergy may compete with other land uses and may have significant impacts on agricultural and food systems, biodiversity, and other ecosystem functions and services (*high confidence*). Effective governance is needed to limit such trade-offs and ensure permanence of carbon removal in terrestrial, geological and ocean reservoirs (*high confidence*). Feasibility and sustainability of CDR use could be enhanced by a portfolio of options deployed at substantial, but lesser scales, rather than a single option at very large scale (*high confidence*). (Figure SPM.3b) {2.3.4, 2.4.4, 2.5.3, 2.6, 3.6.2, 4.3.2, 4.3.7, 4.5.2, 5.4.1, 5.4.2; Cross-Chapter Boxes 7 and 8 in Chapter 3, Table 4.11, Table 5.3, Figure 5.3}

C.3.5 Some AFOLU-related CDR measures such as restoration of natural ecosystems and soil carbon sequestration could provide co-benefits such as improved biodiversity, soil quality, and local food security. If deployed at large scale, they would require governance systems enabling sustainable land management to conserve and protect land carbon stocks and other ecosystem functions and services (*medium confidence*). (Figure SPM.4) {2.3.3, 2.3.4, 2.4.2, 2.4.4, 3.6.2, 5.4.1, Cross-Chapter Boxes 3 in Chapter 1 and 7 in Chapter 3, 4.3.2, 4.3.7, 4.4.1, 4.5.2, Table 2.4}

D. Strengthening the Global Response in the Context of Sustainable Development and Efforts to Eradicate Poverty

D.1 Estimates of the global emissions outcome of current nationally stated mitigation ambitions as submitted under the Paris Agreement would lead to global greenhouse gas emissions[18] in 2030 of 52–58 $GtCO_2eq\ yr^{-1}$ (*medium confidence*). Pathways reflecting these ambitions would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030 (*high confidence*). Avoiding overshoot and reliance on future large-scale deployment of carbon dioxide removal (CDR) can only be achieved if global CO_2 emissions start to decline well before 2030 (*high confidence*). {1.2, 2.3, 3.3, 3.4, 4.2, 4.4, Cross-Chapter Box 11 in Chapter 4}

D.1.1 Pathways that limit global warming to 1.5°C with no or limited overshoot show clear emission reductions by 2030 (*high confidence*). All but one show a decline in global greenhouse gas emissions to below 35 $GtCO_2eq\ yr^{-1}$ in 2030, and half of available pathways fall within the 25–30 $GtCO_2eq\ yr^{-1}$ range (interquartile range), a 40–50% reduction from 2010 levels (*high confidence*). Pathways reflecting current nationally stated mitigation ambition until 2030 are broadly consistent with cost-effective pathways that result in a global warming of about 3°C by 2100, with warming continuing afterwards (*medium confidence*). {2.3.3, 2.3.5, Cross-Chapter Box 11 in Chapter 4, 5.5.3.2}

D.1.2 Overshoot trajectories result in higher impacts and associated challenges compared to pathways that limit global warming to 1.5°C with no or limited overshoot (*high confidence*). Reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR at rates and volumes that might not be achievable given considerable implementation challenges (*medium confidence*). {1.3.3, 2.3.4, 2.3.5, 2.5.1, 3.3, 4.3.7, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4}

D.1.3 The lower the emissions in 2030, the lower the challenge in limiting global warming to 1.5°C after 2030 with no or limited overshoot (*high confidence*). The challenges from delayed actions to reduce greenhouse gas emissions include the risk of cost escalation, lock-in in carbon-emitting infrastructure, stranded assets, and reduced flexibility in future response options in the medium to long term (*high confidence*). These may increase uneven distributional impacts between countries at different stages of development (*medium confidence*). {2.3.5, 4.4.5, 5.4.2}

D.2 The avoided climate change impacts on sustainable development, eradication of poverty and reducing inequalities would be greater if global warming were limited to 1.5°C rather than 2°C, if mitigation and adaptation synergies are maximized while trade-offs are minimized (*high confidence*). {1.1, 1.4, 2.5, 3.3, 3.4, 5.2, Table 5.1}

D.2.1 Climate change impacts and responses are closely linked to sustainable development which balances social well-being, economic prosperity and environmental protection. The United Nations Sustainable Development Goals (SDGs), adopted in 2015, provide an established framework for assessing the links between global warming of 1.5°C or 2°C and development goals that include poverty eradication, reducing inequalities, and climate action. (*high confidence*) {Cross-Chapter Box 4 in Chapter 1, 1.4, 5.1}

D.2.2 The consideration of ethics and equity can help address the uneven distribution of adverse impacts associated with 1.5°C and higher levels of global warming, as well as those from mitigation and adaptation, particularly for poor and disadvantaged populations, in all societies (*high confidence*). {1.1.1, 1.1.2, 1.4.3, 2.5.3, 3.4.10, 5.1, 5.2, 5.3. 5.4, Cross-Chapter Box 4 in Chapter 1, Cross-Chapter Boxes 6 and 8 in Chapter 3, and Cross-Chapter Box 12 in Chapter 5}

D.2.3 Mitigation and adaptation consistent with limiting global warming to 1.5°C are underpinned by enabling conditions, assessed in this Report across the geophysical, environmental-ecological, technological, economic, socio-cultural and institutional

18 GHG emissions have been aggregated with 100-year GWP values as introduced in the IPCC Second Assessment Report.

dimensions of feasibility. Strengthened multilevel governance, institutional capacity, policy instruments, technological innovation and transfer and mobilization of finance, and changes in human behaviour and lifestyles are enabling conditions that enhance the feasibility of mitigation and adaptation options for 1.5°C-consistent systems transitions. (*high confidence*) {1.4, Cross-Chapter Box 3 in Chapter 1, 2.5.1, 4.4, 4.5, 5.6}

D.3 Adaptation options specific to national contexts, if carefully selected together with enabling conditions, will have benefits for sustainable development and poverty reduction with global warming of 1.5°C, although trade-offs are possible (*high confidence*). {1.4, 4.3, 4.5}

D.3.1 Adaptation options that reduce the vulnerability of human and natural systems have many synergies with sustainable development, if well managed, such as ensuring food and water security, reducing disaster risks, improving health conditions, maintaining ecosystem services and reducing poverty and inequality (*high confidence*). Increasing investment in physical and social infrastructure is a key enabling condition to enhance the resilience and the adaptive capacities of societies. These benefits can occur in most regions with adaptation to 1.5°C of global warming (*high confidence*). {1.4.3, 4.2.2, 4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.4.1, 4.4.3, 4.5.3, 5.3.1, 5.3.2}

D.3.2 Adaptation to 1.5°C global warming can also result in trade-offs or maladaptations with adverse impacts for sustainable development. For example, if poorly designed or implemented, adaptation projects in a range of sectors can increase greenhouse gas emissions and water use, increase gender and social inequality, undermine health conditions, and encroach on natural ecosystems (*high confidence*). These trade-offs can be reduced by adaptations that include attention to poverty and sustainable development (*high confidence*). {4.3.2, 4.3.3, 4.5.4, 5.3.2; Cross-Chapter Boxes 6 and 7 in Chapter 3}

D.3.3 A mix of adaptation and mitigation options to limit global warming to 1.5°C, implemented in a participatory and integrated manner, can enable rapid, systemic transitions in urban and rural areas (*high confidence*). These are most effective when aligned with economic and sustainable development, and when local and regional governments and decision makers are supported by national governments (*medium confidence*). {4.3.2, 4.3.3, 4.4.1, 4.4.2}

D.3.4 Adaptation options that also mitigate emissions can provide synergies and cost savings in most sectors and system transitions, such as when land management reduces emissions and disaster risk, or when low-carbon buildings are also designed for efficient cooling. Trade-offs between mitigation and adaptation, when limiting global warming to 1.5°C, such as when bioenergy crops, reforestation or afforestation encroach on land needed for agricultural adaptation, can undermine food security, livelihoods, ecosystem functions and services and other aspects of sustainable development. (*high confidence*) {3.4.3, 4.3.2, 4.3.4, 4.4.1, 4.5.2, 4.5.3, 4.5.4}

D.4 Mitigation options consistent with 1.5°C pathways are associated with multiple synergies and trade-offs across the Sustainable Development Goals (SDGs). While the total number of possible synergies exceeds the number of trade-offs, their net effect will depend on the pace and magnitude of changes, the composition of the mitigation portfolio and the management of the transition. (*high confidence*) (Figure SPM.4) {2.5, 4.5, 5.4}

D.4.1 1.5°C pathways have robust synergies particularly for the SDGs 3 (health), 7 (clean energy), 11 (cities and communities), 12 (responsible consumption and production) and 14 (oceans) (*very high confidence*). Some 1.5°C pathways show potential trade-offs with mitigation for SDGs 1 (poverty), 2 (hunger), 6 (water) and 7 (energy access), if not managed carefully (*high confidence*). (Figure SPM.4) {5.4.2; Figure 5.4, Cross-Chapter Boxes 7 and 8 in Chapter 3}

D.4.2 1.5°C pathways that include low energy demand (e.g., see P1 in Figure SPM.3a and SPM.3b), low material consumption, and low GHG-intensive food consumption have the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and the SDGs (*high confidence*). Such pathways would reduce dependence on CDR. In modelled pathways, sustainable development, eradicating poverty and reducing inequality can support limiting warming to 1.5°C (*high confidence*). (Figure SPM.3b, Figure SPM.4) {2.4.3, 2.5.1, 2.5.3, Figure 2.4, Figure 2.28, 5.4.1, 5.4.2, Figure 5.4}

Indicative linkages between mitigation options and sustainable development using SDGs (The linkages do not show costs and benefits)

Mitigation options deployed in each sector can be associated with potential positive effects (synergies) or negative effects (trade-offs) with the Sustainable Development Goals (SDGs). The degree to which this potential is realized will depend on the selected portfolio of mitigation options, mitigation policy design, and local circumstances and context. Particularly in the energy-demand sector, the potential for synergies is larger than for trade-offs. The bars group individually assessed options by level of confidence and take into account the relative strength of the assessed mitigation-SDG connections.

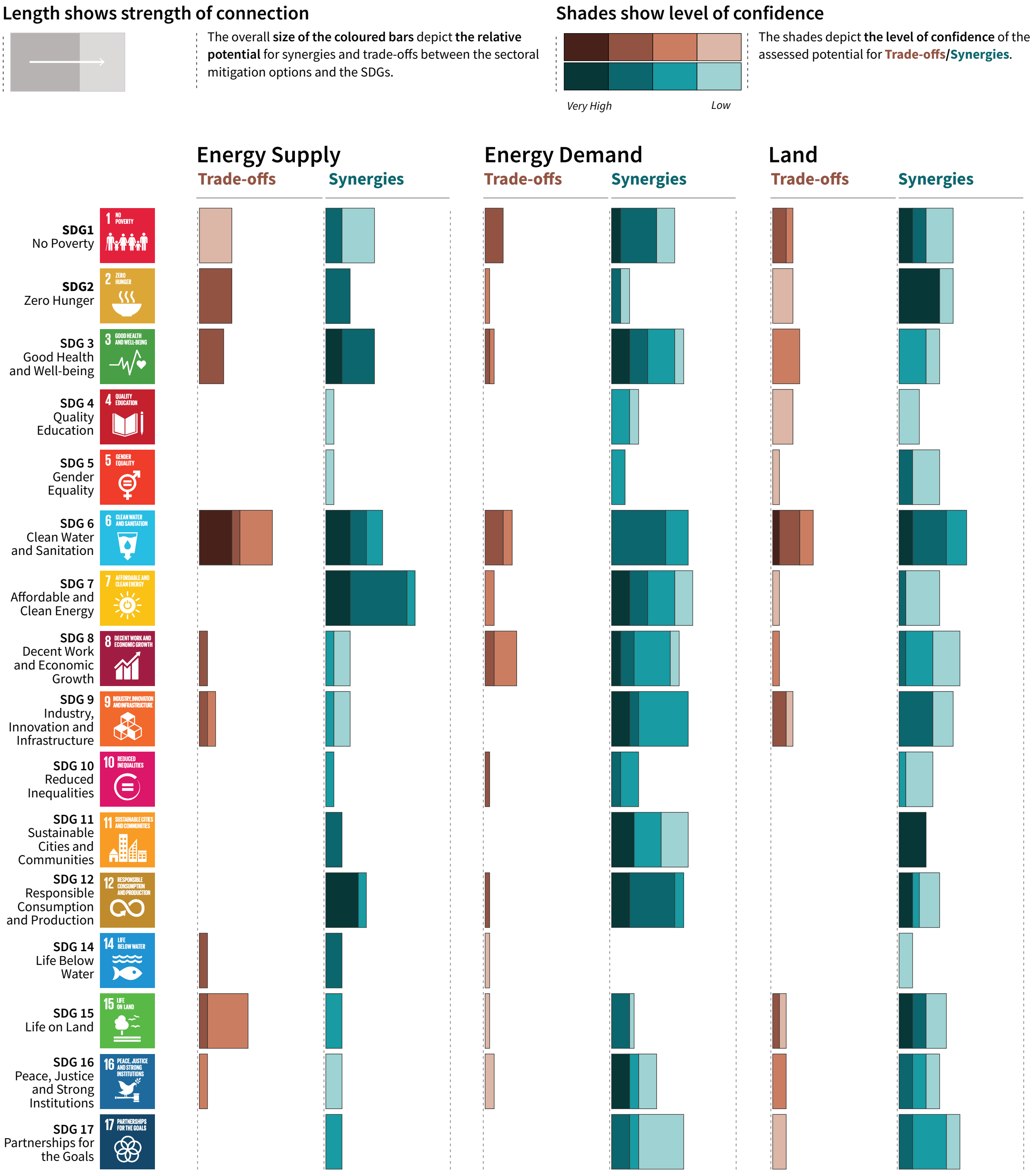


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Figure SPM.4 | Potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs). The SDGs serve as an analytical framework for the assessment of the different sustainable development dimensions, which extend beyond the time frame of the 2030 SDG targets. The assessment is based on literature on mitigation options that are considered relevant for 1.5°C. The assessed strength of the SDG interactions is based on the qualitative and quantitative assessment of individual mitigation options listed in Table 5.2. For each mitigation option, the strength of the SDG-connection as well as the associated confidence of the underlying literature (shades of green and red) was assessed. The strength of positive connections (synergies) and negative connections (trade-offs) across all individual options within a sector (see Table 5.2) are aggregated into sectoral potentials for the whole mitigation portfolio. The (white) areas outside the bars, which indicate no interactions, have *low confidence* due to the uncertainty and limited number of studies exploring indirect effects. The strength of the connection considers only the effect of mitigation and does not include benefits of avoided impacts. SDG 13 (climate action) is not listed because mitigation is being considered in terms of interactions with SDGs and not vice versa. The bars denote the strength of the connection, and do not consider the strength of the impact on the SDGs. The energy demand sector comprises behavioural responses, fuel switching and efficiency options in the transport, industry and building sector as well as carbon capture options in the industry sector. Options assessed in the energy supply sector comprise biomass and non-biomass renewables, nuclear, carbon capture and storage (CCS) with bioenergy, and CCS with fossil fuels. Options in the land sector comprise agricultural and forest options, sustainable diets and reduced food waste, soil sequestration, livestock and manure management, reduced deforestation, afforestation and reforestation, and responsible sourcing. In addition to this figure, options in the ocean sector are discussed in the underlying report. {5.4, Table 5.2, Figure 5.2}

Information about the net impacts of mitigation on sustainable development in 1.5°C pathways is available only for a limited number of SDGs and mitigation options. Only a limited number of studies have assessed the benefits of avoided climate change impacts of 1.5°C pathways for the SDGs, and the co-effects of adaptation for mitigation and the SDGs. The assessment of the indicative mitigation potentials in Figure SPM.4 is a step further from AR5 towards a more comprehensive and integrated assessment in the future.

D.4.3 1.5°C and 2°C modelled pathways often rely on the deployment of large-scale land-related measures like afforestation and bioenergy supply, which, if poorly managed, can compete with food production and hence raise food security concerns (*high confidence*). The impacts of carbon dioxide removal (CDR) options on SDGs depend on the type of options and the scale of deployment (*high confidence*). If poorly implemented, CDR options such as BECCS and AFOLU options would lead to trade-offs. Context-relevant design and implementation requires considering people's needs, biodiversity, and other sustainable development dimensions (*very high confidence*). (Figure SPM.4) {5.4.1.3, Cross-Chapter Box 7 in Chapter 3}

D.4.4 Mitigation consistent with 1.5°C pathways creates risks for sustainable development in regions with high dependency on fossil fuels for revenue and employment generation (*high confidence*). Policies that promote diversification of the economy and the energy sector can address the associated challenges (*high confidence*). {5.4.1.2, Box 5.2}

D.4.5 Redistributive policies across sectors and populations that shield the poor and vulnerable can resolve trade-offs for a range of SDGs, particularly hunger, poverty and energy access. Investment needs for such complementary policies are only a small fraction of the overall mitigation investments in 1.5°C pathways. (*high confidence*) {2.4.3, 5.4.2, Figure 5.5}

D.5 Limiting the risks from global warming of 1.5°C in the context of sustainable development and poverty eradication implies system transitions that can be enabled by an increase of adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behaviour changes (*high confidence*). {2.3, 2.4, 2.5, 3.2, 4.2, 4.4, 4.5, 5.2, 5.5, 5.6}

D.5.1 Directing finance towards investment in infrastructure for mitigation and adaptation could provide additional resources. This could involve the mobilization of private funds by institutional investors, asset managers and development or investment banks, as well as the provision of public funds. Government policies that lower the risk of low-emission and adaptation investments can facilitate the mobilization of private funds and enhance the effectiveness of other public policies. Studies indicate a number of challenges, including access to finance and mobilization of funds. (*high confidence*) {2.5.1, 2.5.2, 4.4.5}

D.5.2 Adaptation finance consistent with global warming of 1.5°C is difficult to quantify and compare with 2°C. Knowledge gaps include insufficient data to calculate specific climate resilience-enhancing investments from the provision of currently underinvested basic infrastructure. Estimates of the costs of adaptation might be lower at global warming of 1.5°C than for 2°C. Adaptation needs have typically been supported by public sector sources such as national and subnational government budgets, and in developing countries together with support from development assistance, multilateral development banks, and United Nations Framework Convention on Climate Change channels (*medium confidence*). More recently there is a growing understanding of the scale and increase in non-governmental organizations and private funding in some regions (*medium confidence*). Barriers include the scale of adaptation financing, limited capacity and access to adaptation finance (*medium confidence*). {4.4.5, 4.6}

D.5.3 Global model pathways limiting global warming to 1.5°C are projected to involve the annual average investment needs in the energy system of around 2.4 trillion USD2010 between 2016 and 2035, representing about 2.5% of the world GDP (*medium confidence*). {4.4.5, Box 4.8}

D.5.4 Policy tools can help mobilize incremental resources, including through shifting global investments and savings and through market and non-market based instruments as well as accompanying measures to secure the equity of the transition, acknowledging the challenges related with implementation, including those of energy costs, depreciation of assets and impacts on international competition, and utilizing the opportunities to maximize co-benefits (*high confidence*). {1.3.3, 2.3.4, 2.3.5, 2.5.1, 2.5.2, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4, 4.4.5, 5.5.2}

D.5.5 The systems transitions consistent with adapting to and limiting global warming to 1.5°C include the widespread adoption of new and possibly disruptive technologies and practices and enhanced climate-driven innovation. These imply enhanced technological innovation capabilities, including in industry and finance. Both national innovation policies and international cooperation can contribute to the development, commercialization and widespread adoption of mitigation and adaptation technologies. Innovation policies may be more effective when they combine public support for research and development with policy mixes that provide incentives for technology diffusion. (*high confidence*) {4.4.4, 4.4.5}.

D.5.6 Education, information, and community approaches, including those that are informed by indigenous knowledge and local knowledge, can accelerate the wide-scale behaviour changes consistent with adapting to and limiting global warming to 1.5°C. These approaches are more effective when combined with other policies and tailored to the motivations, capabilities and resources of specific actors and contexts (*high confidence*). Public acceptability can enable or inhibit the implementation of policies and measures to limit global warming to 1.5°C and to adapt to the consequences. Public acceptability depends on the individual's evaluation of expected policy consequences, the perceived fairness of the distribution of these consequences, and perceived fairness of decision procedures (*high confidence*). {1.1, 1.5, 4.3.5, 4.4.1, 4.4.3, Box 4.3, 5.5.3, 5.6.5}

D.6 Sustainable development supports, and often enables, the fundamental societal and systems transitions and transformations that help limit global warming to 1.5°C. Such changes facilitate the pursuit of climate-resilient development pathways that achieve ambitious mitigation and adaptation in conjunction with poverty eradication and efforts to reduce inequalities (*high confidence*). {Box 1.1, 1.4.3, Figure 5.1, 5.5.3, Box 5.3}

D.6.1 Social justice and equity are core aspects of climate-resilient development pathways that aim to limit global warming to 1.5°C as they address challenges and inevitable trade-offs, widen opportunities, and ensure that options, visions, and values are deliberated, between and within countries and communities, without making the poor and disadvantaged worse off (*high confidence*). {5.5.2, 5.5.3, Box 5.3, Figure 5.1, Figure 5.6, Cross-Chapter Boxes 12 and 13 in Chapter 5}

D.6.2 The potential for climate-resilient development pathways differs between and within regions and nations, due to different development contexts and systemic vulnerabilities (*very high confidence*). Efforts along such pathways to date have been limited (*medium confidence*) and enhanced efforts would involve strengthened and timely action from all countries and non-state actors (*high confidence*). {5.5.1, 5.5.3, Figure 5.1}

D.6.3 Pathways that are consistent with sustainable development show fewer mitigation and adaptation challenges and are associated with lower mitigation costs. The large majority of modelling studies could not construct pathways characterized by lack of international cooperation, inequality and poverty that were able to limit global warming to 1.5°C. (*high confidence*) {2.3.1, 2.5.1, 2.5.3, 5.5.2}

D.7 Strengthening the capacities for climate action of national and sub-national authorities, civil society, the private sector, indigenous peoples and local communities can support the implementation of ambitious actions implied by limiting global warming to 1.5°C (*high confidence*). International cooperation can provide an enabling environment for this to be achieved in all countries and for all people, in the context of sustainable development. International cooperation is a critical enabler for developing countries and vulnerable regions (*high confidence*). {1.4, 2.3, 2.5, 4.2, 4.4, 4.5, 5.3, 5.4, 5.5, 5.6, 5, Box 4.1, Box 4.2, Box 4.7, Box 5.3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 13 in Chapter 5}

D.7.1 Partnerships involving non-state public and private actors, institutional investors, the banking system, civil society and scientific institutions would facilitate actions and responses consistent with limiting global warming to 1.5°C (*very high confidence*). {1.4, 4.4.1, 4.2.2, 4.4.3, 4.4.5, 4.5.3, 5.4.1, 5.6.2, Box 5.3}.

D.7.2 Cooperation on strengthened accountable multilevel governance that includes non-state actors such as industry, civil society and scientific institutions, coordinated sectoral and cross-sectoral policies at various governance levels, gender-sensitive policies, finance including innovative financing, and cooperation on technology development and transfer can ensure participation, transparency, capacity building and learning among different players (*high confidence*). {2.5.1, 2.5.2, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, Cross-Chapter Box 9 in Chapter 4, 5.3.1, 5.5.3, Cross-Chapter Box 13 in Chapter 5, 5.6.1, 5.6.3}

D.7.3 International cooperation is a critical enabler for developing countries and vulnerable regions to strengthen their action for the implementation of 1.5°C-consistent climate responses, including through enhancing access to finance and technology and enhancing domestic capacities, taking into account national and local circumstances and needs (*high confidence*). {2.3.1, 2.5.1, 4.4.1, 4.4.2, 4.4.4, 4.4.5, 5.4.1 5.5.3, 5.6.1, Box 4.1, Box 4.2, Box 4.7}.

D.7.4 Collective efforts at all levels, in ways that reflect different circumstances and capabilities, in the pursuit of limiting global warming to 1.5°C, taking into account equity as well as effectiveness, can facilitate strengthening the global response to climate change, achieving sustainable development and eradicating poverty (*high confidence*). {1.4.2, 2.3.1, 2.5.1, 2.5.2, 2.5.3, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, 5.3.1, 5.4.1, 5.5.3, 5.6.1, 5.6.2, 5.6.3}

Box SPM.1: Core Concepts Central to this Special Report

Global mean surface temperature (GMST): Estimated global average of near-surface air temperatures over land and sea ice, and sea surface temperatures over ice-free ocean regions, with changes normally expressed as departures from a value over a specified reference period. When estimating changes in GMST, near-surface air temperature over both land and oceans are also used.[19] {1.2.1.1}

Pre-industrial: The multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850–1900 is used to approximate pre-industrial GMST. {1.2.1.2}

Global warming: The estimated increase in GMST averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue. {1.2.1}

Net zero CO_2 emissions: Net zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.

Carbon dioxide removal (CDR): Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.

Total carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from the pre-industrial period to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Remaining carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from a given start date to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Temperature overshoot: The temporary exceedance of a specified level of global warming.

Emission pathways: In this Summary for Policymakers, the modelled trajectories of global anthropogenic emissions over the 21st century are termed emission pathways. Emission pathways are classified by their temperature trajectory over the 21st century: pathways giving at least 50% probability based on current knowledge of limiting global warming to below 1.5°C are classified as 'no overshoot'; those limiting warming to below 1.6°C and returning to 1.5°C by 2100 are classified as '1.5°C limited-overshoot'; while those exceeding 1.6°C but still returning to 1.5°C by 2100 are classified as 'higher-overshoot'.

Impacts: Effects of climate change on human and natural systems. Impacts can have beneficial or adverse outcomes for livelihoods, health and well-being, ecosystems and species, services, infrastructure, and economic, social and cultural assets.

Risk: The potential for adverse consequences from a climate-related hazard for human and natural systems, resulting from the interactions between the hazard and the vulnerability and exposure of the affected system. Risk integrates the likelihood of exposure to a hazard and the magnitude of its impact. Risk also can describe the potential for adverse consequences of adaptation or mitigation responses to climate change.

Climate-resilient development pathways (CRDPs): Trajectories that strengthen sustainable development at multiple scales and efforts to eradicate poverty through equitable societal and systems transitions and transformations while reducing the threat of climate change through ambitious mitigation, adaptation and climate resilience.

19 Past IPCC reports, reflecting the literature, have used a variety of approximately equivalent metrics of GMST change.

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INTERGOVERNMENTAL PANEL ON climate change

Climate Change and Land

An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems

Summary for Policymakers

WG I WG II WG III

WMO UNEP

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Climate Change and Land

An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems

Summary for Policymakers

Edited by

Valérie Masson-Delmotte
Co-Chair Working Group I

Panmao Zhai
Co-Chair Working Group I

Hans-Otto Pörtner
Co-Chair Working Group II

Debra Roberts
Co-Chair Working Group II

Jim Skea
Co-Chair Working Group III

Eduardo Calvo Buendía
Co-Chair TFI

Priyadarshi R. Shukla
Co-Chair Working Group III

Raphael Slade
Head of TSU (Science)

Sarah Connors
Senior Science Officer

Renée van Diemen
Scientist

Marion Ferrat
Head of Communications

Eamon Haughey
Senior Scientist

Sigourney Luz
Communications Manager

Suvadip Neogi
Scientist

Minal Pathak
Senior Scientist

Jan Petzold
Science Officer

Joana Portugal Pereira
Senior Scientist

Purvi Vyas
Science Officer

Elizabeth Huntley
Head of TSU (Operations)

Katie Kissick
Head of TSU (Operations)

Malek Belkacemi
IT/Web Manager

Juliette Malley
Senior Administrator

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Summary for Policymakers

Drafting Authors:

Almut Arneth (Germany), Humberto Barbosa (Brazil), Tim Benton (United Kingdom), Katherine Calvin (The United States of America), Eduardo Calvo (Peru), Sarah Connors (United Kingdom), Annette Cowie (Australia), Edouard Davin (France/Switzerland), Fatima Denton (The Gambia), Renée van Diemen (The Netherlands/United Kingdom), Fatima Driouech (Morocco), Aziz Elbehri (Morocco), Jason Evans (Australia), Marion Ferrat (France), Jordan Harold (United Kingdom), Eamon Haughey (Ireland), Mario Herrero (Australia/Costa Rica), Joanna House (United Kingdom), Mark Howden (Australia), Margot Hurlbert (Canada), Gensuo Jia (China), Tom Gabriel Johansen (Norway), Jagdish Krishnaswamy (India), Werner Kurz (Canada), Christopher Lennard (South Africa), Soojeong Myeong (Republic of Korea), Nagmeldin Mahmoud (Sudan), Valérie Masson-Delmotte (France), Cheikh Mbow (Senegal), Pamela McElwee (The United States of America), Alisher Mirzabaev (Germany/Uzbekistan), Angela Morelli (Norway/Italy), Wilfran Moufouma-Okia (France), Dalila Nedjraoui (Algeria), Suvadip Neogi (India), Johnson Nkem (Cameroon), Nathalie De Noblet-Ducoudré (France), Lennart Olsson (Sweden), Minal Pathak (India), Jan Petzold (Germany), Ramón Pichs-Madruga (Cuba), Elvira Poloczanska (United Kingdom/Australia), Alexander Popp (Germany), Hans-Otto Pörtner (Germany), Joana Portugal Pereira (United Kingdom), Prajal Pradhan (Nepal/Germany), Andy Reisinger (New Zealand), Debra C. Roberts (South Africa), Cynthia Rosenzweig (The United States of America), Mark Rounsevell (United Kingdom/Germany), Elena Shevliakova (The United States of America), Priyadarshi R. Shukla (India), Jim Skea (United Kingdom), Raphael Slade (United Kingdom), Pete Smith (United Kingdom), Youba Sokona (Mali), Denis Jean Sonwa (Cameroon), Jean-Francois Soussana (France), Francesco Tubiello (The United States of America/Italy), Louis Verchot (The United States of America/Colombia), Koko Warner (The United States of America/Germany), Nora M. Weyer (Germany), Jianguo Wu (China), Noureddine Yassaa (Algeria), Panmao Zhai (China), Zinta Zommers (Latvia).

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SIGNED

Valérie Masson-Delmotte
Co-Chair Working Group I

Panmao Zhai
Co-Chair Working Group I

Hans-Otto Pörtner
Co-Chair Working Group II

DEBRA ROBERTS

Debra Roberts
Co-Chair Working Group II

Jim Skea
Co-Chair Working Group III

Eduardo Calvo Buendía
Co-Chair TFI

Priyadarshi R. Shukla
Co-Chair Working Group III

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Introduction

This Special Report on Climate Change and Land[1] responds to the Panel decision in 2016 to prepare three Special Reports[2] during the Sixth Assessment cycle, taking account of proposals from governments and observer organisations.[3] This report addresses greenhouse gas (GHG) fluxes in land-based ecosystems, land use and sustainable land management[4] in relation to climate change adaptation and mitigation, desertification[5], land degradation[6] and food security[7]. This report follows the publication of other recent reports, including the IPCC *Special Report on Global Warming of 1.5°C* (SR15), the thematic assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) on *Land Degradation and Restoration*, the IPBES *Global Assessment Report on Biodiversity and Ecosystem Services*, and the *Global Land Outlook* of the UN Convention to Combat Desertification (UNCCD). This report provides an updated assessment of the current state of knowledge[8] while striving for coherence and complementarity with other recent reports.

This Summary for Policymakers (SPM) is structured in four parts: *A) People, land and climate in a warming world; B) Adaptation and mitigation response options; C) Enabling response options; and, D) Action in the near-term.*

Confidence in key findings is indicated using the IPCC calibrated language; the underlying scientific basis of each key finding is indicated by references to the main report.[9]

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1 The terrestrial portion of the biosphere that comprises the natural resources (soil, near-surface air, vegetation and other biota, and water), the ecological processes, topography, and human settlements and infrastructure that operate within that system.

2 The three Special reports are: *Global Warming of 1.5°C: an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty; Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems; The Ocean and Cryosphere in a Changing Climate.*

3 Related proposals were: climate change and desertification; desertification with regional aspects; land degradation – an assessment of the interlinkages and integrated strategies for mitigation and adaptation; agriculture, forestry and other land use; food and agriculture; and food security and climate change.

4 Sustainable land management is defined in this report as 'the stewardship and use of land resources, including soils, water, animals and plants, to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions'.

5 Desertification is defined in this report as 'land degradation in arid, semi-arid, and dry sub-humid areas resulting from many factors, including climatic variations and human activities'.

6 Land degradation is defined in this report as 'a negative trend in land condition, caused by direct or indirect human induced processes, including anthropogenic climate change, expressed as long-term reduction and as loss of at least one of the following: biological productivity; ecological integrity; or value to humans'.

7 Food security is defined in this report as 'a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life'.

8 The assessment covers literature accepted for publication by 7th April 2019.

9 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, medium confidence. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, very likely. This is consistent with IPCC AR5.

A. People, land and climate in a warming world

A.1 Land provides the principal basis for human livelihoods and well-being including the supply of food, freshwater and multiple other ecosystem services, as well as biodiversity. Human use directly affects more than 70% (*likely* 69–76%) of the global, ice-free land surface (*high confidence*). Land also plays an important role in the climate system. (Figure SPM.1) {1.1, 1.2, 2.3, 2.4}

A.1.1 People currently use one quarter to one third of land's potential net primary production[10] for food, feed, fibre, timber and energy. Land provides the basis for many other ecosystem functions and services,[11] including cultural and regulating services, that are essential for humanity (*high confidence*). In one economic approach, the world's terrestrial ecosystem services have been valued on an annual basis to be approximately equivalent to the annual global Gross Domestic Product[12] *(medium confidence*). (Figure SPM.1) {1.1, 1.2, 3.2, 4.1, 5.1, 5.5}

A.1.2 Land is both a source and a sink of GHGs and plays a key role in the exchange of energy, water and aerosols between the land surface and atmosphere. Land ecosystems and biodiversity are vulnerable to ongoing climate change, and weather and climate extremes, to different extents. Sustainable land management can contribute to reducing the negative impacts of multiple stressors, including climate change, on ecosystems and societies (high confidence). (Figure SPM.1) {1.1, 1.2, 3.2, 4.1, 5.1, 5.5}

A.1.3 Data available since 1961[13] show that global population growth and changes in per capita consumption of food, feed, fibre, timber and energy have caused unprecedented rates of land and freshwater use (*very high confidence*) with agriculture currently accounting for ca. 70% of global fresh-water use (*medium confidence*). Expansion of areas under agriculture and forestry, including commercial production, and enhanced agriculture and forestry productivity have supported consumption and food availability for a growing population (*high confidence*). With large regional variation, these changes have contributed to increasing net GHG emissions (*very high confidence*), loss of natural ecosystems (e.g., forests, savannahs, natural grasslands and wetlands) and declining biodiversity (*high confidence*). (Figure SPM.1) {1.1, 1.3, 5.1, 5.5}

A.1.4 Data available since 1961 shows the per capita supply of vegetable oils and meat has more than doubled and the supply of food calories per capita has increased by about one third (*high confidence*). Currently, 25–30% of total food produced is lost or wasted (*medium confidence*). These factors are associated with additional GHG emissions (*high confidence*). Changes in consumption patterns have contributed to about two billion adults now being overweight or obese (*high confidence*). An estimated 821 million people are still undernourished (*high confidence*). (Figure SPM.1) {1.1, 1.3, 5.1, 5.5}

A.1.5 About a quarter of the Earth's ice-free land area is subject to human-induced degradation (*medium confidence*). Soil erosion from agricultural fields is estimated to be currently 10 to 20 times (no tillage) to more than 100 times (conventional tillage) higher than the soil formation rate (*medium confidence*). Climate change exacerbates land degradation, particularly in low-lying coastal areas, river deltas, drylands and in permafrost areas (*high confidence*). Over the period 1961–2013, the annual area of drylands in drought has increased, on average by slightly more than 1% per year, with large inter-annual variability. In 2015, about 500 (380-620) million people lived within areas which experienced desertification between the 1980s and 2000s. The highest numbers of people affected are in South and East Asia, the circum Sahara region including North Africa, and the Middle East including the Arabian Peninsula (*low confidence*). Other dryland regions have also experienced desertification. People living in already degraded or desertified areas are increasingly negatively affected by climate change (*high confidence*). (Figure SPM.1) {1.1, 1.2, 3.1, 3.2, 4.1, 4.2, 4.3}

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10 Land's potential net primary production (NPP) is defined in this report as 'the amount of carbon accumulated through photosynthesis minus the amount lost by plant respiration over a specified time period that would prevail in the absence of land use'.

11 In its conceptual framework, IPBES uses 'nature's contribution to people' in which it includes ecosystem goods and services.

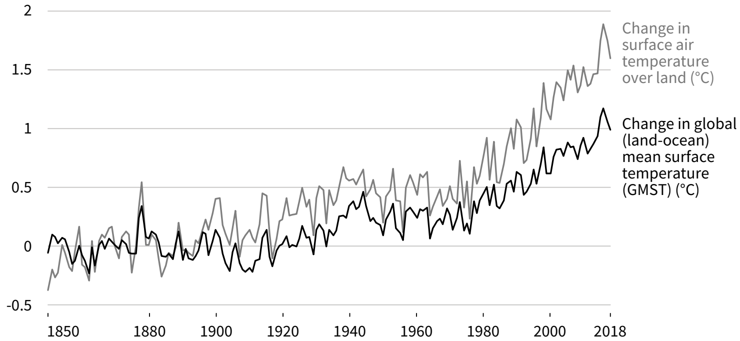
12 I.e., estimated at $75 trillion for 2011, based on US dollars for 2007.

13 This statement is based on the most comprehensive data from national statistics available within FAOSTAT, which starts in 1961. This does not imply that the changes started in 1961. Land use changes have been taking place from well before the pre-industrial period to the present.

Land use and observed climate change

A. Observed temperature change relative to 1850-1900
Since the pre-industrial period (1850-1900) the observed mean land surface air temperature has risen considerably more than the global mean surface (land and ocean) temperature (GMST).

CHANGE in TEMPERATURE rel. to 1850-1900 (°C)

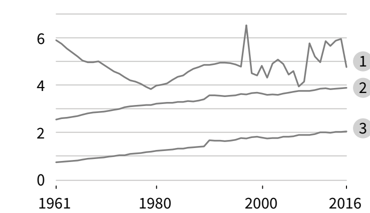


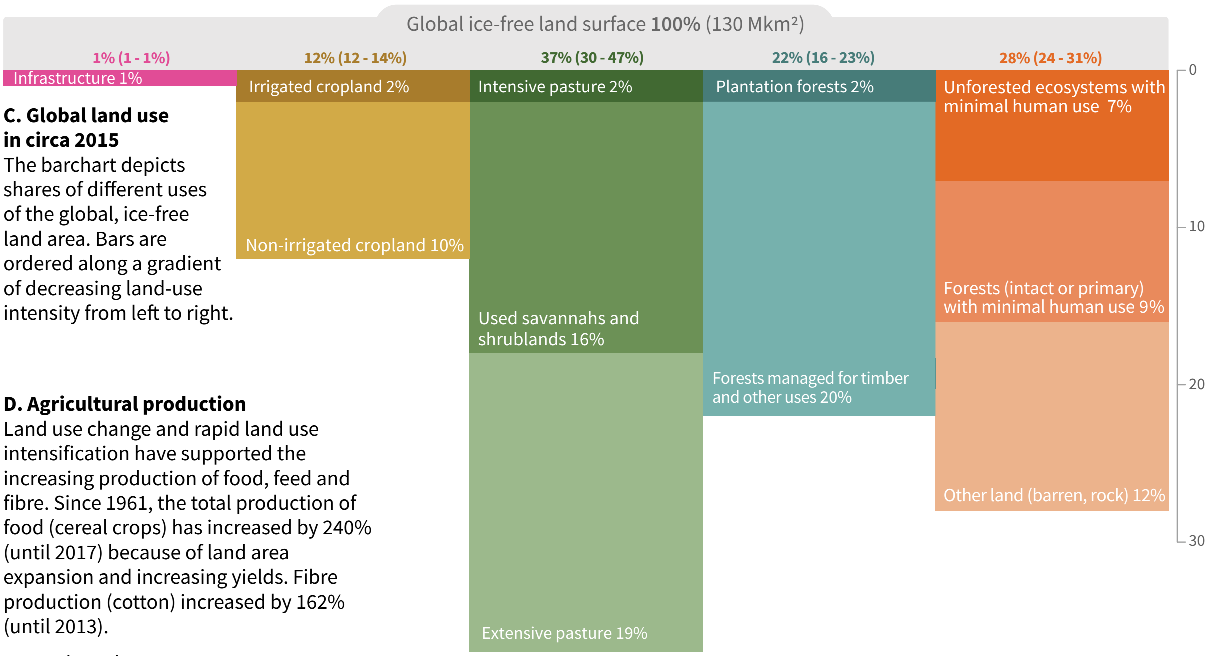
B. GHG emissions
An estimated 23% of total anthropogenic greenhouse gas emissions (2007-2016) derive from Agriculture, Forestry and Other Land Use (AFOLU).

CHANGE in EMISSIONS since 1961

1. Net CO_2 emissions from FOLU ($GtCO_2\ yr^{-1}$)
2. CH_4 emissions from Agriculture ($GtCO_2eq\ yr^{-1}$)
3. N_2O emissions from Agriculture ($GtCO_2eq\ yr^{-1}$)

$GtCO_2eq\ yr^{-1}$



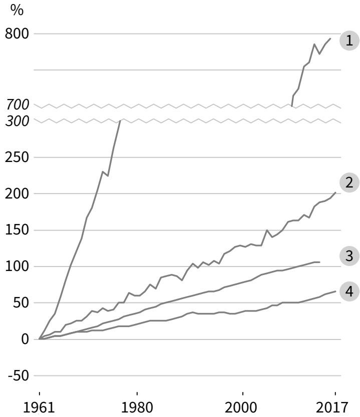


C. Global land use in circa 2015
The barchart depicts shares of different uses of the global, ice-free land area. Bars are ordered along a gradient of decreasing land-use intensity from left to right.

D. Agricultural production
Land use change and rapid land use intensification have supported the increasing production of food, feed and fibre. Since 1961, the total production of food (cereal crops) has increased by 240% (until 2017) because of land area expansion and increasing yields. Fibre production (cotton) increased by 162% (until 2013).

CHANGE in % rel. to 1961

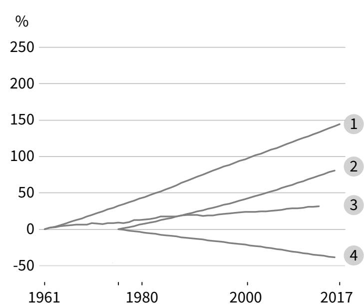
1. Inorganic N fertiliser use
2. Cereal yields
3. Irrigation water volume
4. Total number of ruminant livestock



E. Food demand
Increases in production are linked to consumption changes.

CHANGE in % rel. to 1961 and 1975

1. Population
2. Prevalence of overweight + obese
3. Total calories per capita
4. Prevalence of underweight



F. Desertification and land degradation
Land-use change, land-use intensification and climate change have contributed to desertification and land degradation.

CHANGE in % rel. to 1961 and 1970

1. Population in areas experiencing desertification
2. Dryland areas in drought annually
3. Inland wetland extent

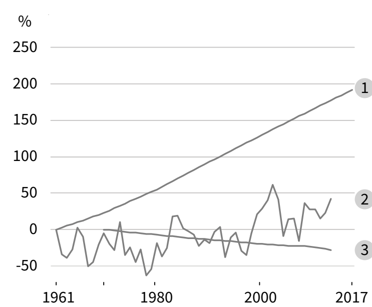


Figure SPM.1: Land use and observed climate change | A representation of the land use and observed climate change covered in this assessment report. Panels A-F show the status and trends in selected land use and climate variables that represent many of the core topics covered in this report. The annual time series in B and D-F are based on the most comprehensive, available data from national statistics, in most cases from FAOSTAT which starts in 1961. Y-axes in panels D-F are expressed relative to the starting year of the time series (rebased to zero). Data sources and notes: **A:** The warming curves are averages of four datasets {2.1, Figure 2.2, Table 2.1} **B:** N_2O and CH_4 from agriculture are from FAOSTAT; Net CO_2 emissions from FOLU using the mean of two bookkeeping models (including emissions from peatland fires since 1997). All values expressed in units of CO_2-eq are based on AR5 100-year Global Warming Potential values without climate-carbon feedbacks (N_2O=265; CH_4=28). (Table SPM.1) {1.1, 2.3} **C:** Depicts shares of different uses of the global, ice-free land area for approximately the year 2015, ordered along a gradient of decreasing land-use intensity from left to right. Each bar represents a broad land cover category; the numbers on top are the total percentage of the ice-free area covered, with uncertainty ranges in brackets. Intensive pasture is defined as having a livestock density greater than 100 animals/km^2. The area of 'forest managed for timber and other uses' was calculated as total forest area minus 'primary/intact' forest area. {1.2, Table 1.1, Figure 1.3} **D:** Note that fertiliser use is shown on a split axis. The large percentage change in fertiliser use reflects the low level of use in 1961 and relates to both increasing fertiliser input per area as well as the expansion of fertilised cropland and grassland to increase food production. {1.1, Figure 1.3} **E:** Overweight population is defined as having a body mass index (BMI) > 25 kg m^{-2}; underweight is defined as BMI < 18.5 kg m^{-2}. {5.1, 5.2} **F:** Dryland areas were estimated using TerraClimate precipitation and potential evapotranspiration (1980-2015) to identify areas where the Aridity Index is below 0.65. Population data are from the HYDE3.2 database. Areas in drought are based on the 12-month accumulation Global Precipitation Climatology Centre Drought Index. The inland wetland extent (including peatlands) is based on aggregated data from more than 2000 time series that report changes in local wetland area over time. {3.1, 4.2, 4.6}

A.2 Since the pre-industrial period, the land surface air temperature has risen nearly twice as much as the global average temperature (*high confidence*). Climate change, including increases in frequency and intensity of extremes, has adversely impacted food security and terrestrial ecosystems as well as contributed to desertification and land degradation in many regions (*high confidence*). {2.2, 3.2, 4.2, 4.3, 4.4, 5.1, 5.2, Executive Summary Chapter 7, 7.2}

A.2.1 Since the pre-industrial period (1850-1900) the observed mean land surface air temperature has risen considerably more than the global mean surface (land and ocean) temperature (GMST) (*high confidence*). From 1850-1900 to 2006-2015 mean land surface air temperature has increased by 1.53°C (*very likely* range from 1.38°C to 1.68°C) while GMST increased by 0.87°C (*likely* range from 0.75°C to 0.99°C). (Figure SPM.1) {2.2.1}

A.2.2 Warming has resulted in an increased frequency, intensity and duration of heat-related events, including heatwaves[14] in most land regions (*high confidence*). Frequency and intensity of droughts has increased in some regions (including the Mediterranean, west Asia, many parts of South America, much of Africa, and north-eastern Asia) (*medium confidence*) and there has been an increase in the intensity of heavy precipitation events at a global scale (*medium confidence*). {2.2.5, 4.2.3, 5.2}

A.2.3 Satellite observations[15] have shown vegetation greening[16] over the last three decades in parts of Asia, Europe, South America, central North America, and southeast Australia. Causes of greening include combinations of an extended growing season, nitrogen deposition, Carbon Dioxide (CO_2) fertilisation[17], and land management (*high confidence*). Vegetation browning[18] has been observed in some regions including northern Eurasia, parts of North America, Central Asia and the Congo Basin, largely as a result of water stress (*medium confidence*). Globally, vegetation greening has occurred over a larger area than vegetation browning (*high confidence*). {2.2.3, Box 2.3, 2.2.4, 3.2.1, 3.2.2, 4.3.1, 4.3.2, 4.6.2, 5.2.2}

A.2.4 The frequency and intensity of dust storms have increased over the last few decades due to land use and land cover changes and climate-related factors in many dryland areas resulting in increasing negative impacts on human health, in regions such as the Arabian Peninsula and broader Middle East, Central Asia (*high confidence*).[19] {2.4.1, 3.4.2}

A.2.5 In some dryland areas, increased land surface air temperature and evapotranspiration and decreased precipitation amount, in interaction with climate variability and human activities, have contributed to desertification. These areas include Sub-Saharan Africa, parts of East and Central Asia, and Australia. (*medium confidence*) {2.2, 3.2.2, 4.4.1}

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[14] A heatwave is defined in this report as 'a period of abnormally hot weather'. Heatwaves and warm spells have various and, in some cases, overlapping definitions.

[15] The interpretation of satellite observations can be affected by insufficient ground validation and sensor calibration. In addition their spatial resolution can make it difficult to resolve small-scale changes.

[16] Vegetation greening is defined in this report as 'an increase in photosynthetically active plant biomass which is inferred from satellite observations'.

[17] CO_2 fertilisation is defined in this report as 'the enhancement of plant growth as a result of increased atmospheric carbon dioxide (CO_2) concentration'. The magnitude of CO_2 fertilisation depends on nutrients and water availability.

[18] Vegetation browning is defined in this report as 'a decrease in photosynthetically active plant biomass which is inferred from satellite observations'.

[19] Evidence relative to such trends in dust storms and health impacts in other regions is limited in the literature assessed in this report.

A.2.6 Global warming has led to shifts of climate zones in many world regions, including expansion of arid climate zones and contraction of polar climate zones (*high confidence*). As a consequence, many plant and animal species have experienced changes in their ranges, abundances, and shifts in their seasonal activities (*high confidence*). {2.2, 3.2.2, 4.4.1}

A.2.7 Climate change can exacerbate land degradation processes (*high confidence*) including through increases in rainfall intensity, flooding, drought frequency and severity, heat stress, dry spells, wind, sea-level rise and wave action, and permafrost thaw with outcomes being modulated by land management. Ongoing coastal erosion is intensifying and impinging on more regions with sea-level rise adding to land use pressure in some regions (*medium confidence*). {4.2.1, 4.2.2, 4.2.3, 4.4.1, 4.4.2, 4.9.6, Table 4.1, 7.2.1, 7.2.2}

A.2.8 Climate change has already affected food security due to warming, changing precipitation patterns, and greater frequency of some extreme events (*high confidence*). Studies that separate out climate change from other factors affecting crop yields have shown that yields of some crops (e.g., maize and wheat) in many lower-latitude regions have been affected negatively by observed climate changes, while in many higher-latitude regions, yields of some crops (e.g., maize, wheat, and sugar beets) have been affected positively over recent decades (*high confidence*). Climate change has resulted in lower animal growth rates and productivity in pastoral systems in Africa (*high confidence*). There is robust evidence that agricultural pests and diseases have already responded to climate change resulting in both increases and decreases of infestations (*high confidence*). Based on indigenous and local knowledge, climate change is affecting food security in drylands, particularly those in Africa, and high mountain regions of Asia and South America.[20] {5.2.1, 5.2.2, 7.2.2}

A.3 Agriculture, Forestry and Other Land Use (AFOLU) activities accounted for around 13% of CO_2, 44% of methane (CH_4), and 81% of nitrous oxide (N_2O) emissions from human activities globally during 2007-2016, representing 23% (12.0 ± 2.9 $GtCO_2eq\ yr^{-1}$) of total net anthropogenic emissions of GHGs (*medium confidence*).[21] The natural response of land to human-induced environmental change caused a net sink of around 11.2 $GtCO_2\ yr^{-1}$ during 2007–2016 (equivalent to 29% of total CO2 emissions) (*medium confidence*); the persistence of the sink is uncertain due to climate change (*high confidence*). If emissions associated with pre- and post-production activities in the global food system[22] are included, the emissions are estimated to be 21–37% of total net anthropogenic GHG emissions (*medium confidence*). {2.3, Table 2.2, 5.4}

A.3.1 Land is simultaneously a source and a sink of CO_2 due to both anthropogenic and natural drivers, making it hard to separate anthropogenic from natural fluxes (*very high confidence*). Global models estimate net CO_2 emissions of 5.2 ± 2.6 $GtCO_2\ yr^{-1}$ (*likely* range) from land use and land-use change during 2007–2016. These net emissions are mostly due to deforestation, partly offset by afforestation/reforestation, and emissions and removals by other land use activities (*very high confidence*).[23] There is no clear trend in annual emissions since 1990 (*medium confidence*). (Figure SPM.1, Table SPM.1) {1.1, 2.3, Table 2.2, Table 2.3}

A.3.2 The natural response of land to human-induced environmental changes such as increasing atmospheric CO_2 concentration, nitrogen deposition, and climate change, resulted in global net removals of 11.2 ± 2.6 $GtCO_2\ yr^{-1}$ (*likely* range) during 2007–2016. The sum of the net removals due to this response and the AFOLU net emissions gives a total net land-atmosphere flux that removed 6.0 ± 3.7 $GtCO_2\ yr^{-1}$ during 2007–2016 (*likely* range). Future net increases in CO_2 emissions from vegetation and soils due to climate change are projected to counteract increased removals due to CO_2 fertilisation and longer growing seasons (*high confidence*). The balance between these processes is a key source of uncertainty for determining the future of the land carbon sink. Projected thawing of permafrost is expected to increase the loss of soil carbon (*high confidence*). During the 21st century, vegetation growth in those areas may compensate in part for this loss (*low confidence*). (Table SPM.1) {Box 2.3, 2.3.1, 2.5.3, 2.7, Table 2.3}

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20 The assessment covered literature whose methodologies included interviews and surveys with indigenous peoples and local communities.

21 This assessment only includes CO_2, CH_4 and N_2O.

22 Global food system in this report is defined as 'all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socioeconomic and environmental outcomes at the global level'. These emissions data are not directly comparable to the national inventories prepared according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

23 The net anthropogenic flux of CO_2 from 'bookkeeping' or 'carbon accounting' models is composed of two opposing gross fluxes: gross emissions (about 20 $GtCO_2\ yr^{-1}$) are from deforestation, cultivation of soils, and oxidation of wood products; gross removals (about 14 $GtCO_2\ yr^{-1}$) are largely from forest growth following wood harvest and agricultural abandonment (*medium confidence*).

A.3.3 Global models and national GHG inventories use different methods to estimate anthropogenic CO_2 emissions and removals for the land sector. Both produce estimates that are in close agreement for land-use change involving forest (e.g., deforestation, afforestation), and differ for managed forest. Global models consider as managed forest those lands that were subject to harvest whereas, consistent with IPCC guidelines, national GHG inventories define managed forest more broadly. On this larger area, inventories can also consider the natural response of land to human-induced environmental changes as anthropogenic, while the global model approach (Table SPM.1) treats this response as part of the non-anthropogenic sink. For illustration, from 2005 to 2014, the sum of the national GHG inventories net emission estimates is 0.1 ± 1.0 $GtCO_2$ yr^{-1}, while the mean of two global bookkeeping models is 5.2 ± 2.6 $GtCO_2$ yr^{-1} (*likely* range). Consideration of differences in methods can enhance understanding of land sector net emission estimates and their applications. {2.4.1, 2.7.3, Fig 2.5, Box 2.2}

Net anthropogenic emissions due to Agriculture, Forestry, and other Land Use (AFOLU) and non-AFOLU (Panel 1) and global food systems (average for 2007–2016)[1] (Panel 2). Positive values represent emissions; negative values represent removals.

		Direct Anthropogenic							
Gas	Units	Net anthropogenic emissions due to Agriculture, Forestry, and Other Land Use (AFOLU)			Non-AFOLU anthropogenic GHG emissions[6]	Total net anthropogenic emissions (AFOLU + non-AFOLU) by gas	AFOLU as a % of total net anthropogenic emissions, by gas	Natural response of land to human-induced environmental change[7]	Net land – atmosphere flux from all lands
Panel 1: Contribution of AFOLU									
		FOLU	Agriculture	Total					
		A	B	C = A + B	D	**E = C + D**	F = (C/E) ×100	G	A + G
CO_2[2]	$GtCO_2\ yr^{-1}$	5.2 ± 2.6	No data[11]	5.2 ± 2.6	33.9 ± 1.8	**39.1 ± 3.2**	13%	-11.2 ± 2.6	-6.0 ± 3.7
CH_4[3,8]	$MtCH_4\ yr^{-1}$	19.2 ± 5.8	142 ± 42	161 ± 43	201 ± 101	**362 ± 109**			
	$GtCO_2eq\ yr^{-1}$	0.5 ± 0.2	4.0 ± 1.2	4.5 ± 1.2	5.6 ± 2.8	**10.1 ± 3.1**	44%		
N_2O[3,8]	$MtN_2O\ yr^{-1}$	0.3 ± 0.1	8.3 ± 2.5	8.7 ± 2.5	2.0 ± 1.0	**10.6 ± 2.7**			
	$GtCO_2eq\ yr^{-1}$	0.09 ± 0.03	2.2 ± 0.7	2.3 ± 0.7	0.5 ± 0.3	**2.8 ± 0.7**	81%		
Total (GHG)	**$GtCO_2eq\ yr^{-1}$**	**5.8 ± 2.6**	**6.2 ± 1.4**	**12.0 ± 2.9**	**40.0 ± 3.4**	**52.0 ± 4.5**	**23%**		
Panel 2: Contribution of global food system									
		Land-use change	Agriculture		Non-AFOLU[5] other sectors pre- to post-production	Total global food system emissions			
CO_2 Land-use change[4]	$GtCO_2\ yr^{-1}$	4.9 ± 2.5							
CH_4 Agriculture[3,8,9]	$GtCO_2eq\ yr^{-1}$		4.0 ± 1.2						
N_2O Agriculture[3,8,9]	$GtCO_2eq\ yr^{-1}$		2.2 ± 0.7						
CO_2 other sectors[5]	$GtCO_2yr^{-1}$				2.6 – 5.2				
Total[10]	**$GtCO_2eq\ yr^{-1}$**	**4.9 ± 2.5**	**6.2 ± 1.4**		**2.6 – 5.2**	**10.8 – 19.1**			

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Table SPM.1 | Data sources and notes:

[1] Estimates are only given until 2016 as this is the latest date when data are available for all gases.

[2] Net anthropogenic flux of CO_2 due to land cover change such as deforestation and afforestation, and land management including wood harvest and regrowth, as well as peatland burning, based on two bookkeeping models as used in the Global Carbon Budget and for AR5. Agricultural soil carbon stock change under the same land use is not considered in these models. {2.3.1.2.1, Table 2.2, Box 2.2}

[3] Estimates show the mean and assessed uncertainty of two databases, FAOSTAT and USEPA. 2012 {2.3, Table 2.2}

[4] Based on FAOSTAT. Categories included in this value are 'net forest conversion' (net deforestation), drainage of organic soils (cropland and grassland), biomass burning (humid tropical forests, other forests, organic soils). It excludes 'forest land' (forest management plus net forest expansion), which is primarily a sink due to afforestation. Note: Total FOLU emissions from FAOSTAT are 2.8 (±1.4) $GtCO_2\ yr^{-1}$ for the period 2007–2016. {Table 2.2, Table 5.4}

[5] CO_2 emissions induced by activities not included in the AFOLU sector, mainly from energy (e.g., grain drying), transport (e.g., international trade), and industry (e.g., synthesis of inorganic fertilisers) part of food systems, including agricultural production activities (e.g., heating in greenhouses), pre-production (e.g., manufacturing of farm inputs) and post-production (e.g., agri-food processing) activities. This estimate is land based and hence excludes emissions from fisheries. It includes emissions from fibre and other non-food agricultural products since these are not separated from food use in databases. The CO_2 emissions related to food system in other sectors than AFOLU are 6–-13% of total anthropogenic CO_2 emissions. These emissions are typically low in smallholder subsistence farming. When added to AFOLU emissions, the estimated share of food systems in global anthropogenic emissions is 21–-37%. {5.4.5, Table 5.4}

[6] Total non-AFOLU emissions were calculated as the sum of total CO_2eq emissions values for energy, industrial sources, waste and other emissions with data from the Global Carbon Project for CO_2, including international aviation and shipping and from the PRIMAP database for CH_4 and N_2O averaged over 2007–2014 only as that was the period for which data were available. {2.3, Table 2.2}.

[7] The natural response of land to human-induced environmental changes is the response of vegetation and soils to environmental changes such as increasing atmospheric CO_2 concentration, nitrogen deposition, and climate change. The estimate shown represents the average from Dynamic Global Vegetation Models {2.3.1.2, Box 2.2, Table 2.3}

[8] All values expressed in units of CO_2eq are based on AR5 100-year Global Warming Potential (GWP) values without climate-carbon feedbacks (N_2O = 265; CH_4 = 28). Note that the GWP has been used across fossil fuel and biogenic sources of methane. If a higher GWP for fossil fuel CH_4 (30 per AR5) were used, then total anthropogenic CH_4 emissions expressed in CO_2eq would be 2% greater.

[9] This estimate is land based and hence excludes emissions from fisheries and emissions from aquaculture (except emissions from feed produced on land and used in aquaculture), and also includes non-food use (e.g. fibre and bioenergy) since these are not separated from food use in databases. It excludes non-CO_2 emissions associated with land use change (FOLU category) since these are from fires in forests and peatlands.

[10] Emissions associated with food loss and waste are included implicitly, since emissions from the food system are related to food produced, including food consumed for nutrition and to food loss and waste. The latter is estimated at 8–10% of total anthropogenic emissions in CO_2eq. {5.5.2.5}

[11] No global data are available for agricultural CO_2 emissions.

A.3.4 Global AFOLU emissions of methane in the period 2007–2016 were 161 ± 43 $MtCH_4\ yr^{-1}$ (4.5 ± 1.2 $GtCO_2eq\ yr^{-1}$) (*medium confidence*). The globally averaged atmospheric concentration of CH_4 shows a steady increase between the mid-1980s and early 1990s, slower growth thereafter until 1999, a period of no growth between 1999–2006, followed by a resumption of growth in 2007 (*high confidence*). Biogenic sources make up a larger proportion of emissions than they did before 2000 (*high confidence*). Ruminants and the expansion of rice cultivation are important contributors to the rising concentration (*high confidence*). (Figure SPM.1) {Table 2.2, 2.3.2, 5.4.2, 5.4.3}

A.3.5 Anthropogenic AFOLU N_2O emissions are rising, and were 8.7 ± 2.5 $MtN_2O\ yr^{-1}$ (2.3 ± 0.7 $GtCO_2eq\ yr^{-1}$) during the period 2007-2016. Anthropogenic N_2O emissions {Figure SPM.1, Table SPM.1} from soils are primarily due to nitrogen application including inefficiencies (over-application or poorly synchronised with crop demand timings) (*high confidence*). Cropland soils emitted around 3 $MtN_2O\ yr^{-1}$ (around 795 $MtCO_2$ eq yr^{-1}) during the period 2007–2016 (*medium confidence*). There has been a major growth in emissions from managed pastures due to increased manure deposition (*medium confidence*). Livestock on managed pastures and rangelands accounted for more than one half of total anthropogenic N_2O emissions from agriculture in 2014 (*medium confidence*). {Table 2.1, 2.3.3, 5.4.2, 5.4.3}

A.3.6 Total net GHG emissions from AFOLU emissions represent 12.0 ± 2.9 $GtCO_2eq\ yr^{-1}$ during 2007–2016. This represents 23% of total net anthropogenic emissions {Table SPM.1}.[24] Other approaches, such as global food system, include agricultural emissions and land use change (i.e., deforestation and peatland degradation), as well as outside farm gate emissions from energy, transport and industry sectors for food production. Emissions within farm gate and from agricultural land expansion contributing to the global food system represent 16–27% of total anthropogenic emissions (*medium confidence*). Emissions outside the farm gate represent 5–10% of total anthropogenic emissions (*medium confidence*). Given the diversity of food systems, there are large regional differences in the contributions from different components of the food system (*very high confidence*). Emissions from agricultural production are projected to increase (*high confidence*), driven by population and income growth and changes in consumption patterns (*medium confidence*). {5.5, Table 5.4}

[24] This assessment only includes CO_2, CH_4 and N_2O.

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A.4 Changes in land conditions,[25] either from land-use or climate change, affect global and regional climate (*high confidence*). At the regional scale, changing land conditions can reduce or accentuate warming and affect the intensity, frequency and duration of extreme events. The magnitude and direction of these changes vary with location and season (*high confidence*). {Executive Summary Chapter 2, 2.3, 2.4, 2.5, 3.3}

A.4.1 Since the pre-industrial period, changes in land cover due to human activities have led to both a net release of CO_2 contributing to global warming (*high confidence*), and an increase in global land albedo[26] causing surface cooling (*medium confidence*). Over the historical period, the resulting net effect on globally averaged surface temperature is estimated to be small (*medium confidence*). {2.4, 2.6.1, 2.6.2}

A.4.2 The likelihood, intensity and duration of many extreme events can be significantly modified by changes in land conditions, including heat related events such as heatwaves (*high confidence*) and heavy precipitation events (*medium confidence*). Changes in land conditions can affect temperature and rainfall in regions as far as hundreds of kilometres away (*high confidence*). {2.5.1, 2.5.2, 2.5.4, 3.3, Cross-Chapter Box 4 in Chapter 2}

A.4.3 Climate change is projected to alter land conditions with feedbacks on regional climate. In those boreal regions where the treeline migrates northward and/or the growing season lengthens, winter warming will be enhanced due to decreased snow cover and albedo while warming will be reduced during the growing season because of increased evapotranspiration (*high confidence*). In those tropical areas where increased rainfall is projected, increased vegetation growth will reduce regional warming (*medium confidence*). Drier soil conditions resulting from climate change can increase the severity of heat waves, while wetter soil conditions have the opposite effect (*high confidence*). {2.5.2, 2.5.3}

A.4.4 Desertification amplifies global warming through the release of CO_2 linked with the decrease in vegetation cover (*high confidence*). This decrease in vegetation cover tends to increase local albedo, leading to surface cooling (*high confidence*). {3.3}

A.4.5 Changes in forest cover, for example from afforestation, reforestation and deforestation, directly affect regional surface temperature through exchanges of water and energy (*high confidence*).[27] Where forest cover increases in tropical regions cooling results from enhanced evapotranspiration (*high confidence*). Increased evapotranspiration can result in cooler days during the growing season (*high confidence*) and can reduce the amplitude of heat related events (*medium confidence*). In regions with seasonal snow cover, such as boreal and some temperate regions, increased tree and shrub cover also has a wintertime warming influence due to reduced surface albedo (*high confidence*).[28] {2.3, 2.4.3, 2.5.1, 2.5.2, 2.5.4}

A.4.6 Both global warming and urbanisation can enhance warming in cities and their surroundings (heat island effect), especially during heat related events, including heat waves (*high confidence*). Night-time temperatures are more affected by this effect than daytime temperatures (*high confidence*). Increased urbanisation can also intensify extreme rainfall events over the city or downwind of urban areas (*medium confidence*). {2.5.1, 2.5.2, 2.5.3, 4.9.1, Cross-Chapter Box 4 in Chapter 2}

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[25] Land conditions encompass changes in land cover (e.g., deforestation, afforestation, urbanisation), in land use (e.g., irrigation), and in land state (e.g., degree of wetness, degree of greening, amount of snow, amount of permafrost).

[26] Land with high albedo reflects more incoming solar radiation than land with low albedo.

[27] The literature indicates that forest cover changes can also affect climate through changes in emissions of reactive gases and aerosols. {2.4, 2.5}

[28] Emerging literature shows that boreal forest-related aerosols may counteract at least partly the warming effect of surface albedo. {2.4.3}

SPM

Box SPM. 1 | Shared Socio-economic Pathways (SSPs)

In this report the implications of future socio-economic development on climate change mitigation, adaptation and land-use are explored using shared socio-economic pathways (SSPs). The SSPs span a range of challenges to climate change mitigation and adaptation.

- SSP1 includes a peak and decline in population (~7 billion in 2100), high income and reduced inequalities, effective land-use regulation, less resource intensive consumption, including food produced in low-GHG emission systems and lower food waste, free trade and environmentally-friendly technologies and lifestyles. Relative to other pathways, SSP1 has low challenges to mitigation and low challenges to adaptation (i.e., high adaptive capacity)

- SSP2 includes medium population growth (~9 billion in 2100), medium income, technological progress, production and consumption patterns are a continuation of past trends, and only a gradual reduction in inequality occurs. Relative to other pathways, SSP2 has medium challenges to mitigation and medium challenges to adaptation (i.e., medium adaptive capacity).

- SSP3 includes high population growth (~13 billion in 2100), low income and continued inequalities, material-intensive consumption and production, barriers to trade, and slow rates of technological change. Relative to other pathways, SSP3 has high challenges to mitigation and high challenges to adaptation (i.e., low adaptive capacity).

- SSP4 includes medium population growth (~9 billion in 2100), medium income, but significant inequality within and across regions. Relative to other pathways, SSP4 has low challenges to mitigation, but high challenges to adaptation (i.e., low adaptive capacity).

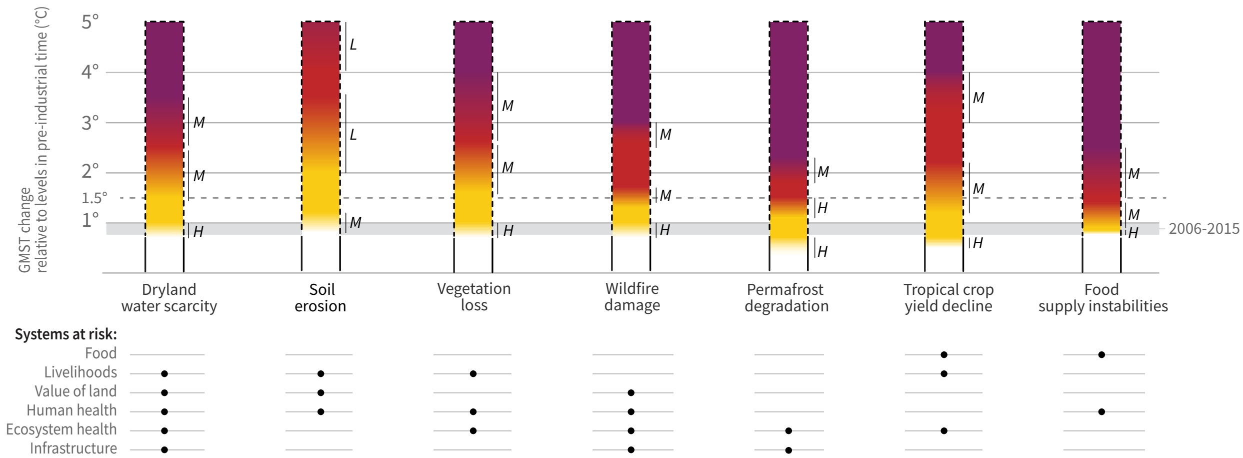
- SSP5 includes a peak and decline in population (~7 billion in 2100), high income, reduced inequalities, and free trade. This pathway includes resource-intensive production, consumption and lifestyles. Relative to other pathways, SSP5 has high challenges to mitigation, but low challenges to adaptation (i.e., high adaptive capacity).

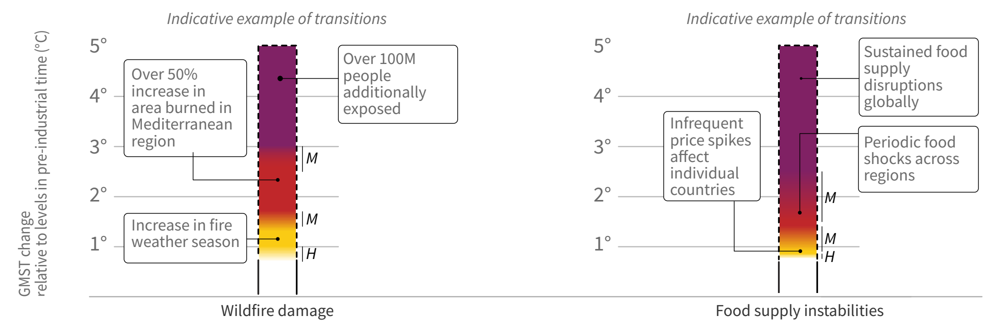
- The SSPs can be combined with Representative Concentration Pathways (RCPs) which imply different levels of mitigation, with implications for adaptation. Therefore, SSPs can be consistent with different levels of global mean surface temperature rise as projected by different SSP-RCP combinations. However, some SSP-RCP combinations are not possible; for instance RCP2.6 and lower levels of future global mean surface temperature rise (e.g., 1.5ºC) are not possible in SSP3 in modelled pathways. {1.2.2, 6.1.4, Cross-Chapter Box 1 in Chapter 1, Cross-Chapter Box 9 in Chapter 6}

SPM

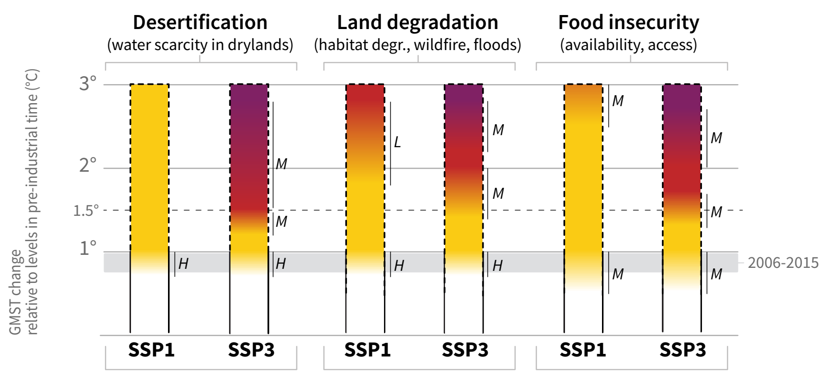
A. Risks to humans and ecosystems from changes in land-based processes as a result of climate change

Increases in global mean surface temperature (GMST), relative to pre-industrial levels, affect processes involved in **desertification** (water scarcity), **land degradation** (soil erosion, vegetation loss, wildfire, permafrost thaw) and **food security** (crop yield and food supply instabilities). Changes in these processes drive risks to food systems, livelihoods, infrastructure, the value of land, and human and ecosystem health. Changes in one process (e.g. wildfire or water scarcity) may result in compound risks. Risks are location-specific and differ by region.





B. Different socioeconomic pathways affect levels of climate related risks



Socio-economic choices can reduce or exacerbate climate related risks as well as influence the rate of temperature increase. The **SSP1** pathway illustrates a world with low population growth, high income and reduced inequalities, food produced in low GHG emission systems, effective land use regulation and high adaptive capacity. The **SSP3** pathway has the opposite trends. Risks are lower in SSP1 compared with SSP3 given the same level of GMST increase.

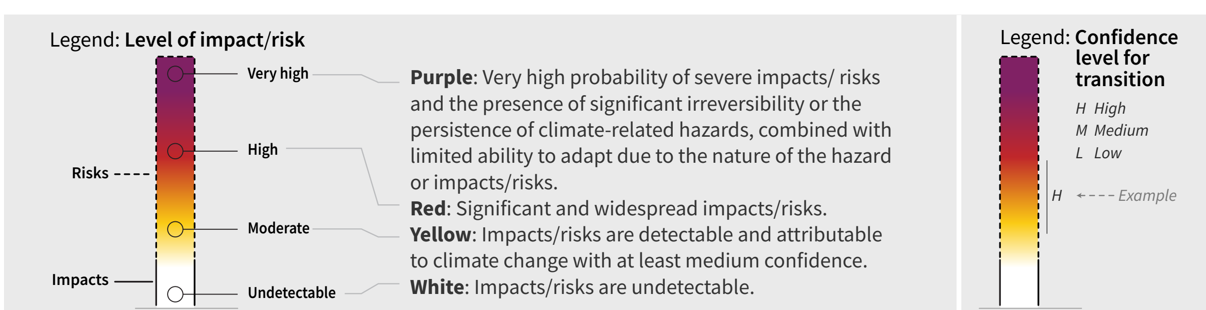


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Figure SPM.2: Risks to land-related human systems and ecosystems from global climate change, socio-economic development and mitigation choices in terrestrial ecosystems. | As in previous IPCC reports the literature was used to make expert judgements to assess the levels of global warming at which levels of risk are undetectable, moderate, high or very high, as described further in Chapter 7 and other parts of the underlying report. The Figure indicates assessed risks at approximate warming levels which may be influenced by a variety of factors, including adaptation responses. The assessment considers adaptive capacity consistent with the SSP pathways as described below. **Panel A**: Risks to selected elements of the land system as a function of global mean surface temperature {2.1, Box 2.1, 3.5, 3.7.1.1, 4.4.1.1, 4.4.1.2, 4.4.1.3, 5.2.2, 5.2.3, 5.2.4, 5.2.5, 7.2, 7.3, Table SM7.1}. Links to broader systems are illustrative and not intended to be comprehensive. Risk levels are estimated assuming medium exposure and vulnerability driven by moderate trends in socioeconomic conditions broadly consistent with an SSP2 pathway. {Table SM7.4} **Panel B**: Risks associated with desertification, land degradation and food security due to climate change and patterns of socio-economic development. Increasing risks associated with desertification include population exposed and vulnerable to water scarcity in drylands. Risks related to land degradation include increased habitat degradation, population exposed to wildfire and floods and costs of floods. Risks to food security include availability and access to food, including population at risk of hunger, food price increases and increases in disability adjusted life years attributable due to childhood underweight. Risks are assessed for two contrasted socio-economic pathways (SSP1 and SSP3 {Box SPM.1}) excluding the effects of targeted mitigation policies. {3.5, 4.2.1.2, 5.2.2, 5.2.3, 5.2.4, 5.2.5, 6.1.4, 7.2, Table SM7.5} Risks are not indicated beyond 3°C because SSP1 does not exceed this level of temperature change. **All panels:** As part of the assessment, literature was compiled and data extracted into a summary table. A formal expert elicitation protocol (based on modified-Delphi technique and the Sheffield Elicitation Framework), was followed to identify risk transition thresholds. This included a multi-round elicitation process with two rounds of independent anonymous threshold judgement, and a final consensus discussion. Further information on methods and underlying literature can be found in Chapter 7 Supplementary Material.

A.5 Climate change creates additional stresses on land, exacerbating existing risks to livelihoods, biodiversity, human and ecosystem health, infrastructure, and food systems (*high confidence*). Increasing impacts on land are projected under all future GHG emission scenarios (*high confidence*). Some regions will face higher risks, while some regions will face risks previously not anticipated (*high confidence*). Cascading risks with impacts on multiple systems and sectors also vary across regions (*high confidence*). (Figure SPM.2) {2.2, 3.5, 4.2, 4.4, 4.7, 5.1, 5.2, 5.8, 6.1, 7.2, 7.3, Cross-Chapter Box 9 in Chapter 6}

A.5.1 With increasing warming, the frequency, intensity and duration of heat related events including heatwaves are projected to continue to increase through the 21st century (*high confidence*). The frequency and intensity of droughts are projected to increase particularly in the Mediterranean region and southern Africa (*medium confidence*). The frequency and intensity of extreme rainfall events are projected to increase in many regions (*high confidence*). {2.2.5, 3.5.1, 4.2.3, 5.2}

A.5.2 With increasing warming, climate zones are projected to further shift poleward in the middle and high latitudes (*high confidence*). In high-latitude regions, warming is projected to increase disturbance in boreal forests, including drought, wildfire, and pest outbreaks (*high confidence*). In tropical regions, under medium and high GHG emissions scenarios, warming is projected to result in the emergence of unprecedented[29] climatic conditions by the mid to late 21st century (*medium confidence*). {2.2.4, 2.2.5, 2.5.3, 4.3.2}

A.5.3 Current levels of global warming are associated with moderate risks from increased dryland water scarcity, soil erosion, vegetation loss, wildfire damage, permafrost thawing, coastal degradation and tropical crop yield decline (*high confidence*). Risks, including cascading risks, are projected to become increasingly severe with increasing temperatures. At around 1.5°C of global warming the risks from dryland water scarcity, wildfire damage, permafrost degradation and food supply instabilities are projected to be high (*medium confidence*). At around 2°C of global warming the risk from permafrost degradation and food supply instabilities are projected to be very high (*medium confidence*). Additionally, at around 3°C of global warming risk from vegetation loss, wildfire damage, and dryland water scarcity are also projected to be very high (*medium confidence*). Risks from droughts, water stress, heat related events such as heatwaves and habitat degradation simultaneously increase between 1.5°C and 3°C warming (*low confidence*). (Figure SPM.2) {7.2.2, Cross-Chapter Box 9 in Chapter 6, Chapter 7 Supplementary Material}

A.5.4 The stability of food supply[30] is projected to decrease as the magnitude and frequency of extreme weather events that disrupt food chains increases (*high confidence*). Increased atmospheric CO_2 levels can also lower the nutritional quality of crops (*high confidence*). In SSP2, global crop and economic models project a median increase of 7.6% (range of 1–23%) in cereal prices in 2050 due to climate change (RCP6.0), leading to higher food prices and increased risk of food insecurity and hunger (*medium*

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[29] Unprecedented climatic conditions are defined in this report as 'not having occurred anywhere during the 20th century'. They are characterised by high temperature with strong seasonality and shifts in precipitation. In the literature assessed, the effect of climatic variables other than temperature and precipitation were not considered.

[30] The supply of food is defined in this report as 'encompassing availability and access (including price)'. Food supply instability refers to variability that influences food security through reducing access.

confidence). The most vulnerable people will be more severely affected (*high confidence*). {5.2.3, 5.2.4, 5.2.5, 5.8.1, 7.2.2.2, 7.3.1}

A.5.5 In drylands, climate change and desertification are projected to cause reductions in crop and livestock productivity (*high confidence*), modify the plant species mix and reduce biodiversity (*medium confidence*). Under SSP2, the dryland population vulnerable to water stress, drought intensity and habitat degradation is projected to reach 178 million people by 2050 at 1.5°C warming, increasing to 220 million people at 2°C warming, and 277 million people at 3°C warming (*low confidence*). {3.5.1, 3.5.2, 3.7.3}

A.5.6 Asia and Africa[31] are projected to have the highest number of people vulnerable to increased desertification. North America, South America, Mediterranean, southern Africa and central Asia may be increasingly affected by wildfire. The tropics and subtropics are projected to be most vulnerable to crop yield decline. Land degradation resulting from the combination of sea-level rise and more intense cyclones is projected to jeopardise lives and livelihoods in cyclone prone areas (*very high confidence*). Within populations, women, the young, elderly and poor are most at risk (*high confidence*). {3.5.1, 3.5.2, 4.4, Table 4.1, 5.2.2, 7.2.2, Cross-Chapter Box 3 in Chapter 2}

A.5.7 Changes in climate can amplify environmentally induced migration both within countries and across borders (*medium confidence*), reflecting multiple drivers of mobility and available adaptation measures (*high confidence*). Extreme weather and climate or slow-onset events may lead to increased displacement, disrupted food chains, threatened livelihoods (*high confidence*), and contribute to exacerbated stresses for conflict (*medium confidence*). {3.4.2, 4.7.3, 5.2.3, 5.2.4, 5.2.5, 5.8.2, 7.2.2, 7.3.1}

A.5.8 Unsustainable land management has led to negative economic impacts (*high confidence*). Climate change is projected to exacerbate these negative economic impacts (*high confidence*). {4.3.1, 4.4.1, 4.7, 4.8.5, 4.8.6, 4.9.6, 4.9.7, 4.9.8, 5.2, 5.8.1, 7.3.4, 7.6.1, Cross-Chapter Box 10 in Chapter 7}

A.6 The level of risk posed by climate change depends both on the level of warming and on how population, consumption, production, technological development, and land management patterns evolve (*high confidence*). Pathways with higher demand for food, feed, and water, more resource-intensive consumption and production, and more limited technological improvements in agriculture yields result in higher risks from water scarcity in drylands, land degradation, and food insecurity (*high confidence*). (Figure SPM.2b) {5.1.4, 5.2.3, 6.1.4, 7.2, Cross-Chapter Box 9 in Chapter 6}

A.6.1 Projected increases in population and income, combined with changes in consumption patterns, result in increased demand for food, feed, and water in 2050 in all SSPs (*high confidence*). These changes, combined with land management practices, have implications for land-use change, food insecurity, water scarcity, terrestrial GHG emissions, carbon sequestration potential, and biodiversity (*high confidence*). Development pathways in which incomes increase and the demand for land conversion is reduced, either through reduced agricultural demand or improved productivity, can lead to reductions in food insecurity (*high confidence*). All assessed future socio-economic pathways result in increases in water demand and water scarcity (*high confidence*). SSPs with greater cropland expansion result in larger declines in biodiversity (*high confidence*). {6.1.4}

A.6.2 Risks related to water scarcity in drylands are lower in pathways with low population growth, less increase in water demand, and high adaptive capacity, as in SSP1 {Box SPM.1}. In these scenarios the risk from water scarcity in drylands is moderate even at global warming of 3°C (*low confidence*). By contrast, risks related to water scarcity in drylands are greater for pathways with high population growth, high vulnerability, higher water demand, and low adaptive capacity, such as SSP3. In SSP3 the transition from moderate to high risk occurs between 1.2°C and 1.5°C (*medium confidence*). (Figure SPM.2b, Box SPM.1) {7.2}

A.6.3 Risks related to climate change driven land degradation are higher in pathways with a higher population, increased land-use change, low adaptive capacity and other barriers to adaptation (e.g., SSP3). These scenarios result in more people exposed to ecosystem degradation, fire, and coastal flooding (*medium confidence*). For land degradation, the projected transition from moderate to high risk occurs for global warming between 1.8°C and 2.8°C in SSP1 (*low confidence*) and between 1.4°C and 2°C in SSP3 (*medium confidence*). The projected transition from high to very high risk occurs between 2.2°C and 2.8°C for SSP3 (*medium confidence*). (Figure SPM.2b) {4.4, 7.2}

[31] West Africa has a high number of people vulnerable to increased desertification and yield decline. North Africa is vulnerable to water scarcity.

A.6.4 Risks related to food security are greater in pathways with lower income, increased food demand, increased food prices resulting from competition for land, more limited trade, and other challenges to adaptation (e.g., SSP3) (*high confidence*). For food security, the transition from moderate to high risk occurs for global warming between 2.5°C and 3.5°C in SSP1 (*medium confidence*) and between 1.3°C and 1.7°C in SSP3 (*medium confidence*). The transition from high to very high risk occurs between 2°C and 2.7°C for SSP3 (*medium confidence*). (Figure SPM.2b) {7.2}

A.6.5 Urban expansion is projected to lead to conversion of cropland leading to losses in food production (*high confidence*). This can result in additional risks to the food system. Strategies for reducing these impacts can include urban and peri-urban food production and management of urban expansion, as well as urban green infrastructure that can reduce climate risks in cities[32] (*high confidence*). (Figure SPM.3) {4.9.1, 5.5, 5.6, 6.3, 6.4, 7.5.6}

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[32] The land systems considered in this report do not include urban ecosystem dynamics in detail. Urban areas, urban expansion, and other urban processes and their relation to land-related processes are extensive, dynamic, and complex. Several issues addressed in this report such as population, growth, incomes, food production and consumption, food security, and diets have close relationships with these urban processes. Urban areas are also the setting of many processes related to land-use change dynamics, including loss of ecosystem functions and services, that can lead to increased disaster risk. Some specific urban issues are assessed in this report.

B. Adaptation and mitigation response options

B.1 Many land-related responses that contribute to climate change adaptation and mitigation can also combat desertification and land degradation and enhance food security. The potential for land-related responses and the relative emphasis on adaptation and mitigation is context specific, including the adaptive capacities of communities and regions. While land-related response options can make important contributions to adaptation and mitigation, there are some barriers to adaptation and limits to their contribution to global mitigation. (*very high confidence*) (Figure SPM.3) {2.6, 4.8, 5.6, 6.1, 6.3, 6.4}

B.1.1 Some land-related actions are already being taken that contribute to climate change adaptation, mitigation and sustainable development. The response options were assessed across adaptation, mitigation, combating desertification and land degradation, food security and sustainable development, and a select set of options deliver across all of these challenges. These options include, but are not limited to, sustainable food production, improved and sustainable forest management, soil organic carbon management, ecosystem conservation and land restoration, reduced deforestation and degradation, and reduced food loss and waste (*high confidence*). These response options require integration of biophysical, socioeconomic and other enabling factors. {6.3, 6.4.5, 7.5.6, Cross-Chapter Box 10 in Chapter 7}

B.1.2 While some response options have immediate impacts, others take decades to deliver measurable results. Examples of response options with immediate impacts include the conservation of high-carbon ecosystems such as peatlands, wetlands, rangelands, mangroves and forests. Examples that provide multiple ecosystem services and functions, but take more time to deliver, include afforestation and reforestation as well as the restoration of high-carbon ecosystems, agroforestry, and the reclamation of degraded soils (*high confidence*). {6.4.5, 7.5.6, Cross-Chapter Box 10 in Chapter 7}

B.1.3 The successful implementation of response options depends on consideration of local environmental and socio-economic conditions. Some options such as soil carbon management are potentially applicable across a broad range of land use types, whereas the efficacy of land management practices relating to organic soils, peatlands and wetlands, and those linked to freshwater resources, depends on specific agro-ecological conditions (*high confidence*). Given the site-specific nature of climate change impacts on food system components and wide variations in agroecosystems, adaptation and mitigation options and their barriers are linked to environmental and cultural context at regional and local levels (*high confidence*). Achieving land degradation neutrality depends on the integration of multiple responses across local, regional and national scales and across multiple sectors including agriculture, pasture, forest and water (*high confidence*). {4.8, 6.2, 6.3, 6.4.4, 7.5.6}

B.1.4 Land-based options that deliver carbon sequestration in soil or vegetation, such as afforestation, reforestation, agroforestry, soil carbon management on mineral soils, or carbon storage in harvested wood products, do not continue to sequester carbon indefinitely (*high confidence*). Peatlands, however, can continue to sequester carbon for centuries (*high confidence*). When vegetation matures or when vegetation and soil carbon reservoirs reach saturation, the annual removal of CO_2 from the atmosphere declines towards zero, while carbon stocks can be maintained (*high confidence*). However, accumulated carbon in vegetation and soils is at risk from future loss (or sink reversal) triggered by disturbances such as flood, drought, fire, or pest outbreaks, or future poor management (*high confidence*). {6.4.1}

B.2 Most of the response options assessed contribute positively to sustainable development and other societal goals (*high confidence*). Many response options can be applied without competing for land and have the potential to provide multiple co-benefits (*high confidence*). A further set of response options has the potential to reduce demand for land, thereby enhancing the potential for other response options to deliver across each of climate change adaptation and mitigation, combating desertification and land degradation, and enhancing food security (*high confidence*). (Figure SPM.3) {4.8, 6.2, 6.3.6, 6.4.3}

B.2.1 A number of land management options, such as improved management of cropland and grazing lands, improved and sustainable forest management, and increased soil organic carbon content, do not require land use change and do not create demand for more land conversion (*high confidence*). Further, a number of response options such as increased food productivity, dietary choices and food losses, and waste reduction, can reduce demand for land conversion, thereby potentially freeing land and creating opportunities for enhanced implementation of other response options (*high confidence*). Response options that reduce competition for land are possible and are applicable at different scales, from farm to regional (*high confidence*). (Figure SPM.3) {4.8, 6.3.6, 6.4}

B.2.2 A wide range of adaptation and mitigation responses, e.g., preserving and restoring natural ecosystems such as peatland, coastal lands and forests, biodiversity conservation, reducing competition for land, fire management, soil management, and most risk management options (e.g., use of local seeds, disaster risk management, risk sharing instruments) have the potential to make positive contributions to sustainable development, enhancement of ecosystem functions and services and other societal goals (*medium confidence*). Ecosystem-based adaptation can, in some contexts, promote nature conservation while alleviating poverty and can even provide co-benefits by removing GHGs and protecting livelihoods (e.g., mangroves) (*medium confidence*). {6.4.3, 7.4.6.2}

B.2.3 Most of the land management-based response options that do not increase competition for land, and almost all options based on value chain management (e.g., dietary choices, reduced post-harvest losses, reduced food waste) and risk management, can contribute to eradicating poverty and eliminating hunger while promoting good health and wellbeing, clean water and sanitation, climate action, and life on land (*medium confidence*). {6.4.3}

B.3 Although most response options can be applied without competing for available land, some can increase demand for land conversion (*high confidence*). At the deployment scale of several $GtCO_2$ yr^{-1}, this increased demand for land conversion could lead to adverse side effects for adaptation, desertification, land degradation and food security (*high confidence*). If applied on a limited share of total land and integrated into sustainably managed landscapes, there will be fewer adverse side-effects and some positive co-benefits can be realised (*high confidence*). (Figure SPM.3) {4.5, 6.2, 6.4, Cross-Chapter Box 7 in Chapter 6}

B.3.1 If applied at scales necessary to remove CO_2 from the atmosphere at the level of several $GtCO_2$ yr^{-1}, afforestation, reforestation and the use of land to provide feedstock for bioenergy with or without carbon capture and storage, or for biochar, could greatly increase demand for land conversion (*high confidence*). Integration into sustainably managed landscapes at appropriate scale can ameliorate adverse impacts (*medium confidence*). Reduced grassland conversion to croplands, restoration and reduced conversion of peatlands, and restoration and reduced conversion of coastal wetlands affect smaller land areas globally, and the impacts on land use change of these options are smaller or more variable (*high confidence*). (Figure SPM.3) {Cross-Chapter Box 7 in Chapter 6, 6.4}

B.3.2 While land can make a valuable contribution to climate change mitigation, there are limits to the deployment of land-based mitigation measures such as bioenergy crops or afforestation. Widespread use at the scale of several millions of km^2 globally could increase risks for desertification, land degradation, food security and sustainable development (*medium confidence*). Applied on a limited share of total land, land-based mitigation measures that displace other land uses have fewer adverse side-effects and can have positive co-benefits for adaptation, desertification, land degradation or food security. (*high confidence*) (Figure SPM.3) {4.2, 4.5, 6.4; Cross-Chapter Box 7 in Chapter 6}

B.3.3 The production and use of biomass for bioenergy can have co-benefits, adverse side-effects, and risks for land degradation, food insecurity, GHG emissions and other environmental and sustainable development goals (*high confidence*). These impacts are context specific and depend on the scale of deployment, initial land use, land type, bioenergy feedstock, initial carbon stocks, climatic region and management regime, and other land-demanding response options can have a similar range of consequences (*high confidence*). The use of residues and organic waste as bioenergy feedstock can mitigate land use change pressures associated with bioenergy deployment, but residues are limited and the removal of residues that would otherwise be left on the soil could lead to soil degradation (*high confidence*). (Figure SPM.3) {2.6.1.5, Cross-Chapter Box 7 in Chapter 6}

B.3.4 For projected socioeconomic pathways with low population, effective land-use regulation, food produced in low-GHG emission systems and lower food loss and waste (SSP1), the transition from low to moderate risk to food security, land degradation and water scarcity in dry lands occur between 1 and 4 million km^2 of bioenergy or bioenergy with carbon capture and storage (BECCS) (*medium confidence*). By contrast, in pathways with high population, low income and slow rates of technological change (SSP3), the transition from low to moderate risk occurs between 0.1 and 1 million km^2 (*medium confidence*). (Box SPM.1) {6.4, Table SM7.6, Cross-Chapter Box 7 in Chapter 6}

B.4 Many activities for combating desertification can contribute to climate change adaptation with mitigation co-benefits, as well as to halting biodiversity loss with sustainable development co-benefits to society (*high confidence*). Avoiding, reducing and reversing desertification would enhance soil fertility, increase carbon storage in soils and biomass, while benefitting agricultural productivity and food security (*high confidence*). Preventing desertification is preferable to attempting to restore degraded land due to the potential for residual risks and maladaptive outcomes (*high confidence*). {3.6.1, 3.6.2, 3.6.3, 3.6.4, 3.7.1, 3.7.2}

B.4.1 Solutions that help adapt to and mitigate climate change while contributing to combating desertification are site and regionally specific and include inter alia: water harvesting and micro-irrigation, restoring degraded lands using drought-resilient ecologically appropriate plants, agroforestry, and other agroecological and ecosystem-based adaptation practices (*high confidence*). {3.3, 3.6.1, 3.7.2, 3.7.5, 5.2, 5.6}

B.4.2 Reducing dust and sand storms and sand dune movement can lessen the negative effects of wind erosion and improve air quality and health (*high confidence*). Depending on water availability and soil conditions, afforestation, tree planting and ecosystem restoration programs, which aim for the creation of windbreaks in the form of 'green walls' and 'green dams' using native and other climate resilient tree species with low water needs, can reduce sand storms, avert wind erosion, and contribute to carbon sinks, while improving micro-climates, soil nutrients and water retention (*high confidence*). {3.3, 3.6.1, 3.7.2, 3.7.5}

B.4.3 Measures to combat desertification can promote soil carbon sequestration (*high confidence*). Natural vegetation restoration and tree planting on degraded land enriches, in the long term, carbon in the topsoil and subsoil (*medium confidence*). Modelled rates of carbon sequestration following the adoption of conservation agriculture practices in drylands depend on local conditions (*medium confidence*). If soil carbon is lost, it may take a prolonged period of time for carbon stocks to recover. {3.1.4, 3.3, 3.6.1, 3.6.3, 3.7.1, 3.7.2}

B.4.4 Eradicating poverty and ensuring food security can benefit from applying measures promoting land degradation neutrality (including avoiding, reducing and reversing land degradation) in rangelands, croplands and forests, which contribute to combating desertification, while mitigating and adapting to climate change within the framework of sustainable development. Such measures include avoiding deforestation and locally suitable practices including management of rangeland and forest fires (*high confidence*). {3.4.2, 3.6.1, 3.6.2, 3.6.3, 4.8.5}

B.4.5 Currently there is a lack of knowledge of adaptation limits and potential maladaptation to combined effects of climate change and desertification. In the absence of new or enhanced adaptation options, the potential for residual risks and maladaptive outcomes is high (*high confidence*). Even when solutions are available, social, economic and institutional constraints could pose barriers to their implementation (*medium confidence*). Some adaptation options can become maladaptive due to their environmental impacts, such as irrigation causing soil salinisation or over extraction leading to ground-water depletion (*medium confidence*). Extreme forms of desertification can lead to the complete loss of land productivity, limiting adaptation options or reaching the limits to adaptation (*high confidence*). {Executive Summary Chapter 3, 3.6.4, 3.7.5, 7.4.9}

B.4.6 Developing, enabling and promoting access to cleaner energy sources and technologies can contribute to adaptation and mitigating climate change and combating desertification and forest degradation through decreasing the use of traditional biomass for energy while increasing the diversity of energy supply (*medium confidence*). This can have socioeconomic and health benefits, especially for women and children. (*high confidence*). The efficiency of wind and solar energy infrastructures is recognised; the efficiency can be affected in some regions by dust and sand storms (*high confidence*). {3.5.3, 3.5.4, 4.4.4, 7.5.2, Cross-Chapter Box 12 in Chapter 7}

B.5 Sustainable land management,[33] including sustainable forest management,[34] can prevent and reduce land degradation, maintain land productivity, and sometimes reverse the adverse impacts of climate change on land degradation (*very high confidence*). It can also contribute to mitigation and adaptation (*high confidence*). Reducing and reversing land degradation, at scales from individual farms to entire watersheds, can provide cost effective, immediate, and long-term benefits to communities and support several Sustainable Development Goals (SDGs) with co-benefits for adaptation (*very high confidence*) and mitigation (*high confidence*). Even with implementation of sustainable land management, limits to adaptation can be exceeded in some situations (*medium confidence*). {1.3.2, 4.1.5, 4.8, 7.5.6, Table 4.2}

B.5.1 Land degradation in agriculture systems can be addressed through sustainable land management, with an ecological and socioeconomic focus, with co-benefits for climate change adaptation. Management options that reduce vulnerability to soil erosion and nutrient loss include growing green manure crops and cover crops, crop residue retention, reduced/zero tillage, and maintenance of ground cover through improved grazing management (*very high confidence*). {4.8}

B.5.2 The following options also have mitigation co-benefits. Farming systems such as agroforestry, perennial pasture phases and use of perennial grains, can substantially reduce erosion and nutrient leaching while building soil carbon (*high confidence*). The global sequestration potential of cover crops would be about 0.44 ± 0.11 $GtCO_2$ yr^{-1} if applied to 25% of global cropland (*high confidence*). The application of certain biochars can sequester carbon (*high confidence*),and improve soil conditions in some soil types/climates (*medium confidence*). {4.8.1.1, 4.8.1.3, 4.9.2, 4.9.5, 5.5.1, 5.5.4, Cross-Chapter Box 6 in Chapter 5}

B.5.3 Reducing deforestation and forest degradation lowers GHG emissions (*high confidence*), with an estimated technical mitigation potential of 0.4–5.8 $GtCO_2$ yr^{-1}. By providing long-term livelihoods for communities, sustainable forest management can reduce the extent of forest conversion to non-forest uses (e.g., cropland or settlements) (*high confidence*). Sustainable forest management aimed at providing timber, fibre, biomass, non-timber resources and other ecosystem functions and services, can lower GHG emissions and can contribute to adaptation (*high confidence*). {2.6.1.2, 4.1.5, 4.3.2, 4.5.3, 4.8.1.3, 4.8.3, 4.8.4}

B.5.4 Sustainable forest management can maintain or enhance forest carbon stocks, and can maintain forest carbon sinks, including by transferring carbon to wood products, thus addressing the issue of sink saturation (*high confidence*). Where wood carbon is transferred to harvested wood products, these can store carbon over the long-term and can substitute for emissions-intensive materials reducing emissions in other sectors (*high confidence*). Where biomass is used for energy, e.g., as a mitigation strategy, the carbon is released back into the atmosphere more quickly (*high confidence*). (Figure SPM.3) {2.6.1, 2.7, 4.1.5, 4.8.4, 6.4.1, Cross-Chapter Box 7 in Chapter 6}

B.5.5 Climate change can lead to land degradation, even with the implementation of measures intended to avoid, reduce or reverse land degradation (*high confidence*). Such limits to adaptation are dynamic, site-specific and are determined through the interaction of biophysical changes with social and institutional conditions (*very high confidence*). In some situations, exceeding the limits of adaptation can trigger escalating losses or result in undesirable transformational changes (*medium confidence*) such as forced migration (*low confidence*), conflicts (*low confidence*) or poverty (*medium confidence*). Examples of climate change induced land degradation that may exceed limits to adaptation include coastal erosion exacerbated by sea level rise where land disappears (*high confidence*), thawing of permafrost affecting infrastructure and livelihoods (*medium confidence*), and extreme soil erosion causing loss of productive capacity (*medium confidence*). {4.7, 4.8.5, 4.8.6, 4.9.6, 4.9.7, 4.9.8}

B.6 Response options throughout the food system, from production to consumption, including food loss and waste, can be deployed and scaled up to advance adaptation and mitigation (*high confidence*). The total technical mitigation potential from crop and livestock activities, and agroforestry is estimated as 2.3 – 9.6 $GtCO_2eq$ yr^{-1} by 2050 (*medium confidence*). The total technical mitigation potential of dietary changes is estimated as 0.7 – 8 $GtCO_2eq$ yr^{-1} by 2050 (*medium confidence*). {5.3, 5.5, 5.6}

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33 Sustainable land management is defined in this report as 'the stewardship and use of land resources, including soils, water, animals and plants, to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions'. Examples of options include, inter alia, agroecology (including agroforestry), conservation agriculture and forestry practices, crop and forest species diversity, appropriate crop and forest rotations, organic farming, integrated pest management, the conservation of pollinators, rain water harvesting, range and pasture management, and precision agriculture systems.

34 Sustainable forest management is defined in this report as 'the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and their potential to fulfil now and in the future, relevant ecological, economic and social functions at local, national and global levels and that does not cause damage to other ecosystems'.

SPM

B.6.1 Practices that contribute to climate change adaptation and mitigation in cropland include increasing soil organic matter, erosion control, improved fertiliser management, improved crop management, for example paddy rice management, and use of varieties and genetic improvements for heat and drought tolerance. For livestock, options include better grazing land management, improved manure management, higher-quality feed, and use of breeds and genetic improvement. Different farming and pastoral systems can achieve reductions in the emissions intensity of livestock products. Depending on the farming and pastoral systems and level of development, reductions in the emissions intensity of livestock products may lead to absolute reductions in GHG emissions (*medium confidence*). Many livestock related options can enhance the adaptive capacity of rural communities, in particular, of smallholders and pastoralists. Significant synergies exist between adaptation and mitigation, for example through sustainable land management approaches (*high confidence*). {4.8, 5.3.3, 5.5.1, 5.6}

B.6.2 Diversification in the food system (e.g., implementation of integrated production systems, broad-based genetic resources, and diets) can reduce risks from climate change (*medium confidence*). Balanced diets, featuring plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission systems, present major opportunities for adaptation and mitigation while generating significant co-benefits in terms of human health (*high confidence*). By 2050, dietary changes could free several million km^2 (*medium confidence*) of land and provide a technical mitigation potential of 0.7 to 8.0 $GtCO_2eq\ yr^{-1}$, relative to business as usual projections (*high confidence*). Transitions towards low-GHG emission diets may be influenced by local production practices, technical and financial barriers and associated livelihoods and cultural habits (*high confidence*). {5.3, 5.5.2, 5.5, 5.6}

B.6.3 Reduction of food loss and waste can lower GHG emissions and contribute to adaptation through reduction in the land area needed for food production (*medium confidence*). During 2010-2016, global food loss and waste contributed 8 –10% of total anthropogenic GHG emissions (*medium confidence*). Currently, 25 –30% of total food produced is lost or wasted (*medium confidence*). Technical options such as improved harvesting techniques, on-farm storage, infrastructure, transport, packaging, retail and education can reduce food loss and waste across the supply chain. Causes of food loss and waste differ substantially between developed and developing countries, as well as between regions (*medium confidence*). By 2050, reduced food loss and waste can free several million km^2 of land (*low confidence*). {5.5.2, 6.3.6}

B.7 Future land use depends, in part, on the desired climate outcome and the portfolio of response options deployed (*high confidence*). All assessed modelled pathways that limit warming to 1.5°C or well below 2°C require land-based mitigation and land-use change, with most including different combinations of reforestation, afforestation, reduced deforestation, and bioenergy (*high confidence*). A small number of modelled pathways achieve 1.5°C with reduced land conversion (*high confidence*) and thus reduced consequences for desertification, land degradation, and food security (*medium confidence*). (Figure SPM.4) {2.6, 6.4, 7.4, 7.6, Cross-Chapter Box 9 in Chapter 6}

B.7.1 Modelled pathways limiting global warming to 1.5°C[35] include more land-based mitigation than higher warming level pathways (*high confidence*), but the impacts of climate change on land systems in these pathways are less severe (*medium confidence*). (Figure SPM.2, Figure SPM.4) {2.6, 6.4, 7.4, Cross-Chapter Box 9 in Chapter 6}

B.7.2 Modelled pathways limiting global warming to 1.5°C and 2°C project a 2 million km^2 reduction to a 12 million km^2 increase in forest area in 2050 relative to 2010 (*medium confidence*). 3°C pathways project lower forest areas, ranging from a 4 million km^2 reduction to a 6 million km^2 increase (*medium confidence*). (Figure SPM.3, Figure SPM.4) {2.5, 6.3, 7.3, 7.5, Cross-Chapter Box 9 in Chapter 6}

B.7.3 The land area needed for bioenergy in modelled pathways varies significantly depending on the socio-economic pathway, the warming level, and the feedstock and production system used (*high confidence*). Modelled pathways limiting global warming to 1.5°C use up to 7 million km^2 for bioenergy in 2050; bioenergy land area is smaller in 2°C (0.4 to 5 million km^2) and 3°C pathways (0.1 to 3 million km^2) (*medium confidence*). Pathways with large levels of land conversion may imply adverse side-effects impacting water scarcity, biodiversity, land degradation, desertification, and food security, if not adequately and carefully managed, whereas best practice implementation at appropriate scales can have co-benefits, such as management of dryland salinity, enhanced biocontrol and biodiversity and enhancing soil carbon sequestration (*high confidence*). (Figure SPM.3) {2.6, 6.1, 6.4, 7.2, Cross-Chapter Box 7 in Chapter 6}

35 In this report references to pathways limiting global warming to a particular level are based on a 66% probability of staying below that temperature level in 2100 using the MAGICC model.

B.7.4 Most mitigation pathways include substantial deployment of bioenergy technologies. A small number of modelled pathways limit warming to 1.5°C with reduced dependence on bioenergy and BECCS (land area below <1 million km^2 in 2050) and other carbon dioxide removal (CDR) options (*high confidence*). These pathways have even more reliance on rapid and far-reaching transitions in energy, land, urban systems and infrastructure, and on behavioural and lifestyle changes compared to other 1.5°C pathways. {2.6.2, 5.5.1, 6.4, Cross-Chapter Box 7 in Chapter 6}

B.7.5 These modelled pathways do not consider the effects of climate change on land or CO_2 fertilisation. In addition, these pathways include only a subset of the response options assessed in this report (*high confidence*); the inclusion of additional response options in models could reduce the projected need for bioenergy or CDR that increases the demand for land. {6.4.4, Cross-Chapter Box 9 in Chapter 6}

Potential global contribution of response options to mitigation, adaptation, combating desertification and land degradation, and enhancing food security

Panel A shows response options that can be implemented without or with limited competition for land, including some that have the potential to reduce the demand for land. Co-benefits and adverse side effects are shown quantitatively based on the high end of the range of potentials assessed. Magnitudes of contributions are categorised using thresholds for positive or negative impacts. Letters within the cells indicate confidence in the magnitude of the impact relative to the thresholds used (see legend). Confidence in the direction of change is generally higher.

	Response options based on land management	Mitigation	Adaptation	Desertification	Land Degradation	Food Security	Cost
Agriculture	Increased food productivity	L	M	L	M	H	——
	Agro-forestry	M	M	M	M	L	●
	Improved cropland management	M	L	L	L	L	●●
	Improved livestock management	M	L	L	L	L	●●●
	Agricultural diversification	L	L	L	M	L	●
	Improved grazing land management	M	L	L	L	L	——
	Integrated water management	L	L	L	L	L	●●
	Reduced grassland conversion to cropland	L	——	L	L	- L	●
Forests	Forest management	M	L	L	L	L	●●
	Reduced deforestation and forest degradation	H	L	L	L	L	●●
Soils	Increased soil organic carbon content	H	L	M	M	L	●●
	Reduced soil erosion	←→ L	L	M	M	L	●●
	Reduced soil salinization	——	L	L	L	L	●●
	Reduced soil compaction	——	L	——	L	L	●
Other ecosystems	Fire management	M	M	M	M	L	●
	Reduced landslides and natural hazards	L	L	L	L	L	——
	Reduced pollution including acidification	←→ M	M	L	L	L	——
	Restoration & reduced conversion of coastal wetlands	M	L	M	M	←→ L	——
	Restoration & reduced conversion of peatlands	M	——	na	M	- L	●
	Response options based on value chain management						
Demand	Reduced post-harvest losses	H	M	L	L	H	——
	Dietary change	H	——	L	H	H	——
	Reduced food waste (consumer or retailer)	H	——	L	M	M	——
Supply	Sustainable sourcing	——	L	——	L	L	——
	Improved food processing and retailing	L	L	——	——	L	——
	Improved energy use in food systems	L	L	——	——	L	——
	Response options based on risk management						
Risk	Livelihood diversification	——	L	——	L	L	——
	Management of urban sprawl	——	L	L	M	L	——
	Risk sharing instruments	←→ L	L	——	←→ L	L	●●

Options shown are those for which data are available to assess global potential for three or more land challenges.
The magnitudes are assessed independently for each option and are not additive.

Key for criteria used to define magnitude of impact of each integrated response option

		Mitigation *Gt CO_2-eq yr^{-1}*	Adaptation *Million people*	Desertification *Million km²*	Land Degradation *Million km²*	Food Security *Million people*
Positive	Large	More than 3	Positive for more than 25	Positive for more than 3	Positive for more than 3	Positive for more than 100
	Moderate	0.3 to 3	1 to 25	0.5 to 3	0.5 to 3	1 to 100
	Small	Less than 0.3	Less than 1	Less than 0.5	Less than 0.5	Less than 1
	Negligible	No effect	No effect	No effect	No effect	No effect
Negative	- Small	Less than -0.3	Less than 1	Less than 0.5	Less than 0.5	Less than 1
	- Moderate	-0.3 to -3	1 to 25	0.5 to 3	0.5 to 3	1 to 100
	- Large	More than -3	Negative for more than 25	Negative for more than 3	Negative for more than 3	Negative for more than 100

←→ **Variable**: Can be positive or negative
—— no data
na not applicable

Confidence level

Indicates confidence in the estimate of magnitude category.

H *High confidence*
M *Medium confidence*
L *Low confidence*

Cost range

See technical caption for cost ranges in US$ tCO_2e^{-1} or US$ ha^{-1}.

●●● High cost
●● Medium cost
● Low cost
—— no data

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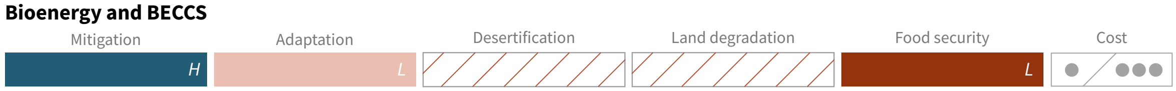
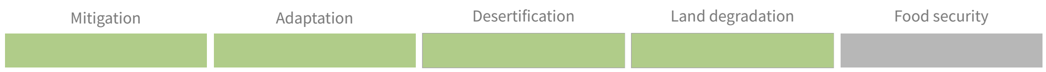
Potential global contribution of response options to mitigation, adaptation, combating desertification and land degradation, and enhancing food security

Panel B shows response options that rely on additional land-use change and could have implications across three or more land challenges under different implementation contexts. For each option, the first row (high level implementation) shows a quantitative assessment (as in Panel A) of implications for global implementation at scales delivering CO_2 removals of more than 3 $GtCO_2$ yr^{-1} using the magnitude thresholds shown in Panel A. The red hatched cells indicate an increasing pressure but unquantified impact. For each option, the second row (best practice implementation) shows qualitative estimates of impact if implemented using best practices in appropriately managed landscape systems that allow for efficient and sustainable resource use and supported by appropriate governance mechanisms. In these qualitative assessments, green indicates a positive impact, grey indicates a neutral interaction.

Bioenergy and BECCS



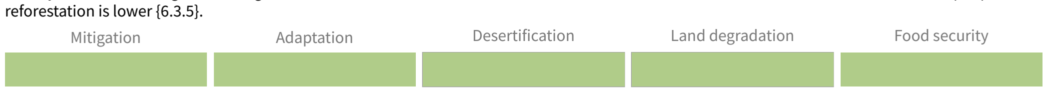
High level: Impacts on adaptation, desertification, land degradation and food security are maximum potential impacts, assuming carbon dioxide removal by BECCS at a scale of 11.3 $GtCO_2$ yr^{-1} in 2050, and noting that bioenergy without CCS can also achieve emissions reductions of up to several $GtCO_2$ yr^{-1} when it is a low carbon energy source {2.6.1; 6.3.1}. Studies linking bioenergy to food security estimate an increase in the population at risk of hunger to up to 150 million people at this level of implementation {6.3.5}. The red hatched cells for desertification and land degradation indicate that while up to 15 million km^2 of additional land is required in 2100 in 2°C scenarios which will increase pressure for desertification and land degradation, the actual area affected by this additional pressure is not easily quantified {6.3.3; 6.3.4}.



Best practice: The sign and magnitude of the effects of bioenergy and BECCS depends on the scale of deployment, the type of bioenergy feedstock, which other response options are included, and where bioenergy is grown (including prior land use and indirect land use change emissions). For example, limiting bioenergy production to marginal lands or abandoned cropland would have negligible effects on biodiversity, food security, and potentially co-benefits for land degradation; however, the benefits for mitigation could also be smaller. {Table 6.58}

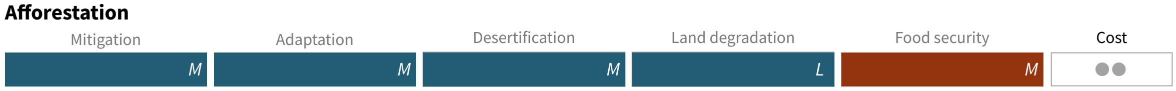
Reforestation and forest restoration

High level: Impacts on adaptation, desertification, land degradation and food security are maximum potential impacts assuming implementation of reforestation and forest restoration (partly overlapping with afforestation) at a scale of 10.1 $GtCO_2$ yr^{-1} removal {6.3.1}. Large-scale afforestation could cause increases in food prices of 80% by 2050, and more general mitigation measures in the AFOLU sector can translate into a rise in undernourishment of 80–300 million people; the impact of reforestation is lower {6.3.5}.

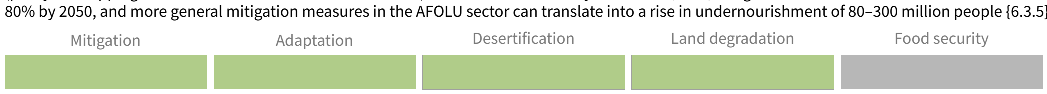


Best practice: There are co-benefits of reforestation and forest restoration in previously forested areas, assuming small scale deployment using native species and involving local stakeholders to provide a safety net for food security. Examples of sustainable implementation include, but are not limited to, reducing illegal logging and halting illegal forest loss in protected areas, reforesting and restoring forests in degraded and desertified lands {Box6.1C; Table 6.6}.

Afforestation

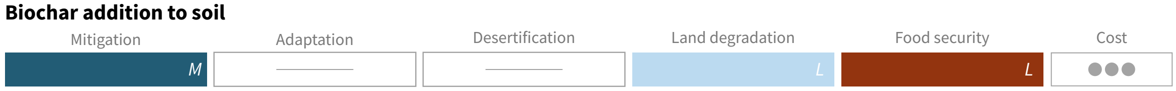


High level: Impacts on adaptation, desertification, land degradation and food security are maximum potential impacts assuming implementation of afforestation (partly overlapping with reforestation and forest restoration) at a scale of 8.9 $GtCO_2$ yr^{-1} removal {6.3.1}. Large-scale afforestation could cause increases in food prices of 80% by 2050, and more general mitigation measures in the AFOLU sector can translate into a rise in undernourishment of 80–300 million people {6.3.5}.

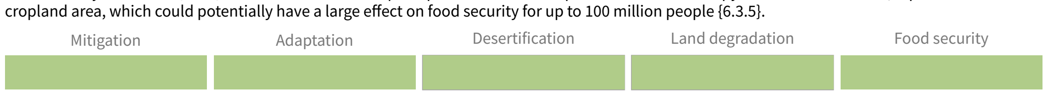


Best practice: Afforestation is used to prevent desertification and to tackle land degradation. Forested land also offers benefits in terms of food supply, especially when forest is established on degraded land, mangroves, and other land that cannot be used for agriculture. For example, food from forests represents a safety-net during times of food and income insecurity {6.3.5}.

Biochar addition to soil



High level: Impacts on adaptation, desertification, land degradation and food security are maximum potential impacts assuming implementation of biochar at a scale of 6.6 $GtCO_2$ yr^{-1} removal {6.3.1}. Dedicated biomass crops required for feedstock production could occupy 0.4–2.6 Mkm^2 of land, equivalent to around 20% of the global cropland area, which could potentially have a large effect on food security for up to 100 million people {6.3.5}.



Best practice: When applied to land, biochar could provide moderate benefits for food security by improving yields by 25% in the tropics, but with more limited impacts in temperate regions, or through improved water holding capacity and nutrient use efficiency. Abandoned cropland could be used to supply biomass for biochar, thus avoiding competition with food production; 5-9 Mkm^2 of land is estimated to be available for biomass production without compromising food security and biodiversity, considering marginal and degraded land and land released by pasture intensification {6.3.5}.

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SPM

Figure SPM.3: Potential global contribution of response options to mitigation, adaptation, combating desertification and land degradation, and enhancing food security. | This Figure is based on an aggregation of information from studies with a wide variety of assumptions about how response options are implemented and the contexts in which they occur. Response options implemented differently at local to global scales could lead to different outcomes. **Magnitude of potential:** For panel A, magnitudes are for the technical potential of response options globally. For each land challenge, magnitudes are set relative to a marker level as follows. For mitigation, potentials are set relative to the approximate potentials for the response options with the largest individual impacts (~3 $GtCO_2$-eq yr^{-1}). The threshold for the 'large' magnitude category is set at this level. For adaptation, magnitudes are set relative to the 100 million lives estimated to be affected by climate change and a carbon-based economy between 2010 and 2030. The threshold for the 'large' magnitude category represents 25% of this total. For desertification and land degradation, magnitudes are set relative to the lower end of current estimates of degraded land, 10–60 million km^2. The threshold for the 'large' magnitude category represents 30% of the lower estimate. For food security, magnitudes are set relative to the approximately 800 million people who are currently undernourished. The threshold for the 'large' magnitude category represents 12.5% of this total. For panel B, for the first row (high level implementation) for each response option, the magnitude and thresholds are as defined for panel A. In the second row (best practice implementation) for each response option, the qualitative assessments that are green denote potential positive impacts, and those shown in grey indicate neutral interactions. Increased food production is assumed to be achieved through sustainable intensification rather than through injudicious application of additional external inputs such as agrochemicals. **Levels of confidence:** Confidence in the magnitude category (high, medium or low) into which each option falls for mitigation, adaptation, combating desertification and land degradation, and enhancing food security. *High confidence* means that there is a high level of agreement and evidence in the literature to support the categorisation as high, medium or low magnitude. *Low confidence* denotes that the categorisation of magnitude is based on few studies. *Medium confidence* reflects medium evidence and agreement in the magnitude of response. **Cost ranges:** Cost estimates are based on aggregation of often regional studies and vary in the components of costs that are included. In panel B, cost estimates are not provided for best practice implementation. One coin indicates low cost (<USD10 tCO_2-eq^{-1} or <USD20 ha^{-1}), two coins indicate medium cost (USD10-USD100 tCO_2-eq^{-1} or USD20 –USD200 ha^{-1}), and three coins indicate high cost (>USD100 tCO_2-eq^{-1} or USD200 ha^{-1}). Thresholds in USD ha^{-1} are chosen to be comparable, but precise conversions will depend on the response option. **Supporting evidence:** Supporting evidence for the magnitude of the quantitative potential for land management-based response options can be found as follows: for mitigation Table's 6.13 to 6.20, with further evidence in Section 2.7.1; for adaptation Table's 6.21 to 6.28; for combating desertification Table's 6.29 to 6.36, with further evidence in Chapter 3; for combating degradation tables 6.37 to 6.44, with further evidence in Chapter 4; for enhancing food security Table's 6.45 to 6.52, with further evidence in Chapter 5. Other synergies and trade-offs not shown here are discussed in Chapter 6. Additional supporting evidence for the qualitative assessments in the second row for each option in panel B can be found in the Table's 6.6, 6.55, 6.56 and 6.58, Section 6.3.5.1.3, and Box 6.1c.

C. Enabling response options

C.1 Appropriate design of policies, institutions and governance systems at all scales can contribute to land-related adaptation and mitigation while facilitating the pursuit of climate-adaptive development pathways (*high confidence*). Mutually supportive climate and land policies have the potential to save resources, amplify social resilience, support ecological restoration, and foster engagement and collaboration between multiple stakeholders (*high confidence*). (Figure SPM.1, Figure SPM.2, Figure SPM.3) {3.6.2, 3.6.3, 4.8, 4.9.4, 5.7, 6.3, 6.4, 7.2.2, 7.3, 7.4, 7.4.7, 7.4.8, 7.5, 7.5.5, 7.5.6, 7.6.6, Cross-Chapter Box 10 in Chapter 7}

C.1.1 Land-use zoning, spatial planning, integrated landscape planning, regulations, incentives (such as payment for ecosystem services), and voluntary or persuasive instruments (such as environmental farm planning, standards and certification for sustainable production, use of scientific, local and indigenous knowledge and collective action), can achieve positive adaptation and mitigation outcomes (*medium confidence*). They can also contribute revenue and provide incentive to rehabilitate degraded lands and adapt to and mitigate climate change in certain contexts (*medium confidence*). Policies promoting the target of land degradation neutrality can also support food security, human wellbeing and climate change adaptation and mitigation (*high confidence*). (Figure SPM.2) {3.4.2, 4.1.6, 4.7, 4.8.5, 5.1.2, 5.7.3, 7.3, 7.4.6, 7.4.7, 7.5}

C.1.2 Insecure land tenure affects the ability of people, communities and organisations to make changes to land that can advance adaptation and mitigation (*medium confidence*). Limited recognition of customary access to land and ownership of land can result in increased vulnerability and decreased adaptive capacity (*medium confidence*). Land policies (including recognition of customary tenure, community mapping, redistribution, decentralisation, co-management, regulation of rental markets) can provide both security and flexibility response to climate change (*medium confidence*). {3.6.1, 3.6.2, 5.3, 7.2.4, 7.6.4, Cross-Chapter Box 6 in Chapter 5}

C.1.3 Achieving land degradation neutrality will involve a balance of measures that avoid and reduce land degradation, through adoption of sustainable land management, and measures to reverse degradation through rehabilitation and restoration of degraded land. Many interventions to achieve land degradation neutrality commonly also deliver climate change adaptation and mitigation benefits. The pursuit of land degradation neutrality provides impetus to address land degradation and climate change simultaneously (*high confidence*). {4.5.3, 4.8.5, 4.8.7, 7.4.5}

C.1.4 Due to the complexity of challenges and the diversity of actors involved in addressing land challenges, a mix of policies, rather than single policy approaches, can deliver improved results in addressing the complex challenges of sustainable land management and climate change (*high confidence*). Policy mixes can strongly reduce the vulnerability and exposure of human and natural systems to climate change (*high confidence*). Elements of such policy mixes may include weather and health insurance, social protection and adaptive safety nets, contingent finance and reserve funds, universal access to early warning systems combined with effective contingency plans (*high confidence*). (Figure SPM.4} {1.2, 4.8, 4.9.2, 5.3.2, 5.6, 5.6.6, 5.7.2, 7.3.2, 7.4, 7.4.2, 7.4.6, 7.4.7, 7.4.8, 7.5.5, 7.5.6, 7.6.4}

C.2 Policies that operate across the food system, including those that reduce food loss and waste and influence dietary choices, enable more sustainable land-use management, enhanced food security and low emissions trajectories (*high confidence*). Such policies can contribute to climate change adaptation and mitigation, reduce land degradation, desertification and poverty as well as improve public health (*high confidence*). The adoption of sustainable land management and poverty eradication can be enabled by improving access to markets, securing land tenure, factoring environmental costs into food, making payments for ecosystem services, and enhancing local and community collective action (*high confidence*). {1.1.2, 1.2.1, 3.6.3, 4.7.1, 4.7.2, 4.8, 5.5, 6.4, 7.4.6, 7.6.5}

C.2.1 Policies that enable and incentivise sustainable land management for climate change adaptation and mitigation include improved access to markets for inputs, outputs and financial services, empowering women and indigenous peoples, enhancing local and community collective action, reforming subsidies and promoting an enabling trade system (*high confidence*). Land restoration and rehabilitation efforts can be more effective when policies support local management of natural resources, while strengthening cooperation between actors and institutions, including at the international level. {3.6.3, 4.1.6, 4.5.4, 4.8.2, 4.8.4, 5.7, 7.2, 7.3}

C.2.2 Reflecting the environmental costs of land-degrading agricultural practices can incentivise more sustainable land management (*high confidence*). Barriers to the reflection of environmental costs arise from technical difficulties in estimating these costs and those embodied in foods. {3.6.3, 5.5.1, 5.5.2, 5.6.6, 5.7, 7.4.4, Cross-Chapter Box 10 in Chapter 7}

C.2.3 Adaptation and enhanced resilience to extreme events impacting food systems can be facilitated by comprehensive risk management, including risk sharing and transfer mechanisms (*high confidence*). Agricultural diversification, expansion of market access, and preparation for increasing supply chain disruption can support the scaling up of adaptation in food systems (*high confidence*). {5.3.2, 5.3.3, 5.3.5}

C.2.4 Public health policies to improve nutrition, such as increasing the diversity of food sources in public procurement, health insurance, financial incentives, and awareness-raising campaigns, can potentially influence food demand, reduce healthcare costs, contribute to lower GHG emissions and enhance adaptive capacity (*high confidence*). Influencing demand for food, through promoting diets based on public health guidelines, can enable more sustainable land management and contribute to achieving multiple SDGs (*high confidence*). {3.4.2, 4.7.2, 5.1, 5.7, 6.3, 6.4}

C.3 Acknowledging co-benefits and trade-offs when designing land and food policies can overcome barriers to implementation (*medium confidence*). Strengthened multi-level, hybrid and cross-sectoral governance, as well as policies developed and adopted in an iterative, coherent, adaptive and flexible manner can maximise co-benefits and minimise trade-offs, given that land management decisions are made from farm level to national scales, and both climate and land policies often range across multiple sectors, departments and agencies (*high confidence*). (Figure SPM.3) {4.8.5, 4.9, 5.6, 6.4, 7.3, 7.4.6, 7.4.8, 7.4.9, 7.5.6, 7.6.2}

C.3.1 Addressing desertification, land degradation, and food security in an integrated, coordinated and coherent manner can assist climate resilient development and provides numerous potential co-benefits (*high confidence*). {3.7.5, 4.8, 5.6, 5.7, 6.4, 7.2.2, 7.3.1, 7.3.4, 7.4.7, 7.4.8, 7.5.6, 7.5.5}

C.3.2 Technological, biophysical, socio-economic, financial and cultural barriers can limit the adoption of many land-based response options, as can uncertainty about benefits (*high confidence*). Many sustainable land management practices are not widely adopted due to insecure land tenure, lack of access to resources and agricultural advisory services, insufficient and unequal private and public incentives, and lack of knowledge and practical experience (*high confidence*). Public discourse, carefully designed policy interventions, incorporating social learning and market changes can together help reduce barriers to implementation (*medium confidence*). {3.6.1, 3.6.2, 5.3.5, 5.5.2, 5.6, 6.2, 6.4, 7.4, 7.5, 7.6}

C.3.3 The land and food sectors face particular challenges of institutional fragmentation and often suffer from a lack of engagement between stakeholders at different scales and narrowly focused policy objectives (*medium confidence*). Coordination with other sectors, such as public health, transportation, environment, water, energy and infrastructure, can increase co-benefits, such as risk reduction and improved health (*medium confidence*). {5.6.3, 5.7, 6.2, 6.4.4, 7.1, 7.3, 7.4.8, 7.6.2, 7.6.3}

C.3.4 Some response options and policies may result in trade-offs, including social impacts, ecosystem functions and services damage, water depletion, or high costs, that cannot be well-managed, even with institutional best practices (*medium confidence*). Addressing such trade-offs helps avoid maladaptation (*medium confidence*). Anticipation and evaluation of potential trade-offs and knowledge gaps supports evidence-based policymaking to weigh the costs and benefits of specific responses for different stakeholders (*medium confidence*). Successful management of trade-offs often includes maximising stakeholder input with structured feedback processes, particularly in community-based models, use of innovative fora like facilitated dialogues or spatially explicit mapping, and iterative adaptive management that allows for continuous readjustments in policy as new evidence comes to light (*medium confidence*). {5.3.5, 6.4.2, 6.4.4, 6.4.5, 7.5.6, Cross-Chapter Box 9 in Chapter 7}

C.4 The effectiveness of decision-making and governance is enhanced by the involvement of local stakeholders (particularly those most vulnerable to climate change including indigenous peoples and local communities, women, and the poor and marginalised) in the selection, evaluation, implementation and monitoring of policy instruments for land-based climate change adaptation and mitigation (*high confidence*). Integration across sectors and scales increases the chance of maximising co-benefits and minimising trade-offs (*medium confidence*). {1.4, 3.1, 3.6, 3.7, 4.8, 4.9, 5.1.3, Box 5.1, 7.4, 7.6}

C.4.1 Successful implementation of sustainable land management practices requires accounting for local environmental and socio-economic conditions (*very high confidence*). Sustainable land management in the context of climate change is typically advanced by involving all relevant stakeholders in identifying land-use pressures and impacts (such as biodiversity decline, soil loss, over-extraction of groundwater, habitat loss, land-use change in agriculture, food production and forestry) as well as preventing, reducing and restoring degraded land (*medium confidence*). {1.4.1, 4.1.6, 4.8.7, 5.2.5, 7.2.4, 7.6.2, 7.6.4}

C.4.2 Inclusiveness in the measurement, reporting and verification of the performance of policy instruments can support sustainable land management (*medium confidence*). Involving stakeholders in the selection of indicators, collection of climate data, land modelling and land-use planning, mediates and facilitates integrated landscape planning and choice of policy (*medium confidence*). {3.7.5, 5.7.4, 7.4.1, 7.4.4, 7.5.3, 7.5.4, 7.5.5, 7.6.4, 7.6.6}

C.4.3 Agricultural practices that include indigenous and local knowledge can contribute to overcoming the combined challenges of climate change, food security, biodiversity conservation, and combating desertification and land degradation (*high confidence*). Coordinated action across a range of actors including businesses, producers, consumers, land managers and policymakers in partnership with indigenous peoples and local communities enable conditions for the adoption of response options (*high confidence*) {3.1.3, 3.6.1, 3.6.2, 4.8.2, 5.5.1, 5.6.4, 5.7.1, 5.7.4, 6.2, 7.3, 7.4.6, 7.6.4}

C.4.4 Empowering women can bring synergies and co-benefits to household food security and sustainable land management (*high confidence*). Due to women's disproportionate vulnerability to climate change impacts, their inclusion in land management and tenure is constrained. Policies that can address land rights and barriers to women's participation in sustainable land management include financial transfers to women under the auspices of anti-poverty programmes, spending on health, education, training and capacity building for women, subsidised credit and program dissemination through existing women's community-based organisations (*medium confidence*). {1.4.1, 4.8.2, 5.1.3, Cross-Chapter Box 11 in Chapter 7}

SPM

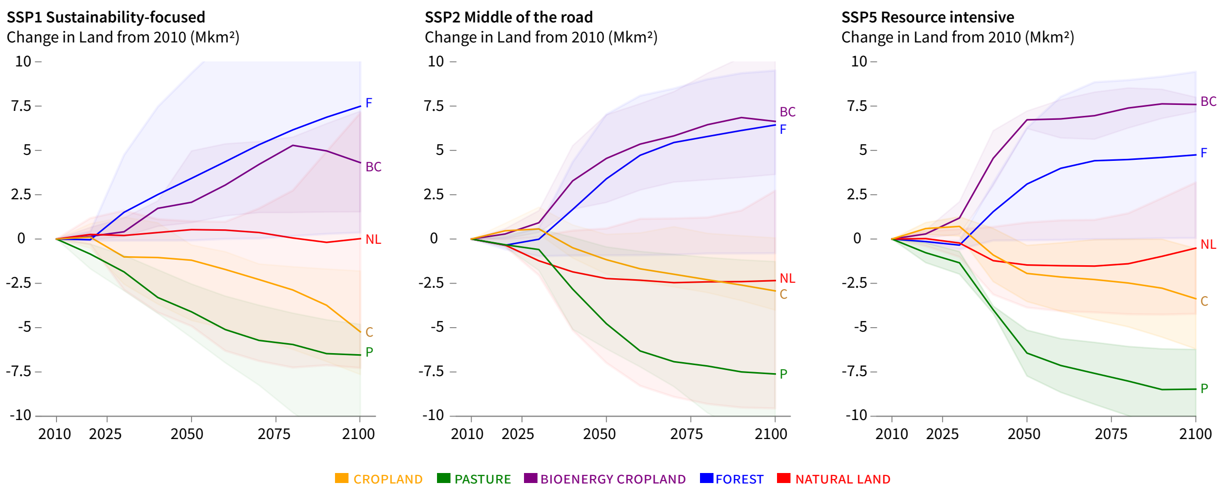
A. Pathways linking socioeconomic development, mitigation responses and land

Socioeconomic development and land management influence the evolution of the land system including the relative amount of land allocated to **CROPLAND**, **PASTURE**, **BIOENERGY CROPLAND**, **FOREST**, and **NATURAL LAND**. The lines show the median across Integrated Assessment Models (IAMs) for three alternative shared socioeconomic pathways (**SSP1**, **SSP2** and **SSP5** at **RCP1.9**); shaded areas show the range across models. Note that pathways illustrate the effects of climate change mitigation but not those of climate change impacts or adaptation.

A. Sustainability-focused (SSP1)
Sustainability in land management, agricultural intensification, production and consumption patterns result in reduced need for agricultural land, despite increases in per capita food consumption. This land can instead be used for reforestation, afforestation, and bioenergy.

B. Middle of the road (SSP2)
Societal as well as technological development follows historical patterns. Increased demand for land mitigation options such as bioenergy, reduced deforestation or afforestation decreases availability of agricultural land for food, feed and fibre.

C. Resource intensive (SSP5)
Resource-intensive production and consumption patterns, results in high baseline emissions. Mitigation focuses on technological solutions including substantial bioenergy and BECCS . Intensification and competing land uses contribute to declines in agricultural land.



B. Land use and land cover change in the SSPs

	Quantitative indicators for the SSPs	Count of models included*	Change in Natural Land from 2010 Mkm²	Change in Bioenergy Cropland from 2010 Mkm²	Change in Cropland from 2010 Mkm²	Change in Forest from 2010 Mkm²	Change in Pasture from 2010 Mkm²
SSP1	**RCP1.9** in 2050	5/5	0.5 (-4.9, 1)	2.1 (0.9, 5)	-1.2 (-4.6, -0.3)	3.4 (-0.1, 9.4)	-4.1 (-5.6, -2.5)
	↳ 2100		0 (-7.3, 7.1)	4.3 (1.5, 7.2)	-5.2 (-7.6, -1.8)	7.5 (0.4, 15.8)	-6.5 (-12.2, -4.8)
	RCP2.6 in 2050	5/5	-0.9 (-2.2, 1.5)	1.3 (0.4, 1.9)	-1 (-4.7, 1)	2.6 (-0.1, 8.4)	-3 (-4, -2.4)
	↳ 2100		0.2 (-3.5, 1.1)	5.1 (1.6, 6.3)	-3.2 (-7.7, -1.8)	6.6 (-0.1, 10.5)	-5.5 (-9.9, -4.2)
	RCP4.5 in 2050	5/5	0.5 (-1, 1.7)	0.8 (0.5, 1.3)	0.1 (-3.2, 1.5)	0.6 (-0.7, 4.2)	-2.4 (-3.3, -0.9)
	↳ 2100		1.8 (-1.7, 6)	1.9 (1.4, 3.7)	-2.3 (-6.4, -1.6)	3.9 (0.2, 8.8)	-4.6 (-7.3, -2.7)
	Baseline in 2050	5/5	0.3 (-1.1, 1.8)	0.5 (0.2, 1.4)	0.2 (-1.6, 1.9)	-0.1 (-0.8, 1.1)	-1.5 (-2.9, -0.2)
	↳ 2100		3.3 (-0.3, 5.9)	1.8 (1.4, 2.4)	-1.5 (-5.7, -0.9)	0.9 (0.3, 3)	-2.1 (-7, 0)
SSP2	**RCP1.9** in 2050	4/5	-2.2 (-7, 0.6)	4.5 (2.1, 7)	-1.2 (-2, 0.3)	3.4 (-0.9, 7)	-4.8 (-6.2, -0.4)
	↳ 2100		-2.3 (-9.6, 2.7)	6.6 (3.6, 11)	-2.9 (-4, 0.1)	6.4 (-0.8, 9.5)	-7.6 (-11.7, -1.3)
	RCP2.6 in 2050	5/5	-3.2 (-4.2, 0.1)	2.2 (1.7, 4.7)	0.6 (-1.9, 1.9)	1.6 (-0.9, 4.2)	-1.4 (-3.7, 0.4)
	↳ 2100		-5.2 (-7.2, 0.5)	6.9 (2.3, 10.8)	-1.4 (-4, 0.8)	5.6 (-0.9, 5.9)	-7.2 (-8, 0.5)
	RCP4.5 in 2050	5/5	-2.2 (-2.2, 0.7)	1.5 (0.1, 2.1)	1.2 (-0.9, 2.7)	-0.9 (-2.5, 2.9)	-0.1 (-2.5, 1.6)
	↳ 2100		-3.4 (-4.7, 1.5)	4.1 (0.4, 6.3)	0.7 (-2.6, 3.1)	-0.5 (-3.1, 5.9)	-2.8 (-5.3, 1.9)
	Baseline in 2050	5/5	-1.5 (-2.6, -0.2)	0.7 (0, 1.5)	1.3 (1, 2.7)	-1.3 (-2.5, -0.4)	-0.1 (-1.2, 1.6)
	↳ 2100		-2.1 (-5.9, 0.3)	1.2 (0.1, 2.4)	1.9 (0.8, 2.8)	-1.3 (-2.7, -0.2)	-0.2 (-1.9, 2.1)
SSP3	**RCP1.9** in 2050	Infeasible in all assessed models		-	-	-	-
	↳ 2100			-	-	-	-
	RCP2.6 in 2050	Infeasible in all assessed models		-	-	-	-
	↳ 2100			-	-	-	-
	RCP4.5 in 2050	3/3	-3.4 (-4.4, -2)	1.3 (1.3, 2)	2.3 (1.2, 3)	-2.4 (-4, -1)	2.1 (-0.1, 3.8)
	↳ 2100		-6.2 (-6.8, -5.4)	4.6 (1.5, 7.1)	3.4 (1.9, 4.5)	-3.1 (-5.5, -0.3)	2 (-2.5, 4.4)
	Baseline in 2050	4/4	-3 (-4.6, -1.7)	1 (0.2, 1.5)	2.5 (1.5, 3)	-2.5 (-4, -1.5)	2.4 (0.6, 3.8)
	↳ 2100		-5 (-7.1, -4.2)	1.1 (0.9, 2.5)	5.1 (3.8, 6.1)	-5.3 (-6, -2.6)	3.4 (0.9, 6.4)
SSP4	**RCP1.9** in 2050	Infeasible in all assessed models**		-	-	-	-
	↳ 2100			-	-	-	-
	RCP2.6 in 2050	3/3	-4.5 (-6, -2.1)	3.3 (1.5, 4.5)	0.5 (-0.1, 0.9)	0.7 (-0.3, 2.2)	-0.6 (-0.7, 0.1)
	↳ 2100		-5.8 (-10.2, -4.7)	2.5 (2.3, 15.2)	-0.8 (-0.8, 1.8)	1.4 (-1.7, 4.1)	-1.2 (-2.5, -0.2)
	RCP4.5 in 2050	3/3	-2.7 (-4.4, -0.4)	1.7 (1, 1.9)	1.1 (-0.1, 1.7)	-1.8 (-2.3, 2.1)	0.8 (-0.5, 1.5)
	↳ 2100		-2.8 (-7.8, -2)	2.7 (2.3, 4.7)	1.1 (0.2, 1.2)	-0.7 (-2.6, 1)	1.4 (-1, 1.8)
	Baseline in 2050	3/3	-2.8 (-2.9, -0.2)	1.1 (0.7, 2)	1.1 (0.7, 1.8)	-1.8 (-2.3, -1)	1.5 (-0.5, 2.1)
	↳ 2100		-2.4 (-5, -1)	1.7 (1.4, 2.6)	1.2 (1.2, 1.9)	-2.4 (-2.5, -2)	1.3 (-1, 4.4)
SSP5	**RCP1.9** in 2050	2/4	-1.5 (-3.9, 0.9)	6.7 (6.2, 7.2)	-1.9 (-3.5, -0.4)	3.1 (-0.1, 6.3)	-6.4 (-7.7, -5.1)
	↳ 2100		-0.5 (-4.2, 3.2)	7.6 (7.2, 8)	-3.4 (-6.2, -0.5)	4.7 (0.1, 9.4)	-8.5 (-10.7, -6.2)
	RCP2.6 in 2050	4/4	-3.4 (-6.9, 0.3)	4.8 (3.8, 5.1)	-2.1 (-4, 1)	3.9 (-0.1, 6.7)	-4.4 (-5, 0.2)
	↳ 2100		-4.3 (-8.4, 0.5)	9.1 (7.7, 9.2)	-3.3 (-6.5, -0.5)	3.9 (-0.1, 9.3)	-6.3 (-9.1, -1.4)
	RCP4.5 in 2050	4/4	-2.5 (-3.7, 0.2)	1.7 (0.6, 2.9)	0.6 (-3.3, 1.9)	-0.1 (-1.7, 6)	-1.2 (-2.6, 2.3)
	↳ 2100		-4.1 (-4.6, 0.7)	4.8 (2, 8)	-1 (-5.5, 1)	-0.2 (-1.4, 9.1)	-3 (-5.2, 2.1)
	Baseline in 2050	4/4	-0.6 (-3.8, 0.4)	0.8 (0, 2.1)	1.5 (-0.7, 3.3)	-1.9 (-3.4, 0.5)	-0.1 (-1.5, 2.9)
	↳ 2100		-0.2 (-2.4, 1.8)	1 (0.2, 2.3)	1 (-2, 2.5)	-2.1 (-3.4, 1.1)	-0.4 (-2.4, 2.8)

** Count of models included / Count of models attempted. One model did not provide land data and is excluded from all entries.*

*** One model could reach RCP1.9 with SSP4, but did not provide land data*

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Figure SPM.4: Pathways linking socioeconomic development, mitigation responses and land | Future scenarios provide a framework for understanding the implications of mitigation and socioeconomics on land. The Shared Socioeconomic Pathways (SSPs) span a range of different socioeconomic assumptions (Box SPM.1). They are combined with Representative Concentration Pathways (RCPs)[36] which imply different levels of mitigation. The changes in cropland, pasture, bioenergy cropland, forest, and natural land from 2010 are shown. For this Figure, Cropland includes all land in food, feed, and fodder crops, as well as other arable land (cultivated area). This category includes first generation non-forest bioenergy crops (e.g., corn for ethanol, sugar cane for ethanol, soybeans for biodiesel), but excludes second generation bioenergy crops. Pasture includes categories of pasture land, not only high-quality rangeland, and is based on FAO definition of 'permanent meadows and pastures'. Bioenergy cropland includes land dedicated to second generation energy crops (e.g., switchgrass, miscanthus, fast-growing wood species). Forest includes managed and unmanaged forest. Natural land includes other grassland, savannah, and shrubland. **Panel A:** This panel shows integrated assessment model (IAM)[37] results for SSP1, SSP2 and SSP5 at RCP1.9.[38] For each pathway, the shaded areas show the range across all IAMs; the line indicates the median across models. For RCP1.9, SSP1, SSP2 and SSP5 results are from five, four and two IAMs respectively. **Panel B:** Land use and land cover change are indicated for various SSP-RCP combinations, showing multi-model median and range (min, max). (Box SPM.1) {1.3.2, 2.7.2, 6.1, 6.4.4, 7.4.2, 7.4.4, 7.4.5, 7.4.6, 7.4.7, 7.4.8, 7.5.3, 7.5.6, Cross-Chapter Box 1 in Chapter 1, Cross-Chapter Box 9 in Chapter 6}

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36 Representative Concentration Pathways (RCPs) are scenarios that include timeseries of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover.

37 Integrated Assessment Models (IAMs) integrate knowledge from two or more domains into a single framework. In this figure, IAMs are used to assess linkages between economic, social and technological development and the evolution of the climate system.

38 The RCP1.9 pathways assessed in this report have a 66% chance of limiting warming to 1.5°C in 2100, but some of these pathways overshoot 1.5°C of warming during the 21st century by >0.1°C.

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D. Action in the near-term

D.1 Actions can be taken in the near-term, based on existing knowledge, to address desertification, land degradation and food security while supporting longer-term responses that enable adaptation and mitigation to climate change. These include actions to build individual and institutional capacity, accelerate knowledge transfer, enhance technology transfer and deployment, enable financial mechanisms, implement early warning systems, undertake risk management and address gaps in implementation and upscaling (*high confidence*). {3.6.1, 3.6.2, 3.7.2, 4.8, 5.3.3, 5.5, 5.6.4, 5.7, 6.2, 6.4, 7.3, 7.4, 7.6, Cross-Chapter Box 10 in Chapter 7}

D.1.1 Near-term capacity-building, technology transfer and deployment, and enabling financial mechanisms can strengthen adaptation and mitigation in the land sector. Knowledge and technology transfer can help enhance the sustainable use of natural resources for food security under a changing climate (*medium confidence*). Raising awareness, capacity building and education about sustainable land management practices, agricultural extension and advisory services, and expansion of access to agricultural services to producers and land users can effectively address land degradation (*medium confidence*). {3.1, 5.7.4, 7.2, 7.3.4, 7.5.4}

D.1.2 Measuring and monitoring land use change including land degradation and desertification is supported by the expanded use of new information and communication technologies (cell phone based applications, cloud-based services, ground sensors, drone imagery), use of climate services, and remotely sensed land and climate information on land resources (*medium confidence*). Early warning systems for extreme weather and climate events are critical for protecting lives and property and enhancing disaster risk reduction and management (*high confidence*). Seasonal forecasts and early warning systems are critical for food security (famine) and biodiversity monitoring including pests and diseases and adaptive climate risk management (*high confidence*). There are high returns on investments in human and institutional capacities. These investments include access to observation and early warning systems, and other services derived from in-situ hydro-meteorological and remote sensing-based monitoring systems and data, field observation, inventory and survey, and expanded use of digital technologies (*high confidence*). {1.2, 3.6.2, 4.2.2, 4.2.4, 5.3.1, 5.3.6, 6.4, 7.3.4, 7.4.3, 7.5.4, 7.5.5, 7.6.4, Cross-Chapter Box 5 in Chapter 3}

D.1.3 Framing land management in terms of risk management, specific to land, can play an important role in adaptation through landscape approaches, biological control of outbreaks of pests and diseases, and improving risk sharing and transfer mechanisms (*high confidence*). Providing information on climate-related risk can improve the capacity of land managers and enable timely decision making (*high confidence*). {5.3.2, 5.3.5, 5.6.2, 5.6.3 5.6.5, 5.7.1, 5.7.2, 7.2.4, Cross-Chapter Box 6 in Chapter 5}

D.1.4 Sustainable land management can be improved by increasing the availability and accessibility of data and information relating to the effectiveness, co-benefits and risks of emerging response options and increasing the efficiency of land use (*high confidence*). Some response options (e.g., improved soil carbon management) have been implemented only at small-scale demonstration facilities and knowledge, financial, and institutional gaps and challenges exist with upscaling and the widespread deployment of these options (*medium confidence*). {4.8, 5.5.1, 5.5.2, 5.6.1, 5.6.5, 5.7.5, 6.2, 6.4}

D.2 Near-term action to address climate change adaptation and mitigation, desertification, land degradation and food security can bring social, ecological, economic and development co-benefits (*high confidence*). Co-benefits can contribute to poverty eradication and more resilient livelihoods for those who are vulnerable (*high confidence*). {3.4.2, 5.7, 7.5}

D.2.1 Near-term actions to promote sustainable land management will help reduce land and food-related vulnerabilities, and can create more resilient livelihoods, reduce land degradation and desertification, and loss of biodiversity (*high confidence*). There are synergies between sustainable land management, poverty eradication efforts, access to market, non-market mechanisms and the elimination of low-productivity practices. Maximising these synergies can lead to adaptation, mitigation, and development co-benefits through preserving ecosystem functions and services (*medium confidence*). {3.4.2, 3.6.3, Table 4.2, 4.7, 4.9, 4.10, 5.6, 5.7, 7.3, 7.4, 7.5, 7.6, Cross-Chapter Box 12 in Chapter 7}

D.2.2 Investments in land restoration can result in global benefits and in drylands can have benefit-cost ratios of between three and six in terms of the estimated economic value of restored ecosystem services (*medium confidence*). Many sustainable land management technologies and practices are profitable within three to ten years (*medium confidence*). While they can require upfront investment, actions to ensure sustainable land management can improve crop yields and the economic value of pasture. Land restoration and rehabilitation measures improve livelihood systems and provide both short-term positive economic returns and longer-term benefits in terms of climate change adaptation and mitigation, biodiversity and enhanced ecosystem functions and services (*high confidence*). {3.6.1, 3.6.3, 4.8.1, 7.2.4, 7.2.3, 7.3.1, 7.4.6, Cross-Chapter Box 10 in Chapter 7}

D.2.3 Upfront investments in sustainable land management practices and technologies can range from about USD20 ha^{-1} to USD5000 ha^{-1}, with a median estimated to be around USD500 ha^{-1}. Government support and improved access to credit can help overcome barriers to adoption, especially those faced by poor smallholder farmers (*high confidence*). Near-term change to balanced diets (SPM B6.2.) can reduce the pressure on land and provide significant health co-benefits through improving nutrition (*medium confidence*). {3.6.3, 4.8, 5.3, 5.5, 5.6, 5.7, 6.4, 7.4.7, 7.5.5, Cross-Chapter Box 9 in Chapter 6}

D.3 Rapid reductions in anthropogenic GHG emissions across all sectors following ambitious mitigation pathways reduce negative impacts of climate change on land ecosystems and food systems (*medium confidence*). Delaying climate mitigation and adaptation responses across sectors would lead to increasingly negative impacts on land and reduce the prospect of sustainable development (*medium confidence*). (Box SPM.1, Figure SPM.2) {2.5, 2.7, 5.2, 6.2, 6.4, 7.2, 7.3.1, 7.4.7, 7.4.8, 7.5.6, Cross-Chapter Box 9 in Chapter 6, Cross-Chapter Box 10 in Chapter 7}

D.3.1 Delayed action across sectors leads to an increasing need for widespread deployment of land-based adaptation and mitigation options and can result in a decreasing potential for the array of these options in most regions of the world and limit their current and future effectiveness (*high confidence*). Acting now may avert or reduce risks and losses, and generate benefits to society (*medium confidence*). Prompt action on climate mitigation and adaptation aligned with sustainable land management and sustainable development depending on the region could reduce the risk to millions of people from climate extremes, desertification, land degradation and food and livelihood insecurity (*high confidence*). {1.3.5, 3.4.2, 3.5.2, 4.1.6, 4.7.1, 4.7.2, 5.2.3, 5.3.1, 6.3, 6.5, 7.3.1}

D.3.2 In future scenarios, deferral of GHG emissions reductions implies trade-offs leading to significantly higher costs and risks associated with rising temperatures (*medium confidence*). The potential for some response options, such as increasing soil organic carbon, decreases as climate change intensifies, as soils have reduced capacity to act as sinks for carbon sequestration at higher temperatures (*high confidence*). Delays in avoiding or reducing land degradation and promoting positive ecosystem restoration risk long-term impacts including rapid declines in productivity of agriculture and rangelands, permafrost degradation and difficulties in peatland rewetting (*medium confidence*). {1.3.1, 3.6.2, 4.8, 4.9, 4.9.1, 5.5.2, 6.3, 6.4, 7.2, 7.3; Cross-Chapter Box 10 in Chapter 7}

D.3.3 Deferral of GHG emissions reductions from all sectors implies trade-offs including irreversible loss in land ecosystem functions and services required for food, health, habitable settlements and production, leading to increasingly significant economic impacts on many countries in many regions of the world (*high confidence*). Delaying action as is assumed in high emissions scenarios could result in some irreversible impacts on some ecosystems, which in the longer-term has the potential to lead to substantial additional GHG emissions from ecosystems that would accelerate global warming (*medium confidence*). {1.3.1, 2.5.3, 2.7, 3.6.2, 4.9, 4.10.1, 5.4.2.4, 6.3, 6.4, 7.2, 7.3, Cross-Chapter Box 9 in Chapter 6, Cross-Chapter Box 10 in Chapter 7}

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Drafting Authors:

Richard P. Allan (United Kingdom), Paola A. Arias (Colombia), Sophie Berger (France/Belgium), Josep G. Canadell (Australia), Christophe Cassou (France), Deliang Chen (Sweden), Annalisa Cherchi (Italy), Sarah L. Connors (France/United Kingdom), Erika Coppola (Italy), Faye Abigail Cruz (Philippines), Aïda Diongue-Niang (Senegal), Francisco J. Doblas-Reyes (Spain), Hervé Douville (France), Fatima Driouech (Morocco), Tamsin L. Edwards (United Kingdom), François Engelbrecht (South Africa), Veronika Eyring (Germany), Erich Fischer (Switzerland), Gregory M. Flato (Canada), Piers Forster (United Kingdom), Baylor Fox-Kemper (United States of America), Jan S. Fuglestvedt (Norway), John C. Fyfe (Canada), Nathan P. Gillett (Canada), Melissa I. Gomis (France/Switzerland), Sergey K. Gulev (Russian Federation), José Manuel Gutiérrez (Spain), Rafiq Hamdi (Belgium), Jordan Harold (United Kingdom), Mathias Hauser (Switzerland), Ed Hawkins (United Kingdom), Helene T. Hewitt (United Kingdom), Tom Gabriel Johansen (Norway), Christopher Jones (United Kingdom), Richard G. Jones (United Kingdom), Darrell S. Kaufman (United States of America), Zbigniew Klimont (Austria/Poland), Robert E. Kopp (United States of America), Charles Koven (United States of America), Gerhard Krinner (France/Germany, France), June-Yi Lee (Republic of Korea), Irene Lorenzoni (United Kingdom/Italy), Jochem Marotzke (Germany), Valérie Masson-Delmotte (France), Thomas K. Maycock (United States of America), Malte Meinshausen (Australia/Germany), Pedro M.S. Monteiro (South Africa), Angela Morelli (Norway/Italy), Vaishali Naik (United States of America), Dirk Notz (Germany), Friederike Otto (United Kingdom/Germany), Matthew D. Palmer (United Kingdom), Izidine Pinto (South Africa/Mozambique), Anna Pirani (Italy), Gian-Kasper Plattner (Switzerland), Krishnan Raghavan (India), Roshanka Ranasinghe (The Netherlands/Sri Lanka, Australia), Joeri Rogelj (United Kingdom/Belgium), Maisa Rojas (Chile), Alex C. Ruane (United States of America), Jean-Baptiste Sallée (France), Bjørn H. Samset (Norway), Sonia I. Seneviratne (Switzerland), Jana Sillmann (Norway/Germany), Anna A. Sörensson (Argentina), Tannecia S. Stephenson (Jamaica), Trude Storelvmo (Norway), Sophie Szopa (France), Peter W. Thorne (Ireland/United Kingdom), Blair Trewin (Australia), Robert Vautard (France), Carolina Vera (Argentina), Noureddine Yassaa (Algeria), Sönke Zaehle (Germany), Panmao Zhai (China), Xuebin Zhang (Canada), Kirsten Zickfeld (Canada/Germany)

Contributing Authors:

Krishna M. AchutaRao (India), Bhupesh Adhikary (Nepal), Edvin Aldrian (Indonesia), Kyle Armour (United States of America), Govindasamy Bala (India/United States of America), Rondrotiana Barimalala (South Africa/Madagascar), Nicolas Bellouin (United Kingdom/France), William Collins (United Kingdom), William D. Collins (United States of America), Susanna Corti (Italy), Peter M. Cox (United Kingdom), Frank J. Dentener (EU/The Netherlands), Claudine Dereczynski (Brazil), Alejandro Di Luca (Australia, Canada/Argentina), Alessandro Dosio (Italy), Leah Goldfarb (France/United States of America), Irina V. Gorodetskaya (Portugal/Belgium, Russian Federation), Pandora Hope (Australia), Mark Howden (Australia), A.K.M Saiful Islam (Bangladesh), Yu Kosaka (Japan), James Kossin (United States of America), Svitlana Krakovska (Ukraine), Chao Li (China), Jian Li (China), Thorsten Mauritsen (Germany/Denmark), Sebastian Milinski (Germany), Seung-Ki Min (Republic of Korea), Thanh Ngo Duc (Vietnam), Andy Reisinger (New Zealand), Lucas Ruiz (Argentina), Shubha Sathyendranath (United Kingdom/Canada, Overseas Citizen of India), Aimée B. A. Slangen (The Netherlands), Chris Smith (United Kingdom), Izuru Takayabu (Japan), Muhammad Irfan Tariq (Pakistan), Anne-Marie Treguier (France), Bart van den Hurk (The Netherlands), Karina von Schuckmann (France/Germany), Cunde Xiao (China)

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Introduction

This Summary for Policymakers (SPM) presents key findings of the Working Group I (WGI) contribution to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6)[1] on the physical science basis of climate change. The report builds upon the 2013 Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) and the 2018–2019 IPCC Special Reports[2] of the AR6 cycle and incorporates subsequent new evidence from climate science.[3]

This SPM provides a high-level summary of the understanding of the current state of the climate, including how it is changing and the role of human influence, the state of knowledge about possible climate futures, climate information relevant to regions and sectors, and limiting human-induced climate change.

Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence indicated using the IPCC calibrated language.[4]

The scientific basis for each key finding is found in chapter sections of the main Report and in the integrated synthesis presented in the Technical Summary (hereafter TS), and is indicated in curly brackets. The AR6 WGI Interactive Atlas facilitates exploration of these key synthesis findings, and supporting climate change information, across the WGI reference regions.[5]

A. The Current State of the Climate

Since AR5, improvements in observationally based estimates and information from paleoclimate archives provide a comprehensive view of each component of the climate system and its changes to date. New climate model simulations, new analyses, and methods combining multiple lines of evidence lead to improved understanding of human influence on a wider range of climate variables, including weather and climate extremes. The time periods considered throughout this section depend upon the availability of observational products, paleoclimate archives and peer-reviewed studies.

A.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.
{2.2, 2.3, Cross-Chapter Box 2.3, 3.3, 3.4, 3.5, 3.6, 3.8, 5.2, 5.3, 6.4, 7.3, 8.3, 9.2, 9.3, 9.5, 9.6, Cross-Chapter Box 9.1} (Figure SPM.1, Figure SPM.2)

A.1.1 Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Since 2011 (measurements reported in AR5), concentrations have continued to increase in the atmosphere, reaching annual averages of 410 parts per million (ppm) for carbon dioxide (CO_2), 1866 parts per billion (ppb) for methane (CH_4), and 332 ppb for nitrous oxide (N_2O) in 2019.[6] Land and ocean have taken up a near-constant proportion (globally about 56% per year) of CO_2 emissions from human activities over the past six decades, with regional differences (*high confidence*).[7]
{2.2, 5.2, 7.3, TS.2.2, Box TS.5}

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1 Decision IPCC/XLVI-2.

2 The three Special Reports are: Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

3 The assessment covers scientific literature accepted for publication by 31 January 2021.

4 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or result: virtually certain 99–100% probability; very likely 90–100%; likely 66–100%; about as likely as not 33–66%; unlikely 0–33%; very unlikely 0–10%; and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; more likely than not >50–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5. In this Report, unless stated otherwise, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

5 The Interactive Atlas is available at https://interactive-atlas.ipcc.ch

6 Other GHG concentrations in 2019 were: perfluorocarbons (PFCs) – 109 parts per trillion (ppt) CF_4 equivalent; sulphur hexafluoride (SF_6) – 10 ppt; nitrogen trifluoride (NF_3) – 2 ppt; hydrofluorocarbons (HFCs) – 237 ppt HFC-134a equivalent; other Montreal Protocol gases (mainly chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)) – 1032 ppt CFC-12 equivalent). Increases from 2011 are 19 ppm for CO_2, 63 ppb for CH_4 and 8 ppb for N_2O.

7 Land and ocean are not substantial sinks for other GHGs.

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A.1.2 Each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature[8] in the first two decades of the 21st century (2001–2020) was 0.99 [0.84 to 1.10] °C higher than 1850–1900.[9] Global surface temperature was 1.09 [0.95 to 1.20] °C higher in 2011–2020 than 1850–1900, with larger increases over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 [0.68 to 1.01] °C). The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22] °C). Additionally, methodological advances and new datasets contributed approximately 0.1°C to the updated estimate of warming in AR6.[10]
{2.3, Cross-Chapter Box 2.3} (Figure SPM.1)

A.1.3 The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019[11] is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural 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. It is *very likely* that well-mixed GHGs were the main driver[12] of tropospheric warming since 1979 and *extremely likely* that human-caused stratospheric ozone depletion was the main driver of cooling of the lower stratosphere between 1979 and the mid-1990s.
{3.3, 6.4, 7.3, TS.2.3, Cross-Section Box TS.1} (Figure SPM.2)

A.1.4 Globally averaged precipitation over land has *likely* increased since 1950, with a faster rate of increase since the 1980s (*medium confidence*). It is *likely* that human influence contributed to the pattern of observed precipitation changes since the mid-20th century and *extremely likely* that human influence contributed to the pattern of observed changes in near-surface ocean salinity. Mid-latitude storm tracks have *likely* shifted poleward in both hemispheres since the 1980s, with marked seasonality in trends (*medium confidence*). For the Southern Hemisphere, human influence *very likely* contributed to the poleward shift of the closely related extratropical jet in austral summer.
{2.3, 3.3, 8.3, 9.2, TS.2.3, TS.2.4, Box TS.6}

A.1.5 Human influence is *very likely* the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019 (decreases of about 40% in September and about 10% in March). There has been no significant trend in Antarctic sea ice area from 1979 to 2020 due to regionally opposing trends and large internal variability. Human influence *very likely* contributed to the decrease in Northern Hemisphere spring snow cover since 1950. It is *very likely* that human influence has contributed to the observed surface melting of the Greenland Ice Sheet over the past two decades, but there is only *limited evidence*, with *medium agreement*, of human influence on the Antarctic Ice Sheet mass loss.
{2.3, 3.4, 8.3, 9.3, 9.5, TS.2.5}

A.1.6 It is *virtually certain* that the global upper ocean (0–700 m) has warmed since the 1970s and *extremely likely* that human influence is the main driver. It is *virtually certain* that human-caused CO_2 emissions are the main driver of current global acidification of the surface open ocean. There is *high confidence* that oxygen levels have dropped in many upper ocean regions since the mid-20th century and *medium confidence* that human influence contributed to this drop.
{2.3, 3.5, 3.6, 5.3, 9.2, TS.2.4}

A.1.7 Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr^{-1} between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr^{-1} between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr^{-1} between 2006 and 2018 (*high confidence*). Human influence was *very likely* the main driver of these increases since at least 1971.
{2.3, 3.5, 9.6, Cross-Chapter Box 9.1, Box TS.4}

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8 The term 'global surface temperature' is used in reference to both global mean surface temperature and global surface air temperature throughout this SPM. Changes in these quantities are assessed with *high confidence* to differ by at most 10% from one another, but conflicting lines of evidence lead to *low confidence* in the sign (direction) of any difference in long-term trend. {Cross-Section Box TS.1}

9 The period 1850–1900 represents the earliest period of sufficiently globally complete observations to estimate global surface temperature and, consistent with AR5 and SR1.5, is used as an approximation for pre-industrial conditions.

10 Since AR5, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5.

11 The period distinction with A.1.2 arises because the attribution studies consider this slightly earlier period. The observed warming to 2010–2019 is 1.06 [0.88 to 1.21] °C.

12 Throughout this SPM, 'main driver' means responsible for more than 50% of the change.

A.1.8 Changes in the land biosphere since 1970 are consistent with global warming: climate zones have shifted poleward in both hemispheres, and the growing season has on average lengthened by up to two days per decade since the 1950s in the Northern Hemisphere extratropics (*high confidence*).
{2.3, TS.2.6}

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850–1900

(a) Change in global surface temperature (decadal average) as reconstructed (1–2000) and **observed** (1850–2020)

(b) Change in global surface temperature (annual average) as **observed** and simulated using human & natural and only natural factors (both 1850–2020)

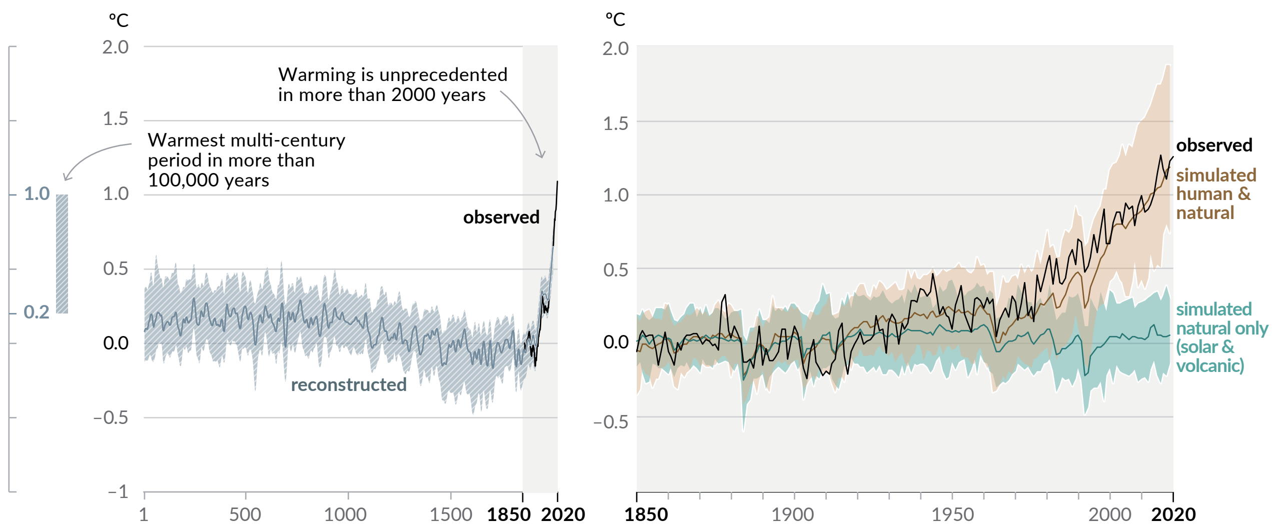

Figure SPM.1 | History of global temperature change and causes of recent warming

Panel (a) Changes in global surface temperature reconstructed from paleoclimate archives (solid grey line, years 1–2000) **and from direct observations** (solid black line, 1850–2020), both relative to 1850–1900 and decadally averaged. The vertical bar on the left shows the estimated temperature (*very likely* range) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125,000 years ago, is the next most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) orbital variations. The grey shading with white diagonal lines shows the *very likely* ranges for the temperature reconstructions.

Panel (b) Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations (see Box SPM.1) of the temperature response to both human and natural drivers (brown) and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the *very likely* range of simulations. (See Figure SPM.2 for the assessed contributions to warming).

{2.3.1; Cross-Chapter Box 2.3; 3.3; TS.2.2; Cross-Section Box TS.1, Figure 1a}

Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling

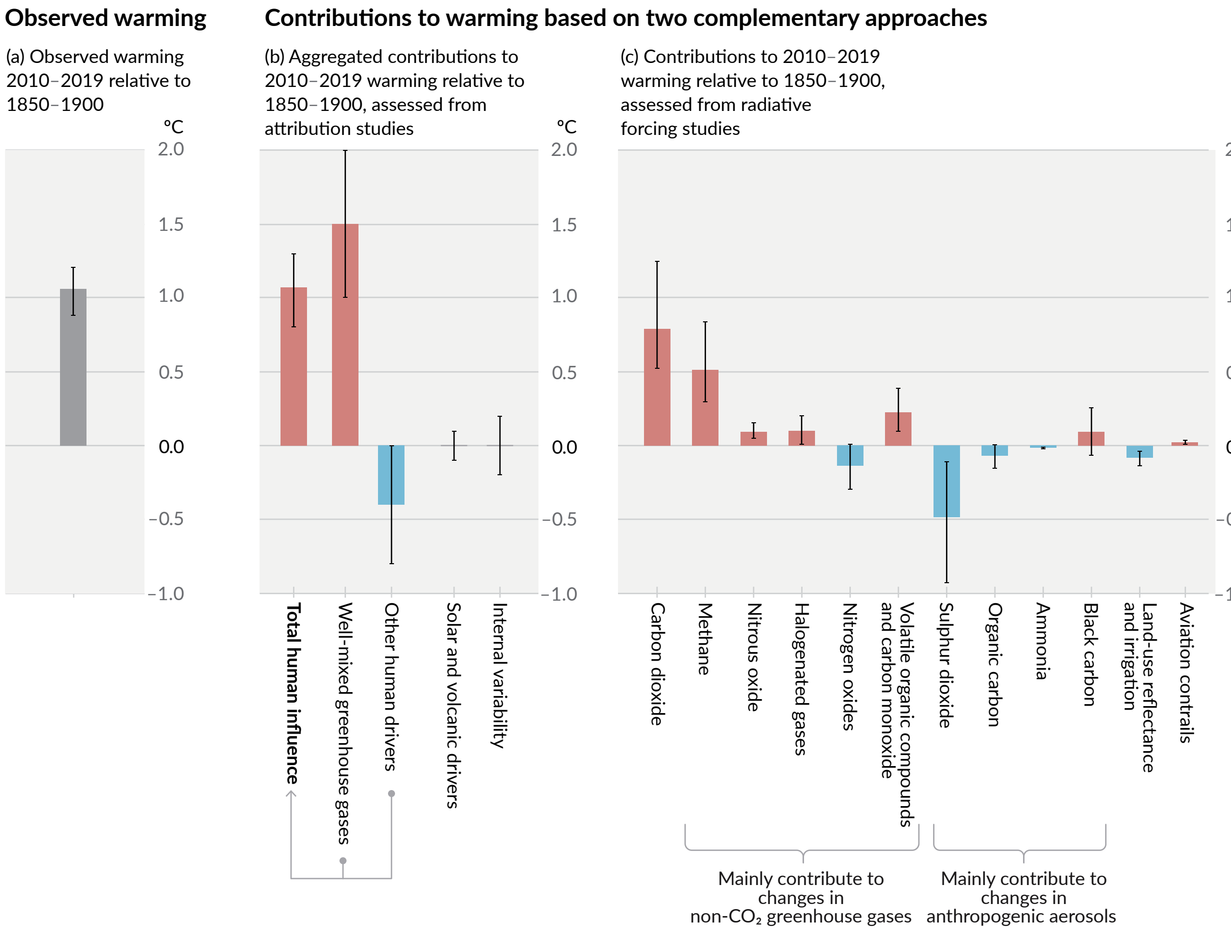

Figure SPM.2 | Assessed contributions to observed warming in 2010–2019 relative to 1850–1900

Panel (a) Observed global warming (increase in global surface temperature). Whiskers show the *very likely* range.

Panel (b) Evidence from attribution studies, which synthesize information from climate models and observations. The panel shows temperature change attributed to: total human influence; changes in well-mixed greenhouse gas concentrations; other human drivers due to aerosols, ozone and land-use change (land-use reflectance); solar and volcanic drivers; and internal climate variability. Whiskers show *likely* ranges.

Panel (c) Evidence from the assessment of radiative forcing and climate sensitivity. The panel shows temperature changes from individual components of human influence: emissions of greenhouse gases, aerosols and their precursors; land-use changes (land-use reflectance and irrigation); and aviation contrails. Whiskers show *very likely* ranges. Estimates account for both direct emissions into the atmosphere and their effect, if any, on other climate drivers. For aerosols, both direct effects (through radiation) and indirect effects (through interactions with clouds) are considered.

{Cross-Chapter Box 2.3, 3.3.1, 6.4.2, 7.3}

A.2 The scale of recent changes across the climate system as a whole – and the present state of many aspects of the climate system – are unprecedented over many centuries to many thousands of years. {2.2, 2.3, Cross-Chapter Box 2.1, 5.1} (Figure SPM.1)

A.2.1 In 2019, atmospheric CO_2 concentrations were higher than at any time in at least 2 million years (*high confidence*), and concentrations of CH_4 and N_2O were higher than at any time in at least 800,000 years (*very high confidence*). Since 1750, increases in CO_2 (47%) and CH_4 (156%) concentrations far exceed – and increases in N_2O (23%) are similar to – the natural multi-millennial changes between glacial and interglacial periods over at least the past 800,000 years (*very high confidence*). {2.2, 5.1, TS.2.2}

A.2.2 Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). Temperatures during the most recent decade (2011–2020) exceed those of the most recent multi-century warm period, around 6500 years ago[13] [0.2°C to 1°C relative to 1850–1900] (*medium confidence*). Prior to that, the next most recent warm period was about 125,000 years ago, when the multi-century temperature [0.5°C to 1.5°C relative to 1850–1900] overlaps the observations of the most recent decade (*medium confidence*). {2.3, Cross-Chapter Box 2.1, Cross-Section Box TS.1} (Figure SPM.1)

A.2.3 In 2011–2020, annual average Arctic sea ice area reached its lowest level since at least 1850 (*high confidence*). Late summer Arctic sea ice area was smaller than at any time in at least the past 1000 years (*medium confidence*). The global nature of glacier retreat since the 1950s, with almost all of the world's glaciers retreating synchronously, is unprecedented in at least the last 2000 years (*medium confidence*). {2.3, TS.2.5}

A.2.4 Global mean sea level has risen faster since 1900 than over any preceding century in at least the last 3000 years (*high confidence*). The global ocean has warmed faster over the past century than since the end of the last deglacial transition (around 11,000 years ago) (*medium confidence*). A long-term increase in surface open ocean pH occurred over the past 50 million years (*high confidence*). However, surface open ocean pH as low as recent decades is unusual in the last 2 million years (*medium confidence*). {2.3, TS.2.4, Box TS.4}

A.3 Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5. {2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, Box 9.2, 10.6, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.9, 12.3} (Figure SPM.3)

A.3.1 It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver[14] of these changes. Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006. {Box 9.2, 11.2, 11.3, 11.9, TS.2.4, TS.2.6, Box TS.10} (Figure SPM.3)

A.3.2 The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis (*high confidence*), and human-induced climate change is *likely* the main driver. Human-induced climate change has contributed to increases in agricultural and ecological droughts[15] in some regions due to increased land evapotranspiration[16] (*medium confidence*). {8.2, 8.3, 11.4, 11.6, 11.9, TS.2.6, Box TS.10} (Figure SPM.3)

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13 As stated in section B.1, even under the very low emissions scenario SSP1-1.9, temperatures are assessed to remain elevated above those of the most recent decade until at least 2100 and therefore warmer than the century-scale period 6500 years ago.

14 As indicated in footnote 12, throughout this SPM, 'main driver' means responsible for more than 50% of the change.

15 Agricultural and ecological drought (depending on the affected biome): a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general (see Annex VII: Glossary). Observed changes in meteorological droughts (precipitation deficits) and hydrological droughts (streamflow deficits) are distinct from those in agricultural and ecological droughts and are addressed in the underlying AR6 material (Chapter 11).

16 The combined processes through which water is transferred to the atmosphere from open water and ice surfaces, bare soils and vegetation that make up the Earth's surface (Glossary).

A.3.3 Decreases in global land monsoon precipitation[17] from the 1950s to the 1980s are partly attributed to human-caused Northern Hemisphere aerosol emissions, but increases since then have resulted from rising GHG concentrations and decadal to multi-decadal internal variability (*medium confidence*). Over South Asia, East Asia and West Africa, increases in monsoon precipitation due to warming from GHG emissions were counteracted by decreases in monsoon precipitation due to cooling from human-caused aerosol emissions over the 20th century (*high confidence*). Increases in West African monsoon precipitation since the 1980s are partly due to the growing influence of GHGs and reductions in the cooling effect of human-caused aerosol emissions over Europe and North America (*medium confidence*).
{2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, 10.6, Box TS.13}

A.3.4 It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and it is *very likely* that the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone (*medium confidence*). There is *low confidence* in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones (*high confidence*), but data limitations inhibit clear detection of past trends on the global scale.
{8.2, 11.7, Box TS.10}

A.3.5 Human influence has *likely* increased the chance of compound extreme events[18] since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale (*high confidence*), fire weather in some regions of all inhabited continents (*medium confidence*), and compound flooding in some locations (*medium confidence*).
{11.6, 11.7, 11.8, 12.3, 12.4, TS.2.6, Table TS.5, Box TS.10}

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17 The global monsoon is defined as the area in which the annual range (local summer minus local winter) of precipitation is greater than 2.5 mm day^{-1} (Glossary). Global land monsoon precipitation refers to the mean precipitation over land areas within the global monsoon.

18 Compound extreme events are the combination of multiple drivers and/or hazards that contribute to societal or environmental risk (Glossary). Examples are concurrent heatwaves and droughts, compound flooding (e.g., a storm surge in combination with extreme rainfall and/or river flow), compound fire weather conditions (i.e., a combination of hot, dry and windy conditions), or concurrent extremes at different locations.

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

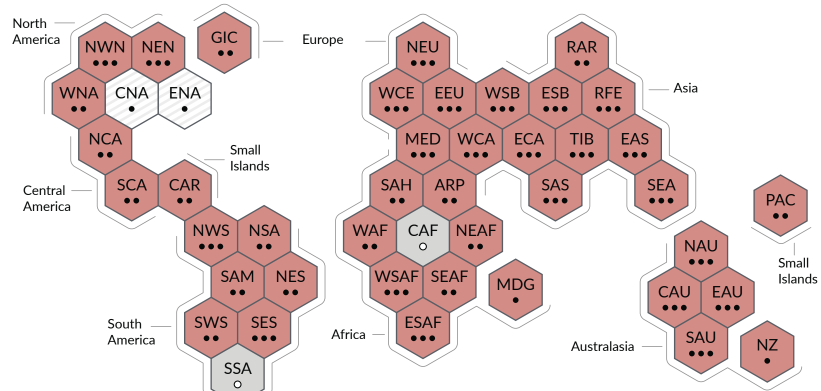
(a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in hot extremes

- Increase (41)
- Decrease (0)
- Low agreement in the type of change (2)
- Limited data and/or literature (2)

Confidence in human contribution to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence



Type of observed change since the 1950s

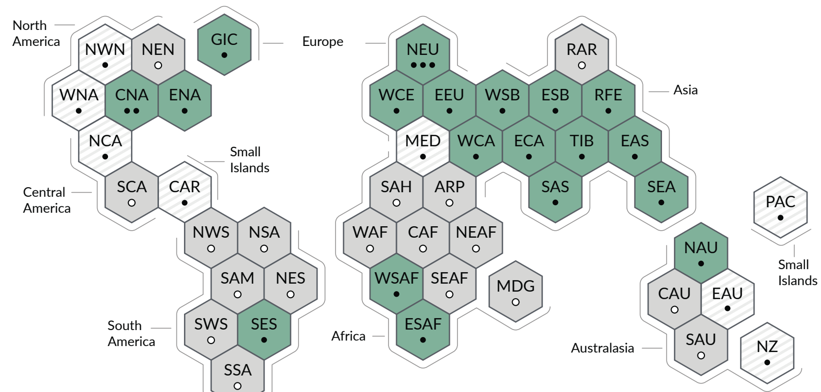
(b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in heavy precipitation

- Increase (19)
- Decrease (0)
- Low agreement in the type of change (8)
- Limited data and/or literature (18)

Confidence in human contribution to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence



Type of observed change since the 1950s

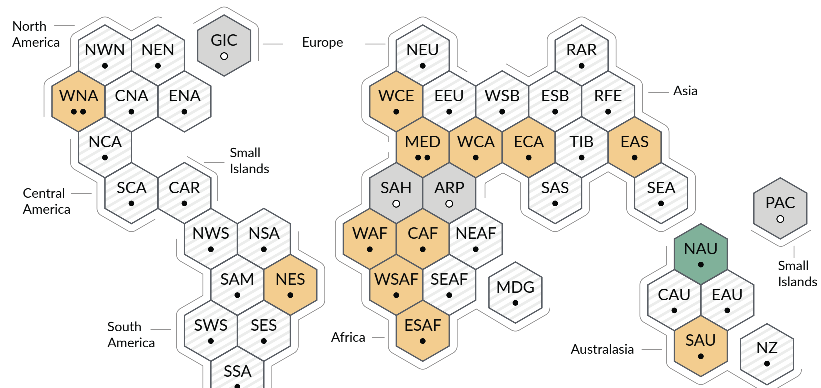
(c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in agricultural and ecological drought

- Increase (12)
- Decrease (1)
- Low agreement in the type of change (28)
- Limited data and/or literature (4)

Confidence in human contribution to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence



Type of observed change since the 1950s

Each hexagon corresponds to one of the IPCC AR6 WGI reference regions

NWN *North-Western North America*

IPCC AR6 WGI reference regions: **North America: NWN** *(North-Western North America)*, **NEN** *(North-Eastern North America)*, **WNA** *(Western North America)*, **CNA** *(Central North America)*, **ENA** *(Eastern North America)*, **Central America: NCA** *(Northern Central America)*, **SCA** *(Southern Central America)*, **CAR** *(Caribbean)*, **South America: NWS** *(North-Western South America)*, **NSA** *(Northern South America)*, **NES** *(North-Eastern South America)*, **SAM** *(South American Monsoon)*, **SWS** *(South-Western South America)*, **SES** *(South-Eastern South America)*, **SSA** *(Southern South America)*, **Europe: GIC** *(Greenland/Iceland)*, **NEU** *(Northern Europe)*, **WCE** *(Western and Central Europe)*, **EEU** *(Eastern Europe)*, **MED** *(Mediterranean)*, **Africa: MED** *(Mediterranean)*, **SAH** *(Sahara)*, **WAF** *(Western Africa)*, **CAF** *(Central Africa)*, **NEAF** *(North Eastern Africa)*, **SEAF** *(South Eastern Africa)*, **WSAF** *(West Southern Africa)*, **ESAF** *(East Southern Africa)*, **MDG** *(Madagascar)*, **Asia: RAR** *(Russian Arctic)*, **WSB** *(West Siberia)*, **ESB** *(East Siberia)*, **RFE** *(Russian Far East)*, **WCA** *(West Central Asia)*, **ECA** *(East Central Asia)*, **TIB** *(Tibetan Plateau)*, **EAS** *(East Asia)*, **ARP** *(Arabian Peninsula)*, **SAS** *(South Asia)*, **SEA** *(South East Asia)*, **Australasia: NAU** *(Northern Australia)*, **CAU** *(Central Australia)*, **EAU** *(Eastern Australia)*, **SAU** *(Southern Australia)*, **NZ** *(New Zealand)*, **Small Islands: CAR** *(Caribbean)*, **PAC** *(Pacific Small Islands)*

Figure SPM.3 | Synthesis of assessed observed and attributable regional changes

The IPCC AR6 WGI inhabited regions are displayed as **hexagons** with identical size in their approximate geographical location (see legend for regional acronyms). All assessments are made for each region as a whole and for the 1950s to the present. Assessments made on different time scales or more local spatial scales might differ from what is shown in the figure. The **colours** in each panel represent the four outcomes of the assessment on observed changes. Striped hexagons (white and light-grey) are used where there is *low agreement* in the type of change for the region as a whole, and grey hexagons are used when there is limited data and/or literature that prevents an assessment of the region as a whole. Other colours indicate at least *medium confidence* in the observed change. The **confidence level** for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution literature, and it is indicated by the number of dots: three dots for *high confidence*, two dots for *medium confidence* and one dot for *low confidence* (single, filled dot: limited agreement; single, empty dot: limited evidence).

Panel (a) For hot extremes, the evidence is mostly drawn from changes in metrics based on daily maximum temperatures; regional studies using other indices (heatwave duration, frequency and intensity) are used in addition. Red hexagons indicate regions where there is at least *medium confidence* in an observed increase in hot extremes.

Panel (b) For heavy precipitation, the evidence is mostly drawn from changes in indices based on one-day or five-day precipitation amounts using global and regional studies. Green hexagons indicate regions where there is at least *medium confidence* in an observed increase in heavy precipitation.

Panel (c) Agricultural and ecological droughts are assessed based on observed and simulated changes in total column soil moisture, complemented by evidence on changes in surface soil moisture, water balance (precipitation minus evapotranspiration) and indices driven by precipitation and atmospheric evaporative demand. Yellow hexagons indicate regions where there is at least *medium confidence* in an observed increase in this type of drought, and green hexagons indicate regions where there is at least *medium confidence* in an observed decrease in agricultural and ecological drought.

For all regions, Table TS.5 shows a broader range of observed changes besides the ones shown in this figure. Note that Southern South America (SSA) is the only region that does not display observed changes in the metrics shown in this figure, but is affected by observed increases in mean temperature, decreases in frost and increases in marine heatwaves.

{11.9, Atlas 1.3.3, Figure Atlas.2, Table TS.5; Box TS.10, Figure 1}

A.4 Improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing gives a best estimate of equilibrium climate sensitivity of 3°C, with a narrower range compared to AR5.

{2.2, 7.3, 7.4, 7.5, Box 7.2, 9.4, 9.5, 9.6, Cross-Chapter Box 9.1}

A.4.1 Human-caused radiative forcing of 2.72 [1.96 to 3.48] W m^{-2} in 2019 relative to 1750 has warmed the climate system. This warming is mainly due to increased GHG concentrations, partly reduced by cooling due to increased aerosol concentrations. The radiative forcing has increased by 0.43 W m^{-2} (19%) relative to AR5, of which 0.34 W m^{-2} is due to the increase in GHG concentrations since 2011. The remainder is due to improved scientific understanding and changes in the assessment of aerosol forcing, which include decreases in concentration and improvement in its calculation (*high confidence*).
{2.2, 7.3, TS.2.2, TS.3.1}

A.4.2 Human-caused net positive radiative forcing causes an accumulation of additional energy (heating) in the climate system, partly reduced by increased energy loss to space in response to surface warming. The observed average rate of heating of the climate system increased from 0.50 [0.32 to 0.69] W m^{-2} for the period 1971–2006[19] to 0.79 [0.52 to 1.06] W m^{-2} for the period 2006–2018[20] (*high confidence*). Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (*high confidence*).
{7.2, Box 7.2, TS.3.1}

A.4.3 Heating of the climate system has caused global mean sea level rise through ice loss on land and thermal expansion from ocean warming. Thermal expansion explained 50% of sea level rise during 1971–2018, while ice loss from glaciers contributed 22%, ice sheets 20% and changes in land-water storage 8%. The rate of ice-sheet loss increased by a factor of four between 1992–1999 and 2010–2019. Together, ice-sheet and glacier mass loss were the dominant contributors to global mean sea level rise during 2006–2018 (*high confidence*).
{9.4, 9.5, 9.6, Cross-Chapter Box 9.1}

A.4.4 The equilibrium climate sensitivity is an important quantity used to estimate how the climate responds to radiative forcing. Based on multiple lines of evidence,[21] the *very likely* range of equilibrium climate sensitivity is between 2°C (*high confidence*) and 5°C (*medium confidence*). The AR6 assessed best estimate is 3°C with a *likely* range of 2.5°C to 4°C (*high confidence*), compared to 1.5°C to 4.5°C in AR5, which did not provide a best estimate.
{7.4, 7.5, TS.3.2}

19 Cumulative energy increase of 282 [177 to 387] ZJ over 1971–2006 (1 ZJ = 10^{21} joules).

20 Cumulative energy increase of 152 [100 to 205] ZJ over 2006–2018.

21 Understanding of climate processes, the instrumental record, paleoclimates and model-based emergent constraints (Glossary).

B. Possible Climate Futures

A set of five new illustrative emissions scenarios is considered consistently across this Report to explore the climate response to a broader range of greenhouse gas (GHG), land-use and air pollutant futures than assessed in AR5. This set of scenarios drives climate model projections of changes in the climate system. These projections account for solar activity and background forcing from volcanoes. Results over the 21st century are provided for the near term (2021–2040), mid-term (2041–2060) and long term (2081–2100) relative to 1850–1900, unless otherwise stated.

Box SPM.1 | Scenarios, Climate Models and Projections

Box SPM.1.1: This Report assesses the climate response to five illustrative scenarios that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. They start in 2015, and include scenarios[22] with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and CO_2 emissions that roughly double from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and CO_2 emissions remaining around current levels until the middle of the century, and scenarios with very low and low GHG emissions and CO_2 emissions declining to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions[23] (SSP1-1.9 and SSP1-2.6), as illustrated in Figure SPM.4. Emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls. Alternative assumptions may result in similar emissions and climate responses, but the socio-economic assumptions and the feasibility or likelihood of individual scenarios are not part of the assessment.
{1.6, Cross-Chapter Box 1.4, TS.1.3} (Figure SPM.4)

Box SPM.1.2: This Report assesses results from climate models participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme. These models include new and better representations of physical, chemical and biological processes, as well as higher resolution, compared to climate models considered in previous IPCC assessment reports. This has improved the simulation of the recent mean state of most large-scale indicators of climate change and many other aspects across the climate system. Some differences from observations remain, for example in regional precipitation patterns. The CMIP6 historical simulations assessed in this Report have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the *very likely* range of the CMIP6 ensemble. However, some CMIP6 models simulate a warming that is either above or below the assessed *very likely* range of observed warming.
{1.5, Cross-Chapter Box 2.2, 3.3, 3.8, TS.1.2, Cross-Section Box TS.1} (Figure SPM.1b, Figure SPM.2)

Box SPM.1.3: The CMIP6 models considered in this Report have a wider range of climate sensitivity than in CMIP5 models and the AR6 assessed *very likely* range, which is based on multiple lines of evidence. These CMIP6 models also show a higher average climate sensitivity than CMIP5 and the AR6 assessed best estimate. The higher CMIP6 climate sensitivity values compared to CMIP5 can be traced to an amplifying cloud feedback that is larger in CMIP6 by about 20%.
{Box 7.1, 7.3, 7.4, 7.5, TS.3.2}

Box SPM.1.4: For the first time in an IPCC report, assessed future changes in global surface temperature, ocean warming and sea level are constructed by combining multi-model projections with observational constraints based on past simulated warming, as well as the AR6 assessment of climate sensitivity. For other quantities, such robust methods do not yet exist to constrain the projections. Nevertheless, robust projected geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached.
{1.6, 4.3, 4.6, Box 4.1, 7.5, 9.2, 9.6, Cross-Chapter Box 11.1, Cross-Section Box TS.1}

22 Throughout this Report, the five illustrative scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socio-economic Pathway or 'SSP' describing the socio-economic trends underlying the scenario, and 'y' refers to the approximate level of radiative forcing (in watts per square metre, or W m^{-2}) resulting from the scenario in the year 2100. A detailed comparison to scenarios used in earlier IPCC reports is provided in Section TS.1.3, and Sections 1.6 and 4.6. The SSPs that underlie the specific forcing scenarios used to drive climate models are not assessed by WGI. Rather, the SSPx-y labelling ensures traceability to the underlying literature in which specific forcing pathways are used as input to the climate models. IPCC is neutral with regard to the assumptions underlying the SSPs, which do not cover all possible scenarios. Alternative scenarios may be considered or developed.

23 Net negative CO_2 emissions are reached when anthropogenic removals of CO_2 exceed anthropogenic emissions (Glossary).

Box SPM.1 (continued)

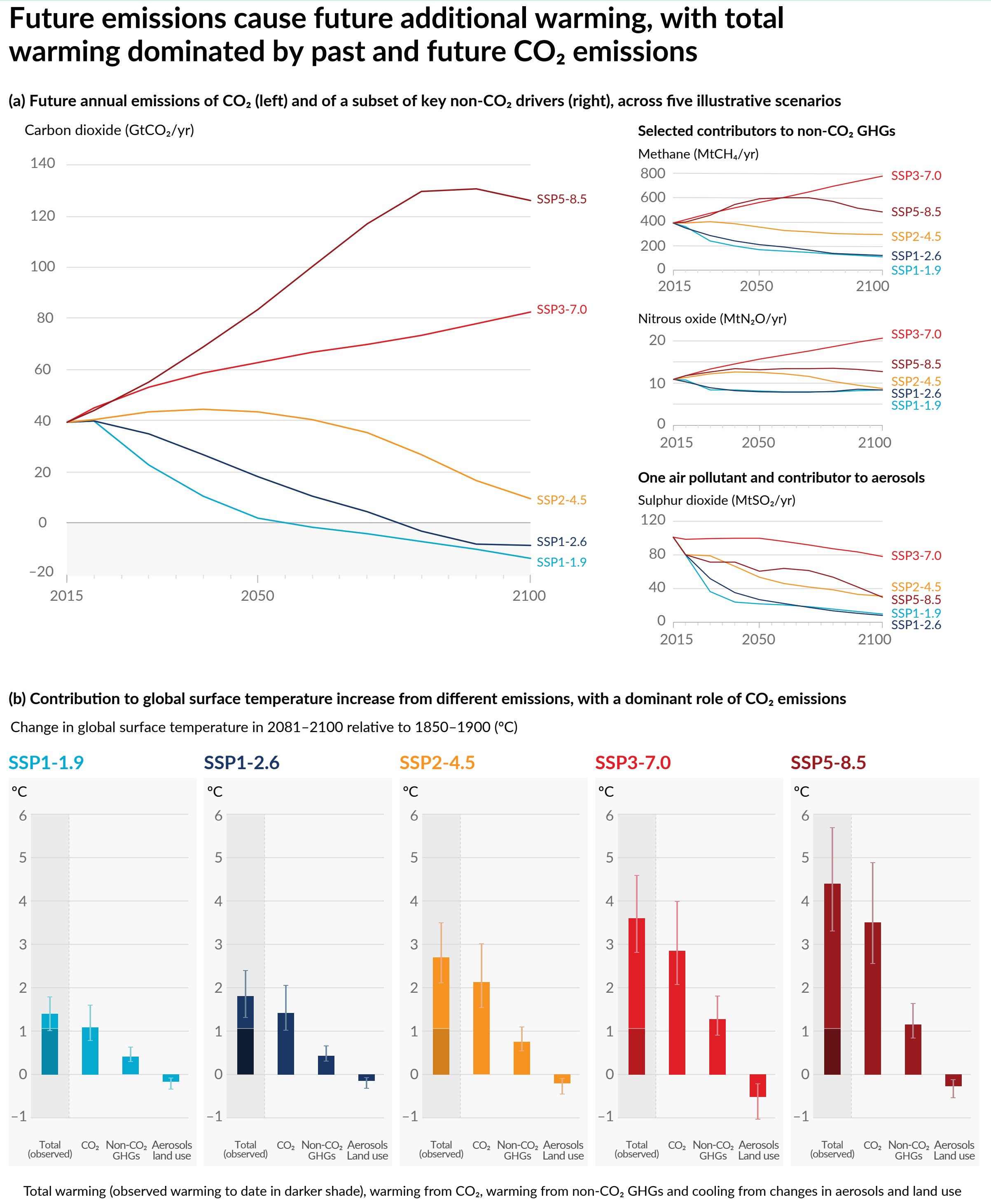


Figure SPM.4 | Future anthropogenic emissions of key drivers of climate change and warming contributions by groups of drivers for the five illustrative scenarios used in this report

The five scenarios are SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5.

Panel (a) Annual anthropogenic (human-caused) emissions over the 2015–2100 period. Shown are emissions trajectories for carbon dioxide (CO_2) from all sectors ($GtCO_2$/yr) (left graph) and for a subset of three key non-CO_2 drivers considered in the scenarios: methane (CH_4, $MtCH_4$/yr, top-right graph); nitrous oxide (N_2O, MtN_2O/yr, middle-right graph); and sulphur dioxide (SO_2, $MtSO_2$/yr, bottom-right graph, contributing to anthropogenic aerosols in panel (b).

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Panel (b) Warming contributions by groups of anthropogenic drivers and by scenario are shown as the change in global surface temperature (°C) in 2081–2100 relative to 1850–1900, with indication of the observed warming to date. Bars and whiskers represent median values and the *very likely* range, respectively. Within each scenario bar plot, the bars represent: total global warming (°C; 'total' bar) (see Table SPM.1); warming contributions (°C) from changes in CO_2 ('CO_2' bar) and from non-CO_2 greenhouse gases (GHGs; 'non-CO_2 GHGs' bar: comprising well-mixed greenhouse gases and ozone); and net cooling from other anthropogenic drivers ('aerosols and land use' bar: anthropogenic aerosols, changes in reflectance due to land-use and irrigation changes, and contrails from aviation) (see Figure SPM.2, panel c, for the warming contributions to date for individual drivers). The best estimate for observed warming in 2010–2019 relative to 1850–1900 (see Figure SPM.2, panel a) is indicated in the darker column in the 'total' bar. Warming contributions in panel (b) are calculated as explained in Table SPM.1 for the total bar. For the other bars, the contribution by groups of drivers is calculated with a physical climate emulator of global surface temperature that relies on climate sensitivity and radiative forcing assessments.

{Cross-Chapter Box 1.4; 4.6; Figure 4.35; 6.7; Figures 6.18, 6.22 and 6.24; 7.3; Cross-Chapter Box 7.1; Figure 7.7; Box TS.7; Figures TS.4 and TS.15}

B.1 Global surface temperature will continue to increase until at least mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades.
{2.3, Cross-Chapter Box 2.3, Cross-Chapter Box 2.4, 4.3, 4.4, 4.5} (Figure SPM.1, Figure SPM.4, Figure SPM.8, Table SPM.1, Box SPM.1)

B.1.1 Compared to 1850–1900, global surface temperature averaged over 2081–2100 is *very likely* to be higher by 1.0°C to 1.8°C under the very low GHG emissions scenario considered (SSP1-1.9), by 2.1°C to 3.5°C in the intermediate GHG emissions scenario (SSP2-4.5) and by 3.3°C to 5.7°C under the very high GHG emissions scenario (SSP5-8.5).[24] The last time global surface temperature was sustained at or above 2.5°C higher than 1850–1900 was over 3 million years ago (*medium confidence*).
{2.3, Cross-Chapter Box 2.4, 4.3, 4.5, Box TS.2, Box TS.4, Cross-Section Box TS.1} (Table SPM.1)

Table SPM.1 | Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to +0.12] °C than in AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014.
{Cross-Chapter Box 2.3, 4.3, 4.4, Cross-Section Box TS.1}

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

B.1.2 Based on the assessment of multiple lines of evidence, global warming of 2°C, relative to 1850–1900, would be exceeded during the 21st century under the high and very high GHG emissions scenarios considered in this report (SSP3-7.0 and SSP5-8.5, respectively). Global warming of 2°C would *extremely likely* be exceeded in the intermediate GHG emissions scenario (SSP2-4.5). Under the very low and low GHG emissions scenarios, global warming of 2°C is *extremely unlikely* to be exceeded (SSP1-1.9) or *unlikely* to be exceeded (SSP1-2.6).[25] Crossing the 2°C global warming level in the mid-term period (2041–2060) is *very likely* to occur under the very high GHG emissions scenario (SSP5-8.5), *likely* to occur under the high GHG emissions scenario (SSP3-7.0), and *more likely than not* to occur in the intermediate GHG emissions scenario (SSP2-4.5).[26]
{4.3, Cross-Section Box TS.1} (Table SPM.1, Figure SPM.4, Box SPM.1)

24 Changes in global surface temperature are reported as running 20-year averages, unless stated otherwise.

25 SSP1-1.9 and SSP1-2.6 are scenarios that start in 2015 and have very low and low GHG emissions, respectively, and CO_2 emissions declining to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions.

26 Crossing is defined here as having the assessed global surface temperature change, averaged over a 20-year period, exceed a particular global warming level.

B.1.3 Global warming of 1.5°C relative to 1850–1900 would be exceeded during the 21st century under the intermediate, high and very high GHG emissions scenarios considered in this report (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the five illustrative scenarios, in the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high GHG emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5 and SSP3-7.0), *more likely than not* to be exceeded under the low GHG emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low GHG emissions scenario (SSP1-1.9).[27] Furthermore, for the very low GHG emissions scenario (SSP1-1.9), it is *more likely than not* that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.
{4.3, Cross-Section Box TS.1} (Table SPM.1, Figure SPM.4)

B.1.4 Global surface temperature in any single year can vary above or below the long-term human-induced trend, due to substantial natural variability.[28] The occurrence of individual years with global surface temperature change above a certain level, for example 1.5°C or 2°C, relative to 1850–1900 does not imply that this global warming level has been reached.[29]
{Cross-Chapter Box 2.3, 4.3, 4.4, Box 4.1, Cross-Section Box TS.1} (Table SPM.1, Figure SPM.1, Figure SPM.8)

B.2 Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, heavy precipitation, and, in some regions, agricultural and ecological droughts; an increase in the proportion of intense tropical cyclones; and reductions in Arctic sea ice, snow cover and permafrost.
{4.3, 4.5, 4.6, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, Box 9.2, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11} (Figure SPM.5, Figure SPM.6, Figure SPM.8)

B.2.1 It is *virtually certain* that the land surface will continue to warm more than the ocean surface (*likely* 1.4 to 1.7 times more). It is *virtually certain* that the Arctic will continue to warm more than global surface temperature, with *high confidence* above two times the rate of global warming.
{2.3, 4.3, 4.5, 4.6, 7.4, 11.1, 11.3, 11.9, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Section Box TS.1, TS.2.6} (Figure SPM.5)

B.2.2 With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (*very likely*), and heavy precipitation (*high confidence*), as well as agricultural and ecological droughts[30] in some regions (*high confidence*). Discernible changes in intensity and frequency of meteorological droughts, with more regions showing increases than decreases, are seen in some regions for every additional 0.5°C of global warming (*medium confidence*). Increases in frequency and intensity of hydrological droughts become larger with increasing global warming in some regions (*medium confidence*). There will be an increasing occurrence of some extreme events unprecedented in the observational record with additional global warming, even at 1.5°C of global warming. Projected percentage changes in frequency are larger for rarer events (*high confidence*).
{8.2, 11.2, 11.3, 11.4, 11.6, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, TS.2.6} (Figure SPM.5, Figure SPM.6)

B.2.3 Some mid-latitude and semi-arid regions, and the South American Monsoon region, are projected to see the highest increase in the temperature of the hottest days, at about 1.5 to 2 times the rate of global warming (*high confidence*). The Arctic is projected to experience the highest increase in the temperature of the coldest days, at about three times the rate of global warming (*high confidence*). With additional global warming, the frequency of marine heatwaves will continue to increase (*high confidence*), particularly in the tropical ocean and the Arctic (*medium confidence*).
{Box 9.2, 11.1, 11.3, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, 12.4, TS.2.4, TS.2.6} (Figure SPM.6)

27 The AR6 assessment of when a given global warming level is first exceeded benefits from the consideration of the illustrative scenarios, the multiple lines of evidence entering the assessment of future global surface temperature response to radiative forcing, and the improved estimate of historical warming. The AR6 assessment is thus not directly comparable to the SR1.5 SPM, which reported *likely* reaching 1.5°C global warming between 2030 and 2052, from a simple linear extrapolation of warming rates of the recent past. When considering scenarios similar to SSP1-1.9 instead of linear extrapolation, the SR1.5 estimate of when 1.5°C global warming is first exceeded is close to the best estimate reported here.

28 Natural variability refers to climatic fluctuations that occur without any human influence, that is, internal variability combined with the response to external natural factors such as volcanic eruptions, changes in solar activity and, on longer time scales, orbital effects and plate tectonics (Glossary).

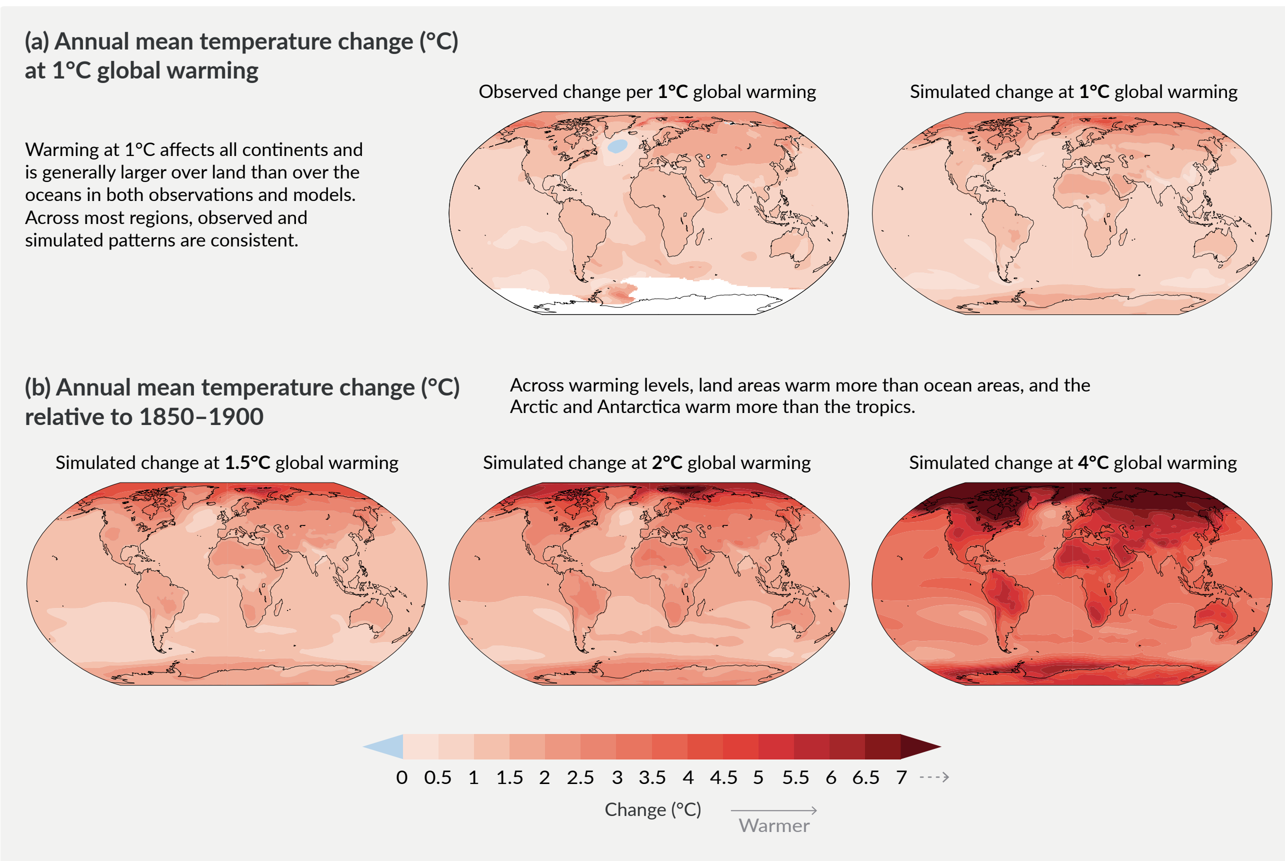
29 The internal variability in any single year is estimated to be about ±0.25°C (5–95% range, *high confidence*).

30 Projected changes in agricultural and ecological droughts are primarily assessed based on total column soil moisture. See footnote 15 for definition and relation to precipitation and evapotranspiration.

B.2.4 It is *very likely* that heavy precipitation events will intensify and become more frequent in most regions with additional global warming. At the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1°C of global warming (*high confidence*). The proportion of intense tropical cyclones (Category 4–5) and peak wind speeds of the most intense tropical cyclones are projected to increase at the global scale with increasing global warming (*high confidence*).
{8.2, 11.4, 11.7, 11.9, Cross-Chapter Box 11.1, Box TS.6, TS.4.3.1} (Figure SPM.5, Figure SPM.6)

B.2.5 Additional warming is projected to further amplify permafrost thawing and loss of seasonal snow cover, of land ice and of Arctic sea ice (*high confidence*). The Arctic is *likely* to be practically sea ice-free in September[31] at least once before 2050 under the five illustrative scenarios considered in this report, with more frequent occurrences for higher warming levels. There is *low confidence* in the projected decrease of Antarctic sea ice.
{4.3, 4.5, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, 12.4, Cross-Chapter Box 12.1, Atlas.5, Atlas.6, Atlas.8, Atlas.9, Atlas.11, TS.2.5} (Figure SPM.8)

With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture



31 Monthly average sea ice area of less than 1 million km^2, which is about 15% of the average September sea ice area observed in 1979–1988.

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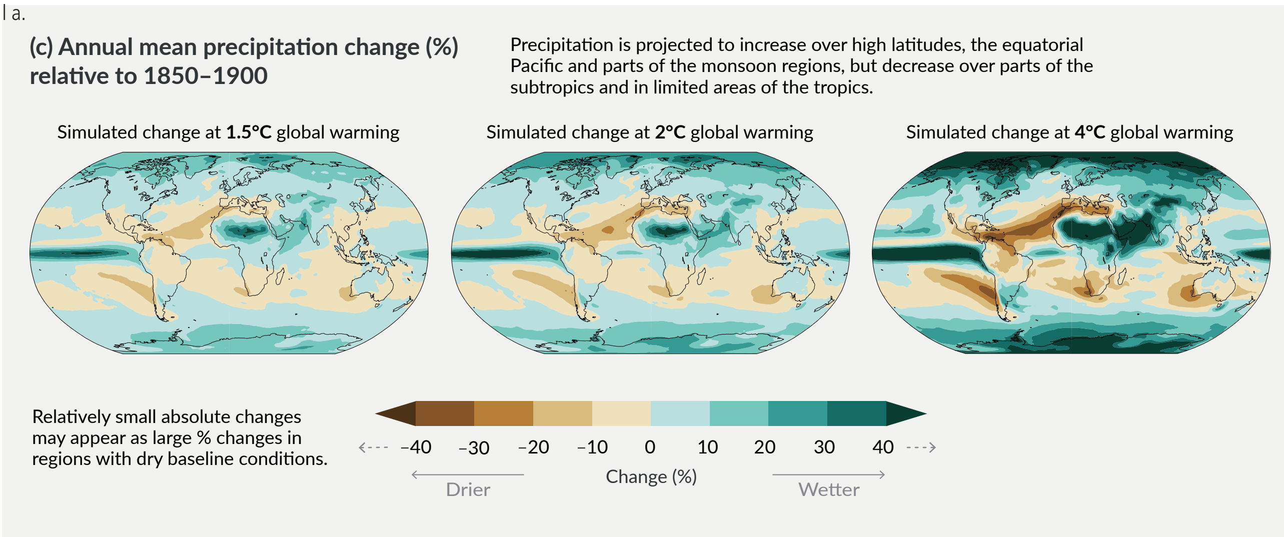

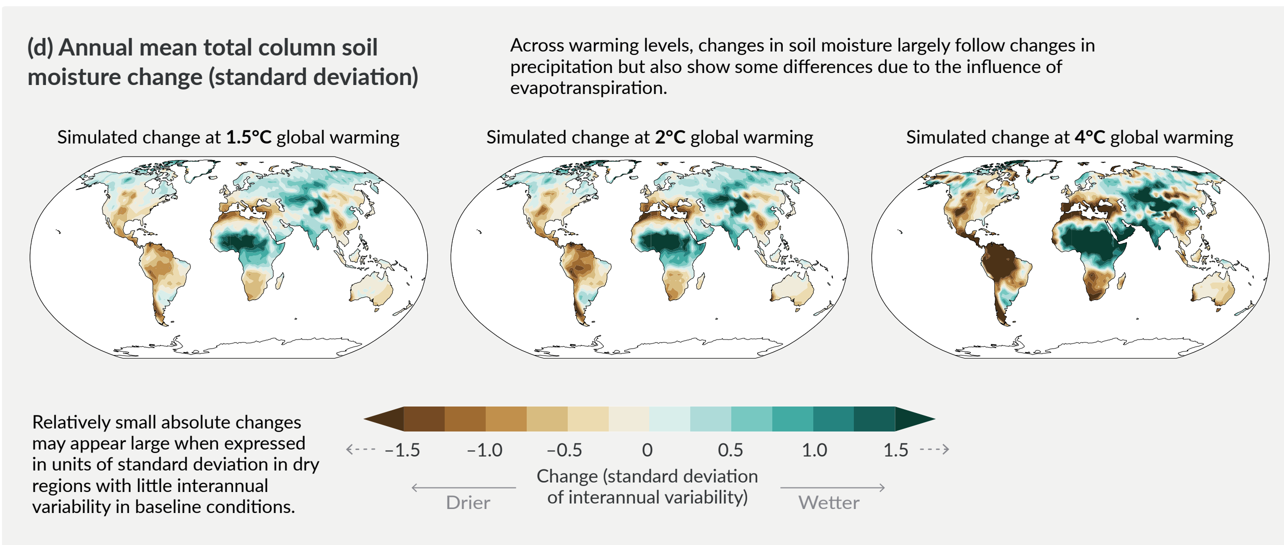

Figure SPM.5 | Changes in annual mean surface temperature, precipitation, and soil moisture

Panel (a) Comparison of observed and simulated annual mean surface temperature change. The **left map** shows the observed changes in annual mean surface temperature in the period 1850–2020 per °C of global warming (°C). The local (i.e., grid point) observed annual mean surface temperature changes are linearly regressed against the global surface temperature in the period 1850–2020. Observed temperature data are from Berkeley Earth, the dataset with the largest coverage and highest horizontal resolution. Linear regression is applied to all years for which data at the corresponding grid point is available. The regression method was used to take into account the complete observational time series and thereby reduce the role of internal variability at the grid point level. White indicates areas where time coverage was 100 years or less and thereby too short to calculate a reliable linear regression. The **right map** is based on model simulations and shows change in annual multi-model mean simulated temperatures at a global warming level of 1°C (20-year mean global surface temperature change relative to 1850–1900). The triangles at each end of the colour bar indicate out-of-bound values, that is, values above or below the given limits.

Panel (b) Simulated annual mean temperature change (°C), panel (c) precipitation change (%), and panel (d) total column soil moisture change (standard deviation of interannual variability) at global warming levels of 1.5°C, 2°C and 4°C (20-year mean global surface temperature change relative to 1850–1900). Simulated changes correspond to Coupled Model Intercomparison Project Phase 6 (CMIP6) multi-model mean change (median change for soil moisture) at the corresponding global warming level, that is, the same method as for the right map in panel (a).

In **panel (c)**, high positive percentage changes in dry regions may correspond to small absolute changes. In **panel (d)**, the unit is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterizing drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of droughts that occurred about once every six years during 1850–1900. In panel (d), large changes in dry regions with little interannual variability in the baseline conditions can correspond to small absolute change. The triangles at each end of the colour bars indicate out-of-bound values, that is, values above or below the given limits. Results from all models reaching the corresponding warming level in any of the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are averaged. Maps of annual mean temperature and precipitation changes at a global warming level of 3°C are available in Figure 4.31 and Figure 4.32 in Section 4.6. Corresponding maps of panels (b), (c) and (d), including hatching to indicate the level of model agreement at grid-cell level, are found in Figures 4.31, 4.32 and 11.19, respectively; as highlighted in Cross-Chapter Box Atlas.1, grid-cell level hatching is not informative for larger spatial scales (e.g., over AR6 reference regions) where the aggregated signals are less affected by small-scale variability, leading to an increase in robustness.

{Figure 1.14, 4.6.1, Cross-Chapter Box 11.1, Cross-Chapter Box Atlas.1, TS.1.3.2, Figures TS.3 and TS.5}

Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming

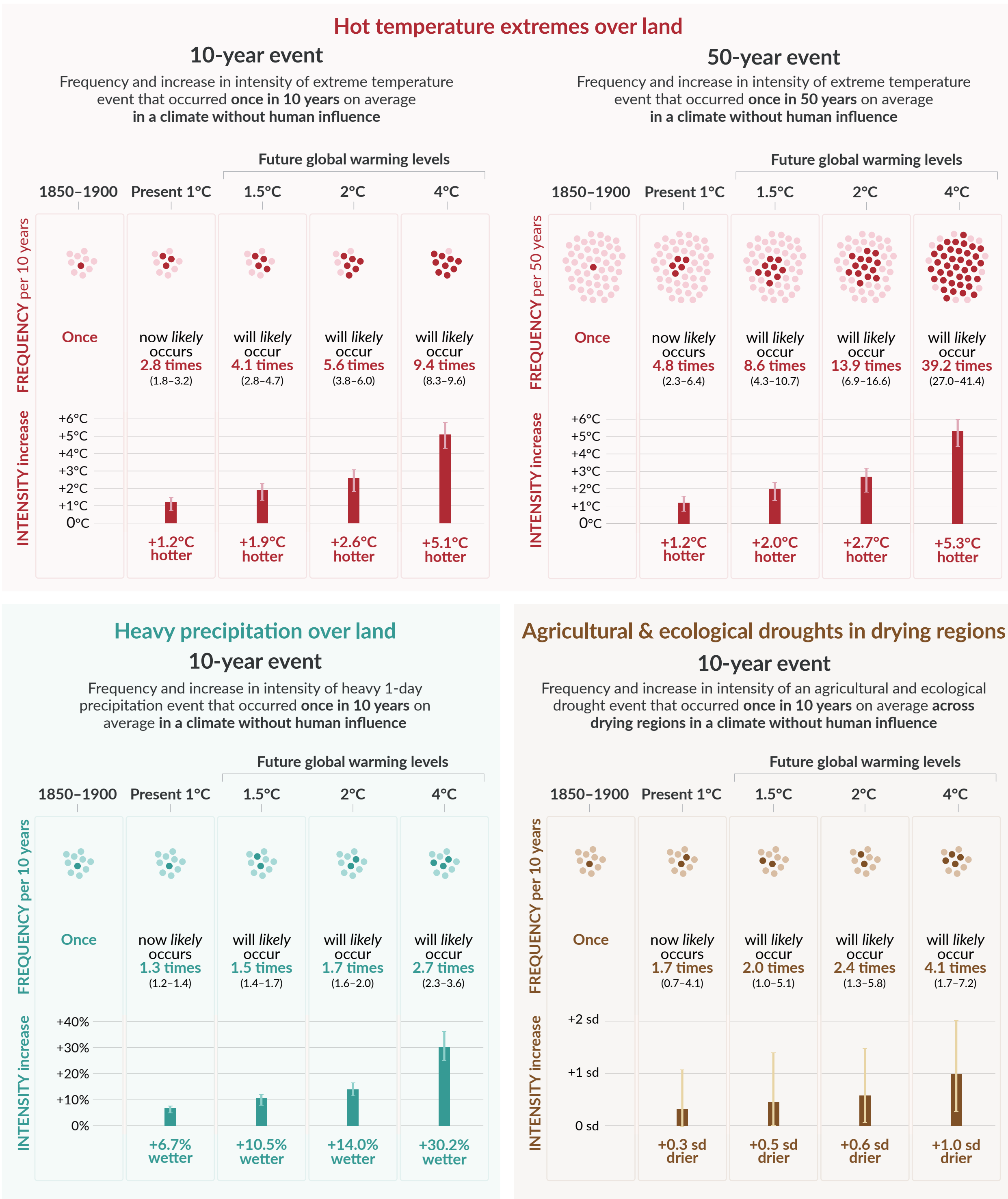

Figure SPM.6 | Projected changes in the intensity and frequency of hot temperature extremes over land, extreme precipitation over land, and agricultural and ecological droughts in drying regions

Projected changes are shown at global warming levels of 1°C, 1.5°C, 2°C, and 4°C and are relative to 1850–1900,[9] representing a climate without human influence. The figure depicts frequencies and increases in intensity of 10- or 50-year extreme events from the base period (1850–1900) under different global warming levels.

Hot temperature extremes are defined as the daily maximum temperatures over land that were exceeded on average once in a decade (10-year event) or once in 50 years (50-year event) during the 1850–1900 reference period. **Extreme precipitation events** are defined as the daily precipitation amount over land that

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was exceeded on average once in a decade during the 1850–1900 reference period. **Agricultural and ecological drought events** are defined as the annual average of total column soil moisture below the 10th percentile of the 1850–1900 base period. These extremes are defined on model grid box scale. For hot temperature extremes and extreme precipitation, results are shown for the global land. For agricultural and ecological drought, results are shown for drying regions only, which correspond to the AR6 regions in which there is at least *medium confidence* in a projected increase in agricultural and ecological droughts at the 2°C warming level compared to the 1850–1900 base period in the Coupled Model Intercomparison Project Phase 6 (CMIP6). These regions include Western North America, Central North America, Northern Central America, Southern Central America, Caribbean, Northern South America, North-Eastern South America, South American Monsoon, South-Western South America, Southern South America, Western and Central Europe, Mediterranean, West Southern Africa, East Southern Africa, Madagascar, Eastern Australia, and Southern Australia (Caribbean is not included in the calculation of the figure because of the too-small number of full land grid cells). The non-drying regions do not show an overall increase or decrease in drought severity. Projections of changes in agricultural and ecological droughts in the CMIP Phase 5 (CMIP5) multi-model ensemble differ from those in CMIP6 in some regions, including in parts of Africa and Asia. Assessments of projected changes in meteorological and hydrological droughts are provided in Chapter 11.

In the **'frequency' section**, each year is represented by a dot. The dark dots indicate years in which the extreme threshold is exceeded, while light dots are years when the threshold is not exceeded. Values correspond to the medians (in bold) and their respective *likely* ranges based on the 5–95% range of the multi-model ensemble from simulations of CMIP6 under different Shared Socio-economic Pathway scenarios. For consistency, the number of dark dots is based on the rounded-up median. In the **'intensity' section**, medians and their *likely* ranges, also based on the 5–95% range of the multi-model ensemble from simulations of CMIP6, are displayed as dark and light bars, respectively. Changes in the intensity of hot temperature extremes and extreme precipitation are expressed as degree Celsius and percentage. As for agricultural and ecological drought, intensity changes are expressed as fractions of standard deviation of annual soil moisture.

{11.1; 11.3; 11.4; 11.6; 11.9; Figures 11.12, 11.15, 11.6, 11.7, and 11.18}

B.3 Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.
{4.3, 4.4, 4.5, 4.6, 8.2, 8.3, 8.4, 8.5, Box 8.2, 11.4, 11.6, 11.9, 12.4, Atlas.3} (Figure SPM.5, Figure SPM.6)

B.3.1 There is strengthened evidence since AR5 that the global water cycle will continue to intensify as global temperatures rise (*high confidence*), with precipitation and surface water flows projected to become more variable over most land regions within seasons (*high confidence*) and from year to year (*medium confidence*). The average annual global land precipitation is projected to increase by 0–5% under the very low GHG emissions scenario (SSP1-1.9), 1.5–8% for the intermediate GHG emissions scenario (SSP2-4.5) and 1–13% under the very high GHG emissions scenario (SSP5-8.5) by 2081–2100 relative to 1995–2014 (*likely* ranges). Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and limited areas in the tropics in SSP2-4.5, SSP3-7.0 and SSP5-8.5 (*very likely*). The portion of the global land experiencing detectable increases or decreases in seasonal mean precipitation is projected to increase (*medium confidence*). There is *high confidence* in an earlier onset of spring snowmelt, with higher peak flows at the expense of summer flows in snow-dominated regions globally.
{4.3, 4.5, 4.6, 8.2, 8.4, Atlas.3, TS.2.6, TS.4.3, Box TS.6} (Figure SPM.5)

B.3.2 A warmer climate will intensify very wet and very dry weather and climate events and seasons, with implications for flooding or drought (*high confidence*), but the location and frequency of these events depend on projected changes in regional atmospheric circulation, including monsoons and mid-latitude storm tracks. It is *very likely* that rainfall variability related to the El Niño–Southern Oscillation is projected to be amplified by the second half of the 21st century in the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios.
{4.3, 4.5, 4.6, 8.2, 8.4, 8.5, 11.4, 11.6, 11.9, 12.4, TS.2.6, TS.4.2, Box TS.6} (Figure SPM.5, Figure SPM.6)

B.3.3 Monsoon precipitation is projected to increase in the mid- to long term at the global scale, particularly over South and South East Asia, East Asia and West Africa apart from the far west Sahel (*high confidence*). The monsoon season is projected to have a delayed onset over North and South America and West Africa (*high confidence*) and a delayed retreat over West Africa (*medium confidence*).
{4.4, 4.5, 8.2, 8.3, 8.4, Box 8.2, Box TS.13}

B.3.4 A projected southward shift and intensification of Southern Hemisphere summer mid-latitude storm tracks and associated precipitation is *likely* in the long term under high GHG emissions scenarios (SSP3-7.0, SSP5-8.5), but in the near term the effect of stratospheric ozone recovery counteracts these changes (*high confidence*). There is *medium confidence* in a continued poleward shift of storms and their precipitation in the North Pacific, while there is *low confidence* in projected changes in the North Atlantic storm tracks.
{4.4, 4.5, 8.4, TS.2.3, TS.4.2}

B.4 Under scenarios with increasing CO_2 emissions, the ocean and land carbon sinks are projected to be less effective at slowing the accumulation of CO_2 in the atmosphere.
{4.3, 5.2, 5.4, 5.5, 5.6} (Figure SPM.7)

B.4.1 While natural land and ocean carbon sinks are projected to take up, in absolute terms, a progressively larger amount of CO_2 under higher compared to lower CO_2 emissions scenarios, they become less effective, that is, the proportion of emissions taken up by land and ocean decrease with increasing cumulative CO_2 emissions. This is projected to result in a higher proportion of emitted CO_2 remaining in the atmosphere (*high confidence*).
{5.2, 5.4, Box TS.5} (Figure SPM.7)

B.4.2 Based on model projections, under the intermediate GHG emissions scenario that stabilizes atmospheric CO_2 concentrations this century (SSP2-4.5), the rates of CO_2 taken up by the land and ocean are projected to decrease in the second half of the 21st century (*high confidence*). Under the very low and low GHG emissions scenarios (SSP1-1.9, SSP1-2.6), where CO_2 concentrations peak and decline during the 21st century, the land and ocean begin to take up less carbon in response to declining atmospheric CO_2 concentrations (*high confidence*) and turn into a weak net source by 2100 under SSP1-1.9 (*medium confidence*). It is *very unlikely* that the combined global land and ocean sink will turn into a source by 2100 under scenarios without net negative emissions (SSP2-4.5, SSP3-7.0, SSP5-8.5).[32]
{4.3, 5.4, 5.5, 5.6, Box TS.5, TS.3.3}

B.4.3 The magnitude of feedbacks between climate change and the carbon cycle becomes larger but also more uncertain in high CO_2 emissions scenarios (*very high confidence*). However, climate model projections show that the uncertainties in atmospheric CO_2 concentrations by 2100 are dominated by the differences between emissions scenarios (*high confidence*). Additional ecosystem responses to warming not yet fully included in climate models, such as CO_2 and CH_4 fluxes from wetlands, permafrost thaw and wildfires, would further increase concentrations of these gases in the atmosphere (*high confidence*).
{5.4, Box TS.5, TS.3.2}

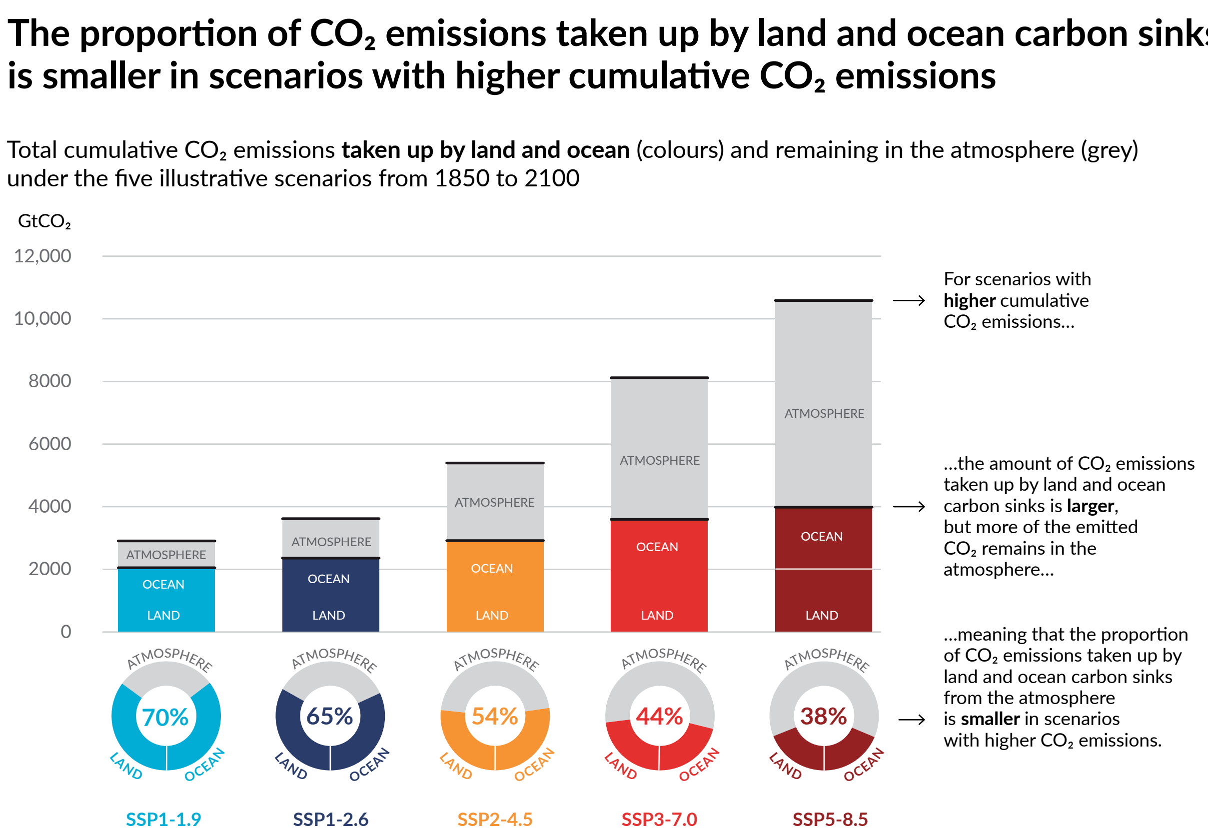

Figure SPM.7 | Cumulative anthropogenic CO_2 emissions taken up by land and ocean sinks by 2100 under the five illustrative scenarios

The cumulative anthropogenic (human-caused) carbon dioxide (CO_2) emissions taken up by the land and ocean sinks under the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are simulated from 1850 to 2100 by Coupled Model Intercomparison Project Phase 6 (CMIP6) climate models in the concentration-driven simulations. Land and ocean carbon sinks respond to past, current and future emissions; therefore, cumulative sinks from 1850 to 2100 are presented here. During the historical period (1850–2019) the observed land and ocean sink took up 1430 $GtCO_2$ (59% of the emissions).

32 These projected adjustments of carbon sinks to stabilization or decline of atmospheric CO_2 are accounted for in calculations of remaining carbon budgets.

The bar chart illustrates the projected amount of cumulative anthropogenic CO_2 emissions ($GtCO_2$) between 1850 and 2100 remaining in the atmosphere (grey part) and taken up by the land and ocean (coloured part) in the year 2100. **The doughnut chart** illustrates the proportion of the cumulative anthropogenic CO_2 emissions taken up by the land and ocean sinks and remaining in the atmosphere in the year 2100. Values in % indicate the proportion of the cumulative anthropogenic CO_2 emissions taken up by the combined land and ocean sinks in the year 2100. The overall anthropogenic carbon emissions are calculated by adding the net global land-use emissions from the CMIP6 scenario database to the other sectoral emissions calculated from climate model runs with prescribed CO_2 concentrations.[33] Land and ocean CO_2 uptake since 1850 is calculated from the net biome productivity on land, corrected for CO_2 losses due to land-use change by adding the land-use change emissions, and net ocean CO_2 flux.

{5.2.1; Table 5.1; 5.4.5; Figure 5.25; Box TS.5; Box TS.5, Figure 1}

B.5 Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.
{2.3, Cross-Chapter Box 2.4, 4.3, 4.5, 4.7, 5.3, 9.2, 9.4, 9.5, 9.6, Box 9.4} (Figure SPM.8)

B.5.1 Past GHG emissions since 1750 have committed the global ocean to future warming (*high confidence*). Over the rest of the 21st century, *likely* ocean warming ranges from 2–4 (SSP1-2.6) to 4–8 times (SSP5-8.5) the 1971–2018 change. Based on multiple lines of evidence, upper ocean stratification (*virtually certain*), ocean acidification (*virtually certain*) and ocean deoxygenation (*high confidence*) will continue to increase in the 21st century, at rates dependent on future emissions. Changes are irreversible on centennial to millennial time scales in global ocean temperature (*very high confidence*), deep-ocean acidification (*very high confidence*) and deoxygenation (*medium confidence*).
{4.3, 4.5, 4.7, 5.3, 9.2, TS.2.4} (Figure SPM.8)

B.5.2 Mountain and polar glaciers are committed to continue melting for decades or centuries (*very high confidence*). Loss of permafrost carbon following permafrost thaw is irreversible at centennial time scales (*high confidence*). Continued ice loss over the 21st century is *virtually certain* for the Greenland Ice Sheet and *likely* for the Antarctic Ice Sheet. There is *high confidence* that total ice loss from the Greenland Ice Sheet will increase with cumulative emissions. There is *limited evidence* for low-likelihood, high-impact outcomes (resulting from ice-sheet instability processes characterized by deep uncertainty and in some cases involving tipping points) that would strongly increase ice loss from the Antarctic Ice Sheet for centuries under high GHG emissions scenarios.[34]
{4.3, 4.7, 5.4, 9.4, 9.5, Box 9.4, Box TS.1, TS.2.5}

B.5.3 It is *virtually certain* that global mean sea level will continue to rise over the 21st century. Relative to 1995–2014, the *likely* global mean sea level rise by 2100 is 0.28–0.55 m under the very low GHG emissions scenario (SSP1-1.9); 0.32–0.62 m under the low GHG emissions scenario (SSP1-2.6); 0.44–0.76 m under the intermediate GHG emissions scenario (SSP2-4.5); and 0.63–1.01 m under the very high GHG emissions scenario (SSP5-8.5); and by 2150 is 0.37–0.86 m under the very low scenario (SSP1-1.9); 0.46–0.99 m under the low scenario (SSP1-2.6); 0.66–1.33 m under the intermediate scenario (SSP2-4.5); and 0.98–1.88 m under the very high scenario (SSP5-8.5) (*medium confidence*).[35] Global mean sea level rise above the *likely* range – approaching 2 m by 2100 and 5 m by 2150 under a very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be ruled out due to deep uncertainty in ice-sheet processes.
{4.3, 9.6, Box 9.4, Box TS.4} (Figure SPM.8)

B.5.4 In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep-ocean warming and ice-sheet melt and will remain elevated for thousands of years (*high confidence*). Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5°C, 2 to 6 m if limited to 2°C and 19 to 22 m with 5°C of warming, and it will continue to rise over subsequent millennia (*low confidence*). Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods: *likely* 5–10 m higher than today around 125,000 years ago, when global temperatures were *very likely* 0.5°C–1.5°C higher than 1850–1900; and *very likely* 5–25 m higher roughly 3 million years ago, when global temperatures were 2.5°C–4°C higher (*medium confidence*).
{2.3, Cross-Chapter Box 2.4, 9.6, Box TS.2, Box TS.4, Box TS.9}

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33 The other sectoral emissions are calculated as the residual of the net land and ocean CO_2 uptake and the prescribed atmospheric CO_2 concentration changes in the CMIP6 simulations. These calculated emissions are net emissions and do not separate gross anthropogenic emissions from removals, which are included implicitly.

34 Low-likelihood, high-impact outcomes are those whose probability of occurrence is low or not well known (as in the context of deep uncertainty) but whose potential impacts on society and ecosystems could be high. A tipping point is a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly. (Glossary) {1.4, Cross-Chapter Box 1.3, 4.7}

35 To compare to the 1986–2005 baseline period used in AR5 and SROCC, add 0.03 m to the global mean sea level rise estimates. To compare to the 1900 baseline period used in Figure SPM.8, add 0.16 m.

SPM

Human activities affect all the major climate system components, with some responding over decades and others over centuries

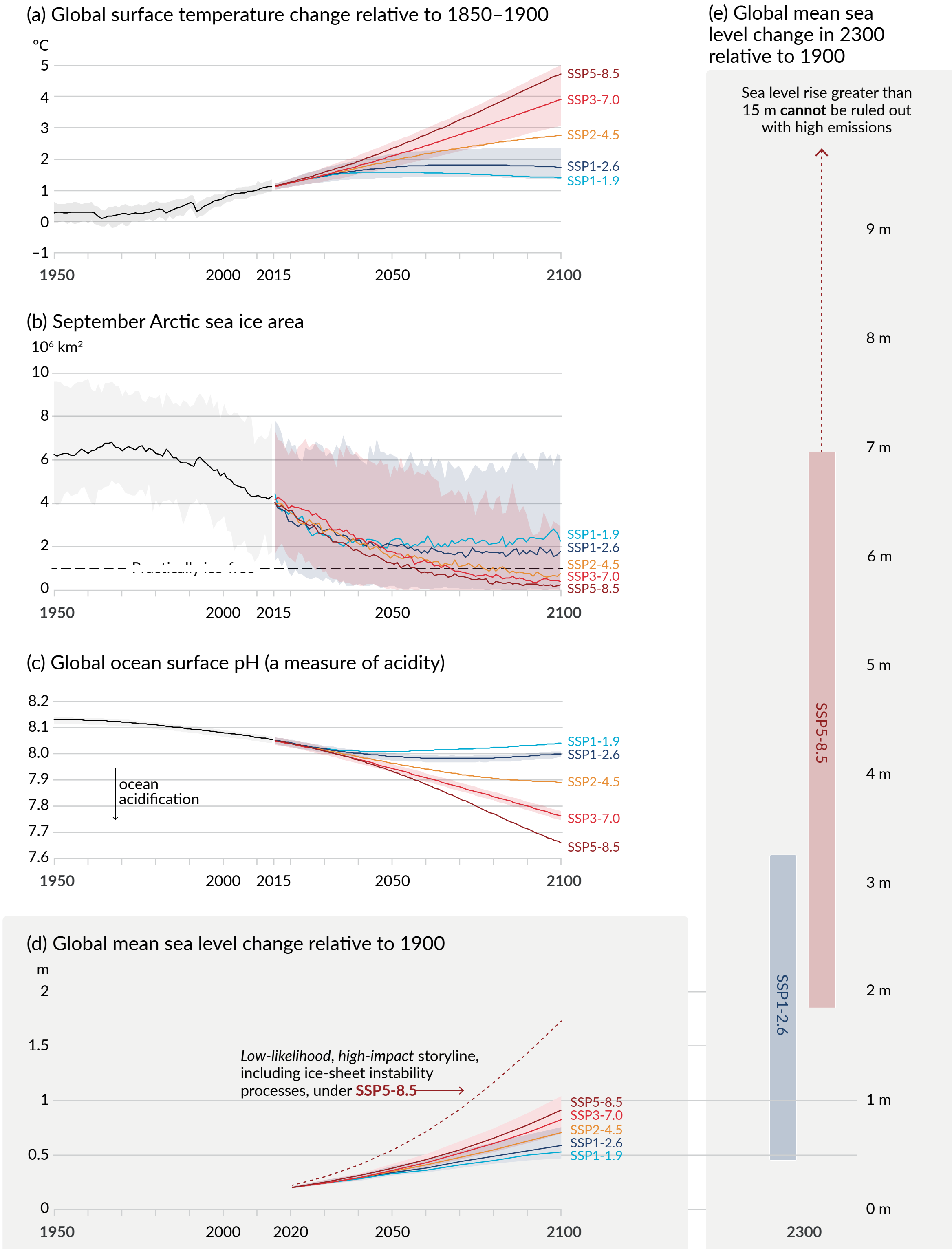

Figure SPM.8 | Selected indicators of global climate change under the five illustrative scenarios used in this Report

The projections for each of the five scenarios are shown in colour. Shades represent uncertainty ranges – more detail is provided for each panel below. The black curves represent the historical simulations (panels a, b, c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes.

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Panel (a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining Coupled Model Intercomparison Project Phase 6 (CMIP6) model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity (see Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel (b) September Arctic sea ice area in 10^6 km^2 based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. The Arctic is projected to be practically ice-free near mid-century under intermediate and high GHG emissions scenarios.

Panel (c) Global ocean surface pH (a measure of acidity) based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel (d) Global mean sea level change in metres, relative to 1900. The historical changes are observed (from tide gauges before 1992 and altimeters afterwards), and the future changes are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models. *Likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Only *likely* ranges are assessed for sea level changes due to difficulties in estimating the distribution of deeply uncertain processes. The dashed curve indicates the potential impact of these deeply uncertain processes. It shows the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out; because of *low confidence* in projections of these processes, this curve does not constitute part of a *likely* range. Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated and observed changes relative to 1995–2014.

Panel (e) Global mean sea level change at 2300 in metres relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out.

Panels (b) and (c) are based on single simulations from each model, and so include a component of internal variability. Panels (a), (d) and (e) are based on long-term averages, and hence the contributions from internal variability are small.

{4.3; Figures 4.2, 4.8, and 4.11; 9.6; Figure 9.27; Figures TS.8 and TS.11; Box TS.4, Figure 1}

C. Climate Information for Risk Assessment and Regional Adaptation

Physical climate information addresses how the climate system responds to the interplay between human influence, natural drivers and internal variability. Knowledge of the climate response and the range of possible outcomes, including low-likelihood, high impact outcomes, informs climate services, the assessment of climate-related risks, and adaptation planning. Physical climate information at global, regional and local scales is developed from multiple lines of evidence, including observational products, climate model outputs and tailored diagnostics.

C.1 Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.
{1.4, 2.2, 3.3, Cross-Chapter Box 3.1, 4.4, 4.6, Cross-Chapter Box 4.1, Box 7.2, 8.3, 8.5, 9.2, 10.3, 10.4, 10.6, 11.3, 12.5, Atlas.4, Atlas.5, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Chapter Box Atlas.2}

C.1.1 The historical global surface temperature record highlights that decadal variability has both enhanced and masked underlying human-caused long-term changes, and this variability will continue into the future (*very high confidence*). For example, internal decadal variability and variations in solar and volcanic drivers partially masked human-caused surface global warming during 1998–2012, with pronounced regional and seasonal signatures (*high confidence*). Nonetheless, the heating of the climate system continued during this period, as reflected in both the continued warming of the global ocean (*very high confidence*) and in the continued rise of hot extremes over land (*medium confidence*).
{1.4, 3.3, Cross-Chapter Box 3.1, 4.4, Box 7.2, 9.2, 11.3, Cross-Section Box TS.1} (Figure SPM.1)

C.1.2 Projected human-caused changes in mean climate and climatic impact-drivers (CIDs),[36] including extremes, will be either amplified or attenuated by internal variability (*high confidence*).[37] Near-term cooling at any particular location with respect to present climate could occur and would be consistent with the global surface temperature increase due to human influence (*high confidence*).
{1.4, 4.4, 4.6, 10.4, 11.3, 12.5, Atlas.5, Atlas.10, Atlas.11, TS.4.2}

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36 Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions (Glossary). CID types include heat and cold, wet and dry, wind, snow and ice, coastal and open ocean.

37 The main internal variability phenomena include El Niño–Southern Oscillation, Pacific Decadal Variability and Atlantic Multi-decadal Variability through their regional influence.

C.1.3 Internal variability has largely been responsible for the amplification and attenuation of the observed human-caused decadal-to-multi-decadal mean precipitation changes in many land regions (*high confidence*). At global and regional scales, near-term changes in monsoons will be dominated by the effects of internal variability (*medium confidence*). In addition to the influence of internal variability, near-term projected changes in precipitation at global and regional scales are uncertain because of model uncertainty and uncertainty in forcings from natural and anthropogenic aerosols (*medium confidence*).
{1.4, 4.4, 8.3, 8.5, 10.3, 10.4, 10.5, 10.6, Atlas.4, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Chapter Box Atlas.2, TS.4.2, Box TS.6, Box TS.13}

C.1.4 Based on paleoclimate and historical evidence, it is *likely* that at least one large explosive volcanic eruption would occur during the 21st century.[38] Such an eruption would reduce global surface temperature and precipitation, especially over land, for one to three years, alter the global monsoon circulation, modify extreme precipitation and change many CIDs (*medium confidence*). If such an eruption occurs, this would therefore temporarily and partially mask human-caused climate change.
{2.2, 4.4, Cross-Chapter Box 4.1, 8.5, TS.2.1}

C.2 With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels.
{8.2, 9.3, 9.5, 9.6, Box 10.3, 11.3, 11.4, 11.5, 11.6, 11.7, 11.9, Box 11.3, Box 11.4, Cross-Chapter Box 11.1, 12.2, 12.3, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11} (Table SPM.1, Figure SPM.9)

C.2.1 All regions[39] are projected to experience further increases in hot climatic impact-drivers (CIDs) and decreases in cold CIDs (*high confidence*). Further decreases are projected in permafrost; snow, glaciers and ice sheets; and lake and Arctic sea ice (*medium* to *high confidence*).[40] These changes would be larger at 2°C global warming or above than at 1.5°C (*high confidence*). For example, extreme heat thresholds relevant to agriculture and health are projected to be exceeded more frequently at higher global warming levels (*high confidence*).
{9.3, 9.5, 11.3, 11.9, Cross-Chapter Box 11.1, 12.3, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3} (Table SPM.1, Figure SPM.9)

C.2.2 At 1.5°C global warming, heavy precipitation and associated flooding are projected to intensify and be more frequent in most regions in Africa and Asia (*high confidence*), North America (*medium* to *high confidence*)[40] and Europe (*medium confidence*). Also, more frequent and/or severe agricultural and ecological droughts are projected in a few regions in all inhabited continents except Asia compared to 1850–1900 (*medium confidence*); increases in meteorological droughts are also projected in a few regions (*medium confidence*). A small number of regions are projected to experience increases or decreases in mean precipitation (*medium confidence*).
{11.4, 11.5, 11.6, 11.9, Atlas.4, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3} (Table SPM.1)

C.2.3 At 2°C global warming and above, the level of confidence in and the magnitude of the change in droughts and heavy and mean precipitation increase compared to those at 1.5°C. Heavy precipitation and associated flooding events are projected to become more intense and frequent in the Pacific Islands and across many regions of North America and Europe (*medium* to *high confidence*).[40] These changes are also seen in some regions in Australasia and Central and South America (*medium confidence*). Several regions in Africa, South America and Europe are projected to experience an increase in frequency and/or severity of agricultural and ecological droughts with *medium* to *high confidence*;[40] increases are also projected in Australasia, Central and North America, and the Caribbean with *medium confidence*. A small number of regions in Africa, Australasia, Europe and North America are also projected to be affected by increases in hydrological droughts, and several regions are projected to be affected by increases or decreases in meteorological droughts, with more regions displaying an increase (*medium confidence*). Mean precipitation is projected to increase in all polar, northern European and northern North American regions, most Asian regions and two regions of South America (*high confidence*).
{11.4, 11.6, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.11, TS.4.3} (Table SPM.1, Figure SPM.5, Figure SPM.6, Figure SPM.9)

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38 Based on 2500 year reconstructions, eruptions more negative than -1 W m^{-2} occur on average twice per century.

39 Regions here refer to the AR6 WGI reference regions used in this Report to summarize information in sub-continental and oceanic regions. Changes are compared to averages over the last 20–40 years unless otherwise specified. {1.4, 12.4, Atlas.1}.

40 The specific level of confidence or likelihood depends on the region considered. Details can be found in the Technical Summary and the underlying Report.

C.2.4 More CIDs across more regions are projected to change at 2°C and above compared to 1.5°C global warming (*high confidence*). Region-specific changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), increases in river floods (*medium* to *high confidence*),[40] reductions in mean precipitation and increases in aridity (*medium* to *high confidence*),[40] and increases in fire weather (*medium* to *high confidence*).[40] There is *low confidence* in most regions in potential future changes in other CIDs, such as hail, ice storms, severe storms, dust storms, heavy snowfall and landslides.
{11.7, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.6, Atlas.7, Atlas.8, Atlas.10, TS.4.3.1, TS.4.3.2, TS.5} (Table SPM.1, Figure SPM.9)

C.2.5 It is *very likely* to *virtually certain*[40] that regional mean relative sea level rise will continue throughout the 21st century, except in a few regions with substantial geologic land uplift rates. Approximately two-thirds of the global coastline has a projected regional relative sea level rise within ±20% of the global mean increase (*medium confidence*). Due to relative sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by 2100 (*high confidence*). Relative sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts (*high confidence*).
{9.6, 12.4, 12.5, Cross-Chapter Box 12.1, Box TS.4, TS.4.3} (Figure SPM.9)

C.2.6 Cities intensify human-induced warming locally, and further urbanization together with more frequent hot extremes will increase the severity of heatwaves (*very high confidence*). Urbanization also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*). In coastal cities, the combination of more frequent extreme sea level events (due to sea level rise and storm surge) and extreme rainfall/riverflow events will make flooding more probable (*high confidence*).
{8.2, Box 10.3, 11.3, 12.4, Box TS.14}

C.2.7 Many regions are projected to experience an increase in the probability of compound events with higher global warming (*high confidence*). In particular, concurrent heatwaves and droughts are *likely* to become more frequent. Concurrent extremes at multiple locations, including in crop-producing areas, become more frequent at 2°C and above compared to 1.5°C global warming (*high confidence*).
{11.8, Box 11.3, Box 11.4, 12.3, 12.4, Cross-Chapter Box 12.1, TS.4.3} (Table SPM.1)

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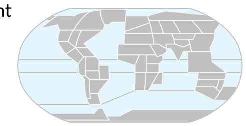
SPM

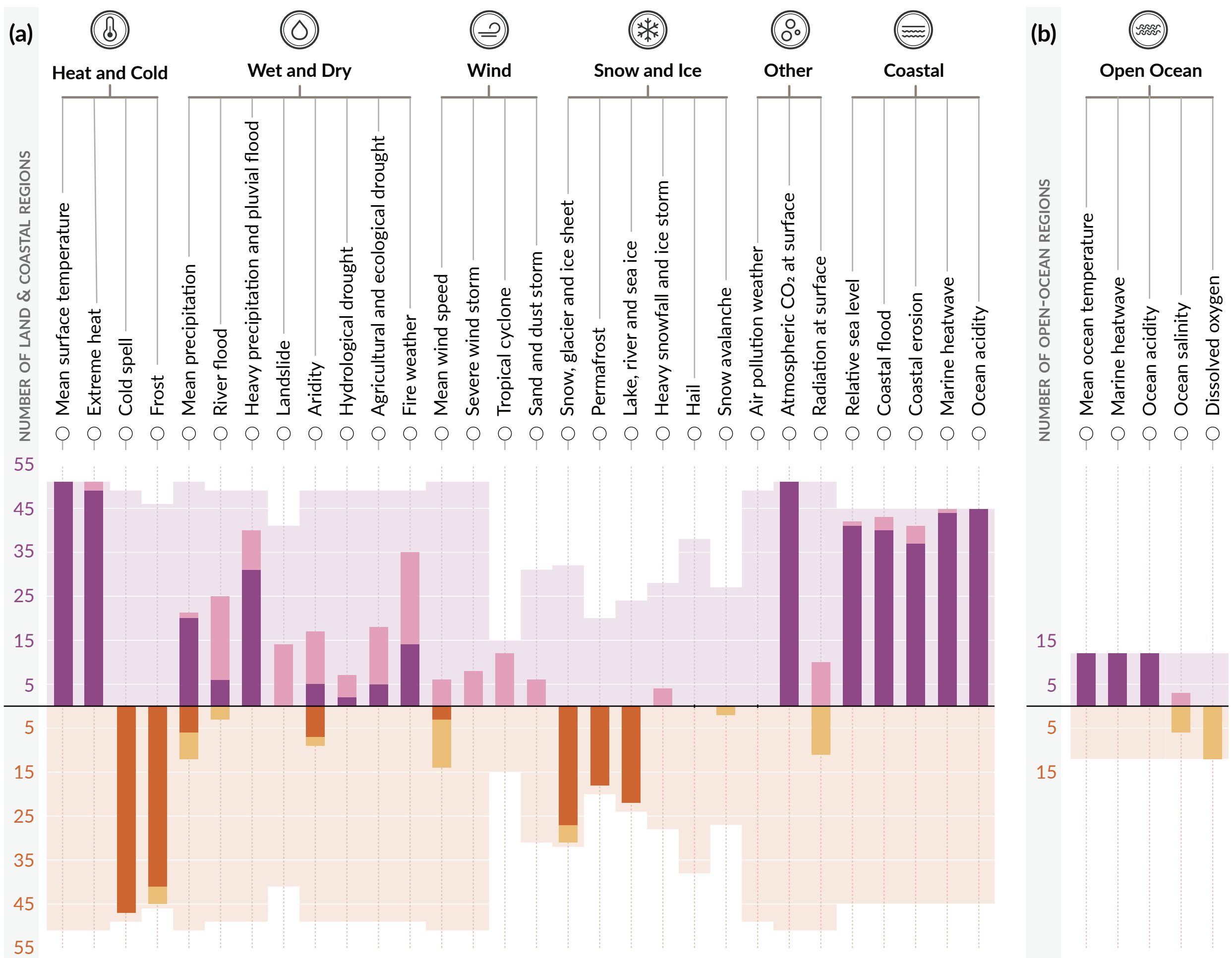
Multiple climatic impact-drivers are projected to change in all regions of the world

Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions. The CIDs are grouped into seven types, which are summarized under the icons in the figure. All regions are projected to experience changes in at least 5 CIDs. Almost all (96%) are projected to experience changes in at least 10 CIDs and half in at least 15 CIDs. For many CID changes, there is wide geographical variation, and so each region is projected to experience a specific set of CID changes. Each bar in the chart represents a specific geographical set of changes that can be explored in the WGI Interactive Atlas.



interactive-atlas.ipcc.ch

Number of land & coastal regions (a) and **open-ocean regions** (b) where each **climatic impact-driver** (CID) is projected to **increase** or **decrease** with ***high** confidence* (dark shade) or ***medium** confidence* (light shade)



BAR CHART LEGEND

- Regions with ***high** confidence* **increase**
- Regions with ***medium** confidence* **increase**
- Regions with ***high** confidence* **decrease**
- Regions with ***medium** confidence* **decrease**

LIGHTER-SHADED 'ENVELOPE' LEGEND

The height of the lighter shaded 'envelope' behind each bar represents the maximum number of regions for which each CID is relevant. The envelope is symmetrical about the x-axis showing the maximum possible number of relevant regions for CID increase (upper part) or decrease (lower part).

ASSESSED FUTURE CHANGES

Changes refer to a 20–30 year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960–2014 or 1850–1900.

Figure SPM.9 | Synthesis of the number of AR6 WGI reference regions where climatic impact-drivers are projected to change

A total of 35 climatic impact-drivers (CIDs) grouped into seven types are shown: heat and cold; wet and dry; wind; snow and ice; coastal; open ocean; and other. For each CID, the bar in the graph below displays the number of AR6 WGI reference regions where it is projected to change. The **colours** represent the direction of change and the level of confidence in the change: purple indicates an increase while brown indicates a decrease; darker and lighter shades refer to *high* and *medium confidence*, respectively. Lighter background colours represent the maximum number of regions for which each CID is broadly relevant.

Panel (a) shows the 30 CIDs relevant to the **land and coastal regions**, while **panel (b)** shows the five CIDs relevant to the **open-ocean regions**. Marine heatwaves and ocean acidity are assessed for coastal ocean regions in panel (a) and for open-ocean regions in panel (b). Changes refer to a 20–30-year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960–2014, except for hydrological drought and agricultural and ecological drought, which is compared to 1850–1900. Definitions of the regions are provided in Sections 12.4 and Atlas.1 and the Interactive Atlas (see https://interactive-atlas.ipcc.ch/).

{11.9, 12.2, 12.4, Atlas.1, Table TS.5, Figures TS.22 and TS.25} (Table SPM.1)

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C.3 Low-likelihood outcomes, such as ice-sheet collapse, abrupt ocean circulation changes, some compound extreme events, and warming substantially larger than the assessed *very likely* range of future warming, cannot be ruled out and are part of risk assessment.
{1.4, Cross-Chapter Box 1.3, 4.3, 4.4, 4.8, Cross-Chapter Box 4.1, 8.6, 9.2, Box 9.4, 11.8, Box 11.2, Cross-Chapter Box 12.1} (Table SPM.1)

C.3.1 If global warming exceeds the assessed *very likely* range for a given GHG emissions scenario, including low GHG emissions scenarios, global and regional changes in many aspects of the climate system, such as regional precipitation and other CIDs, would also exceed their assessed *very likely* ranges (*high confidence*). Such low-likelihood, high-warming outcomes are associated with potentially very large impacts, such as through more intense and more frequent heatwaves and heavy precipitation, and high risks for human and ecological systems, particularly for high GHG emissions scenarios.
{Cross-Chapter Box 1.3, 4.3, 4.4, 4.8, Box 9.4, Box 11.2, Cross-Chapter Box 12.1, TS.1.4, Box TS.3, Box TS.4} (Table SPM.1)

C.3.2 Low-likelihood, high-impact outcomes[34] could occur at global and regional scales even for global warming within the *very likely* range for a given GHG emissions scenario. The probability of low-likelihood, high-impact outcomes increases with higher global warming levels (*high confidence*). Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice-sheet melt and forest dieback, cannot be ruled out (*high confidence*).
{1.4, 4.3, 4.4, 4.8, 5.4, 8.6, Box 9.4, Cross-Chapter Box 12.1, TS.1.4, TS.2.5, Box TS.3, Box TS.4, Box TS.9} (Table SPM.1)

C.3.3 If global warming increases, some compound extreme events[18] with low likelihood in past and current climate will become more frequent, and there will be a higher likelihood that events with increased intensities, durations and/or spatial extents unprecedented in the observational record will occur (*high confidence*).
{11.8, Box 11.2, Cross-Chapter Box 12.1, Box TS.3, Box TS.9}

C.3.4 The Atlantic Meridional Overturning Circulation is *very likely* to weaken over the 21st century for all emissions scenarios. While there is *high confidence* in the 21st century decline, there is only *low confidence* in the magnitude of the trend. There is *medium confidence* that there will not be an abrupt collapse before 2100. If such a collapse were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle, such as a southward shift in the tropical rain belt, weakening of the African and Asian monsoons and strengthening of Southern Hemisphere monsoons, and drying in Europe.
{4.3, 8.6, 9.2, TS2.4, Box TS.3}

C.3.5 Unpredictable and rare natural events not related to human influence on climate may lead to low-likelihood, high-impact outcomes. For example, a sequence of large explosive volcanic eruptions within decades has occurred in the past, causing substantial global and regional climate perturbations over several decades. Such events cannot be ruled out in the future, but due to their inherent unpredictability they are not included in the illustrative set of scenarios referred to in this Report
{2.2, Cross-Chapter Box 4.1, Box TS.3} (Box SPM.1)

D. Limiting Future Climate Change

Since AR5, estimates of remaining carbon budgets have been improved by a new methodology first presented in SR1.5, updated evidence, and the integration of results from multiple lines of evidence. A comprehensive range of possible future air pollution controls in scenarios is used to consistently assess the effects of various assumptions on projections of climate and air pollution. A novel development is the ability to ascertain when climate responses to emissions reductions would become discernible above natural climate variability, including internal variability and responses to natural drivers.

D.1 From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in CH_4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.
{3.3, 4.6, 5.1, 5.2, 5.4, 5.5, 5.6, Box 5.2, Cross-Chapter Box 5.1, 6.7, 7.6, 9.6} (Figure SPM.10, Table SPM.2)

D.1.1 This Report reaffirms with *high confidence* the AR5 finding that there is a near-linear relationship between cumulative anthropogenic CO_2 emissions and the global warming they cause. Each 1000 $GtCO_2$ of cumulative CO_2 emissions is assessed to *likely* cause a 0.27°C to 0.63°C increase in global surface temperature with a best estimate of 0.45°C.[41] This is a narrower range compared to AR5 and SR1.5. This quantity is referred to as the transient climate response to cumulative CO_2 emissions (TCRE). This relationship implies that reaching net zero anthropogenic CO_2 emissions[42] is a requirement to stabilize human-induced global temperature increase at any level, but that limiting global temperature increase to a specific level would imply limiting cumulative CO_2 emissions to within a carbon budget.[43] {5.4, 5.5, TS.1.3, TS.3.3, Box TS.5} (Figure SPM.10)

Every tonne of CO_2 emissions adds to global warming

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)

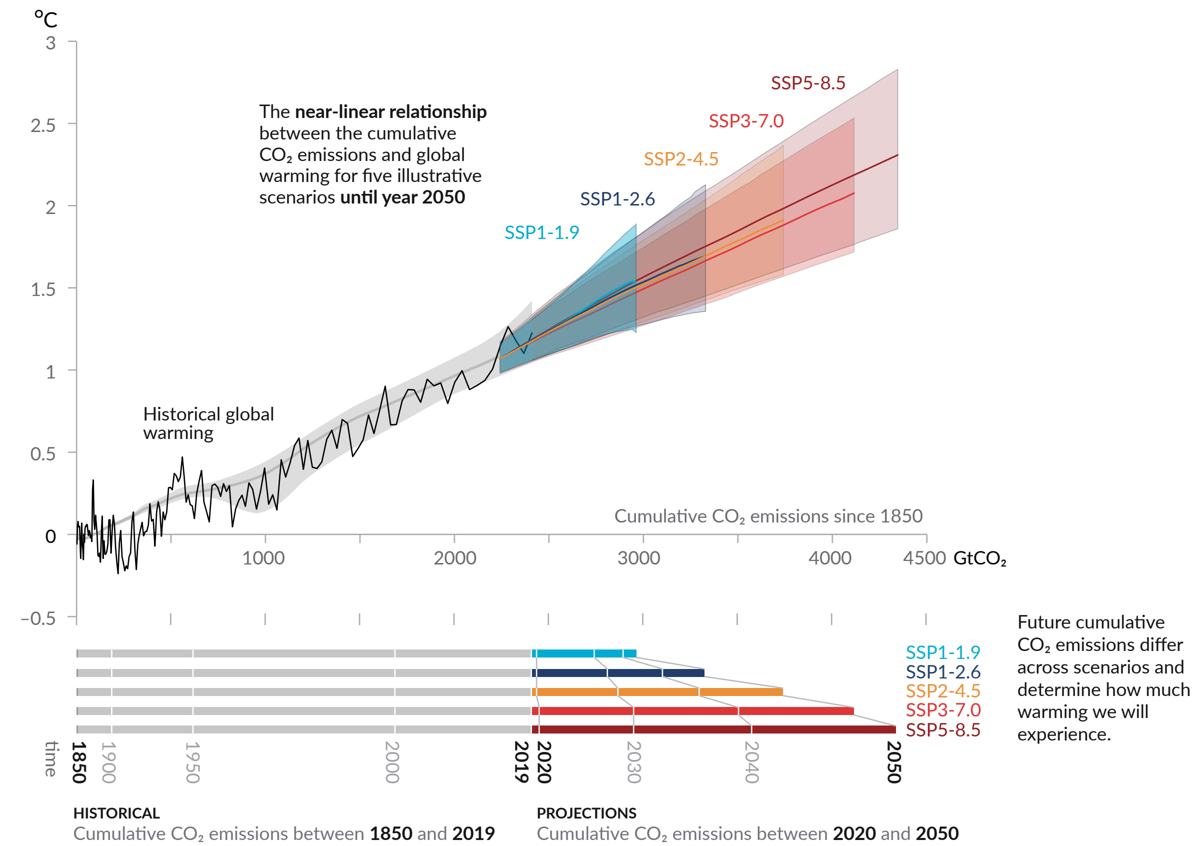

Figure SPM.10 | Near-linear relationship between cumulative CO_2 emissions and the increase in global surface temperature

Top panel: Historical data (thin black line) shows observed global surface temperature increase in °C since 1850–1900 as a function of historical cumulative carbon dioxide (CO_2) emissions in $GtCO_2$ from 1850 to 2019. The grey range with its central line shows a corresponding estimate of the historical human-caused surface warming (see Figure SPM.2). Coloured areas show the assessed *very likely* range of global surface temperature projections, and thick coloured central lines show the median estimate as a function of cumulative CO_2 emissions from 2020 until year 2050 for the set of illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5; see Figure SPM.4). Projections use the cumulative CO_2 emissions of each respective scenario, and the projected global warming includes the contribution from all anthropogenic forcers. The relationship is illustrated over the domain of cumulative CO_2 emissions for which there is *high confidence* that the transient climate response to cumulative CO_2 emissions (TCRE) remains constant, and for the time period from 1850 to 2050 over which global CO_2 emissions remain net positive under all illustrative scenarios, as there is *limited evidence* supporting the quantitative application of TCRE to estimate temperature evolution under net negative CO_2 emissions.

Bottom panel: Historical and projected cumulative CO_2 emissions in $GtCO_2$ for the respective scenarios.

{Section 5.5, Figure 5.31, Figure TS.18}

41 In the literature, units of °C per 1000 PgC (petagrams of carbon) are used, and the AR6 reports the TCRE ***likely*** range as 1.0°C to 2.3°C per 1000 PgC in the underlying report, with a best estimate of 1.65°C.

42 The condition in which anthropogenic carbon dioxide (CO_2) emissions are balanced by anthropogenic CO_2 removals over a specified period (Glossary).

43 The term 'carbon budget' refers to the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcers. This is referred to as the total carbon budget when expressed starting from the pre-industrial period, and as the remaining carbon budget when expressed from a recent specified date (Glossary). Historical cumulative CO_2 emissions determine to a large degree warming to date, while future emissions cause future additional warming. The remaining carbon budget indicates how much CO_2 could still be emitted while keeping warming below a specific temperature level.

D.1.2 Over the period 1850–2019, a total of 2390 ± 240 (*likely* range) $GtCO_2$ of anthropogenic CO_2 was emitted. Remaining carbon budgets have been estimated for several global temperature limits and various levels of probability, based on the estimated value of TCRE and its uncertainty, estimates of historical warming, variations in projected warming from non-CO_2 emissions, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic CO_2 emissions reach net zero.
{5.1, 5.5, Box 5.2, TS.3.3} (Table SPM.2)

Table SPM.2 | Estimates of historical carbon dioxide (CO_2) emissions and remaining carbon budgets. Estimated remaining carbon budgets are calculated from the beginning of 2020 and extend until global net zero CO_2 emissions are reached. They refer to CO_2 emissions, while accounting for the global warming effect of non-CO_2 emissions. Global warming in this table refers to human-induced global surface temperature increase, which excludes the impact of natural variability on global temperatures in individual years.
{Table 3.1, 5.5.1, 5.5.2, Box 5.2, Table 5.1, Table 5.7, Table 5.8, Table TS.3}

Global Warming Between 1850–1900 and 2010–2019 (°C)		Historical Cumulative CO_2 Emissions from 1850 to 2019 ($GtCO_2$)					
1.07 (0.8–1.3; likely range)		2390 (± 240; likely range)					
Approximate global warming relative to 1850–1900 until temperature limit (°C)[a]	Additional global warming relative to 2010–2019 until temperature limit (°C)	Estimated remaining carbon budgets from the beginning of 2020 ($GtCO_2$) *Likelihood of limiting global warming to temperature limit*[b]					Variations in reductions in non-CO_2 emissions[c]
		17%	*33%*	*50%*	*67%*	*83%*	
1.5	0.43	900	650	500	400	300	Higher or lower reductions in accompanying non-CO_2 emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more
1.7	0.63	1450	1050	850	700	550	
2.0	0.93	2300	1700	1350	1150	900	

[a] Values at each 0.1°C increment of warming are available in Tables TS.3 and 5.8.

[b] This likelihood is based on the uncertainty in transient climate response to cumulative CO_2 emissions (TCRE) and additional Earth system feedbacks and provides the probability that global warming will not exceed the temperature levels provided in the two left columns. Uncertainties related to historical warming (±550 $GtCO_2$) and non-CO_2 forcing and response (±220 $GtCO_2$) are partially addressed by the assessed uncertainty in TCRE, but uncertainties in recent emissions since 2015 (±20 $GtCO_2$) and the climate response after net zero CO_2 emissions are reached (±420 $GtCO_2$) are separate.

[c] Remaining carbon budget estimates consider the warming from non-CO_2 drivers as implied by the scenarios assessed in SR1.5. The Working Group III Contribution to AR6 will assess mitigation of non-CO_2 emissions.

D.1.3 Several factors that determine estimates of the remaining carbon budget have been re-assessed, and updates to these factors since SR1.5 are small. When adjusted for emissions since previous reports, estimates of remaining carbon budgets are therefore of similar magnitude compared to SR1.5 but larger compared to AR5 due to methodological improvements.[44]
{5.5, Box 5.2, TS.3.3} (Table SPM.2)

D.1.4 Anthropogenic CO_2 removal (CDR) has the potential to remove CO_2 from the atmosphere and durably store it in reservoirs (*high confidence*). CDR aims to compensate for residual emissions to reach net zero CO_2 or net zero GHG emissions or, if implemented at a scale where anthropogenic removals exceed anthropogenic emissions, to lower surface temperature. CDR methods can have potentially wide-ranging effects on biogeochemical cycles and climate, which can either weaken or strengthen the potential of these methods to remove CO_2 and reduce warming, and can also influence water availability and quality, food production and biodiversity[45] (*high confidence*).
{5.6, Cross-Chapter Box 5.1, TS.3.3}

D.1.5 Anthropogenic CO_2 removal (CDR) leading to global net negative emissions would lower the atmospheric CO_2 concentration and reverse surface ocean acidification (*high confidence*). Anthropogenic CO_2 removals and emissions are partially

44 Compared to AR5, and when taking into account emissions since AR5, estimates in AR6 are about 300–350 $GtCO_2$ larger for the remaining carbon budget consistent with limiting warming to 1.5°C; for 2°C, the difference is about 400–500 $GtCO_2$.

45 Potential negative and positive effects of CDR for biodiversity, water and food production are methods-specific and are often highly dependent on local context, management, prior land use, and scale. IPCC Working Groups II and III assess the CDR potential and ecological and socio-economic effects of CDR methods in their AR6 contributions.

compensated by CO_2 release and uptake respectively, from or to land and ocean carbon pools (*very high confidence*). CDR would lower atmospheric CO_2 by an amount approximately equal to the increase from an anthropogenic emission of the same magnitude (*high confidence*). The atmospheric CO_2 decrease from anthropogenic CO_2 removals could be up to 10% less than the atmospheric CO_2 increase from an equal amount of CO_2 emissions, depending on the total amount of CDR (*medium confidence*).
{5.3, 5.6, TS.3.3}

D.1.6 If global net negative CO_2 emissions were to be achieved and be sustained, the global CO_2-induced surface temperature increase would be gradually reversed but other climate changes would continue in their current direction for decades to millennia (*high confidence*). For instance, it would take several centuries to millennia for global mean sea level to reverse course even under large net negative CO_2 emissions (*high confidence*).
{4.6, 9.6, TS.3.3}

D.1.7 In the five illustrative scenarios, simultaneous changes in CH_4, aerosol and ozone precursor emissions, which also contribute to air pollution, lead to a net global surface warming in the near and long term (*high confidence*). In the long term, this net warming is lower in scenarios assuming air pollution controls combined with strong and sustained CH_4 emissions reductions (*high confidence*). In the low and very low GHG emissions scenarios, assumed reductions in anthropogenic aerosol emissions lead to a net warming, while reductions in CH_4 and other ozone precursor emissions lead to a net cooling. Because of the short lifetime of both CH_4 and aerosols, these climate effects partially counterbalance each other, and reductions in CH_4 emissions also contribute to improved air quality by reducing global surface ozone (*high confidence*).
{6.7, Box TS.7} (Figure SPM.2, Box SPM.1)

D.1.8 Achieving global net zero CO_2 emissions, with anthropogenic CO_2 emissions balanced by anthropogenic removals of CO_2, is a requirement for stabilizing CO_2-induced global surface temperature increase. This is different from achieving net zero GHG emissions, where metric-weighted anthropogenic GHG emissions equal metric-weighted anthropogenic GHG removals. For a given GHG emissions pathway, the pathways of individual GHGs determine the resulting climate response,[46] whereas the choice of emissions metric[47] used to calculate aggregated emissions and removals of different GHGs affects what point in time the aggregated GHGs are calculated to be net zero. Emissions pathways that reach and sustain net zero GHG emissions defined by the 100-year global warming potential are projected to result in a decline in surface temperature after an earlier peak (*high confidence*).
{4.6, 7.6, Box 7.3, TS.3.3}

D.2 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) lead within years to discernible effects on greenhouse gas and aerosol concentrations and air quality, relative to high and very high GHG emissions scenarios (SSP3-7.0 or SSP5-8.5). Under these contrasting scenarios, discernible differences in trends of global surface temperature would begin to emerge from natural variability within around 20 years, and over longer time periods for many other climatic impact-drivers (*high confidence*).
{4.6, 6.6, 6.7, Cross-Chapter Box 6.1, 9.6, 11.2, 11.4, 11.5, 11.6, Cross-Chapter Box 11.1, 12.4, 12.5} (Figure SPM.8, Figure SPM.10)

D.2.1 Emissions reductions in 2020 associated with measures to reduce the spread of COVID-19 led to temporary but detectable effects on air pollution (*high confidence*) and an associated small, temporary increase in total radiative forcing, primarily due to reductions in cooling caused by aerosols arising from human activities (*medium confidence*). Global and regional climate responses to this temporary forcing are, however, undetectable above natural variability (*high confidence*). Atmospheric CO_2 concentrations continued to rise in 2020, with no detectable decrease in the observed CO_2 growth rate (*medium confidence*).[48]
{Cross-Chapter Box 6.1, TS.3.3}

D.2.2 Reductions in GHG emissions also lead to air quality improvements. However, in the near term,[49] even in scenarios with strong reduction of GHGs, as in the low and very low GHG emissions scenarios (SSP1-2.6 and SSP1-1.9), these improvements

46 A general term for how the climate system responds to a radiative forcing (Glossary).

47 The choice of emissions metric depends on the purposes for which gases or forcing agents are being compared. This Report contains updated emissions metric values and assesses new approaches to aggregating gases.

48 For other GHGs, there was insufficient literature available at the time of the assessment to assess detectable changes in their atmospheric growth rate during 2020.

49 Near term: 2021–2040.

are not sufficient in many polluted regions to achieve air quality guidelines specified by the World Health Organization (*high confidence*). Scenarios with targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but from 2040, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions, with the magnitude of the benefit varying between regions (*high confidence*).
{6.6, 6.7, Box TS.7}.

D.2.3 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) would have rapid and sustained effects to limit human-caused climate change, compared with scenarios with high or very high GHG emissions (SSP3-7.0 or SSP5-8.5), but early responses of the climate system can be masked by natural variability. For global surface temperature, differences in 20-year trends would *likely* emerge during the near term under a very low GHG emissions scenario (SSP1-1.9), relative to a high or very high GHG emissions scenario (SSP3-7.0 or SSP5-8.5). The response of many other climate variables would emerge from natural variability at different times later in the 21st century (*high confidence*).
{4.6, Cross-Section Box TS.1} (Figure SPM.8, Figure SPM.10)

D.2.4 Scenarios with very low and low GHG emissions (SSP1-1.9 and SSP1-2.6) would lead to substantially smaller changes in a range of CIDs[36] beyond 2040 than under high and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5). By the end of the century, scenarios with very low and low GHG emissions would strongly limit the change of several CIDs, such as the increases in the frequency of extreme sea level events, heavy precipitation and pluvial flooding, and exceedance of dangerous heat thresholds, while limiting the number of regions where such exceedances occur, relative to higher GHG emissions scenarios (*high confidence*). Changes would also be smaller in very low compared to low GHG emissions scenarios, as well as for intermediate (SSP2-4.5) compared to high or very high GHG emissions scenarios (*high confidence*).
{9.6, 11.2, 11.3, 11.4, 11.5, 11.6, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, TS.4.3}

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INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2022

Mitigation of Climate Change

Summary for Policymakers

WGIII

Working Group III contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change

WMO UNEP

D2853

WORKING GROUP III CONTRIBUTION

TO THE IPCC SIXTH ASSESSMENT REPORT (AR6)

Summary for Policymakers

Drafting Authors:

Jim Skea (United Kingdom), Priyadarshi R Shukla (India), Andy Reisinger (New Zealand), Raphael Slade (United Kingdom), Minal Pathak (India), Alaa Al Khourdajie (United Kingdom/Syria), Renée van Diemen (the Netherlands/United Kingdom), Amjad Abdulla (Maldives), Keigo Akimoto (Japan), Mustafa Babiker (Sudan/Saudi Arabia), Quan Bai (China), Igor Bashmakov (Russian Federation), Christopher Bataille (Canada), Göran Berndes (Sweden), Gabriel Blanco (Argentina), Kornelis Blok (the Netherlands), Mercedes Bustamante (Brazil), Edward Byers (Austria), Luisa F. Cabeza (Spain), Katherine Calvin (the United States of America), Carlo Carraro (Italy), Leon Clarke (the United States of America), Annette Cowie (Australia), Felix Creutzig (Germany), Diriba Korecha Dadi (Ethiopia), Dipak Dasgupta (India), Heleen de Coninck (the Netherlands), Fatima Denton (the Gambia), Shobhakar Dhakal (Nepal/Thailand), Navroz K. Dubash (India), Oliver Geden (Germany), Michael Grubb (United Kingdom), Céline Guivarch (France), Shreekant Gupta (India), Andrea Hahmann (Chile), Kirsten Halsnaes (Denmark), Paulina Jaramillo (the United States of America), Kejun Jiang (China), Frank Jotzo (Australia), Tae Yong Jung (Republic of Korea), Suzana Kahn Ribeiro (Brazil), Smail Khennas (Algeria), Şiir Kılkış (Turkey), Silvia Kreibiehl (Germany), Volker Krey (Austria), Elmar Kriegler (Germany), William Lamb (Germany), Franck Lecocq (France), Shuaib Lwasa (Uganda), Nagmeldin Mahmoud (Sudan), Cheikh Mbow (Senegal), David McCollum (the United States of America), Jan Christoph Minx (Germany), Catherine Mitchell (United Kingdom), Rachid Mrabet (Morocco), Yacob Mulugetta (Ethiopia), Gert-Jan Nabuurs (the Netherlands), Gregory Nemet (the United States of America/Canada), Peter Newman (Australia), Leila Niamir (Germany/Iran), Lars J. Nilsson (Sweden), Sudarmanto Budi Nugroho (Indonesia), Chukwumerije Okereke (Nigeria/United Kingdom), Shonali Pachauri (India), Anthony Patt (Switzerland), Ramón Pichs-Madruga (Cuba), Joana Portugal Pereira (Brazil), Lavanya Rajamani (India), Keywan Riahi (Austria), Joyashree Roy (India/Thailand), Yamina Saheb (France/Algeria), Roberto Schaeffer (Brazil), Karen Seto (the United States of America), Shreya Some (India), Linda Steg (the Netherlands), Ferenc L. Toth (Hungary), Diana Ürge-Vorsatz (Hungary), Detlef van Vuuren (the Netherlands), Elena Verdolini (Italy), Purvi Vyas (India), Yi-Ming Wei (China), Mariama Williams (Jamaica/the United States of America), Harald Winkler (Republic of South Africa).

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A. Introduction and framing

The Working Group III (WG III) contribution to the IPCC's Sixth Assessment Report (AR6) assesses literature on the scientific, technological, environmental, economic and social aspects of mitigation of climate change. [FOOTNOTE 1] Levels of confidence [FOOTNOTE 2] are given in () brackets. Numerical ranges are presented in square [] brackets. References to Chapters, Sections, Figures and Boxes in the underlying report and Technical Summary (TS) are given in {} brackets.

FOOTNOTE 1: The Report covers literature accepted for publication by 11 October 2021.

FOOTNOTE 2: Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers, typeset in italics: *very low*, *low*, *medium*, *high* and *very high*. The assessed likelihood of an outcome or a result is described as: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, more likely than not 50–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms may also be used when appropriate, consistent with the IPCC uncertainty guidance: https://www.ipcc.ch/site/assets/uploads/2018/05/uncertainty-guidance-note.pdf.

The report reflects new findings in the relevant literature and builds on previous IPCC reports, including the WG III contribution to the IPCC's Fifth Assessment Report (AR5), the WG I and WG II contributions to AR6 and the three Special Reports in the Sixth Assessment cycle, [FOOTNOTE 3] as well as other UN assessments. Some of the main developments relevant for this report include {TS.1, TS.2}:

FOOTNOTE 3: The three Special Reports are: Global Warming of 1.5°C: an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (2018); Climate Change and Land: an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (2019); IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019).

- **An evolving international landscape.** The literature reflects, among other factors: developments in the UN Framework Convention on Climate Change (UNFCCC) process, including the outcomes of the Kyoto Protocol and the adoption of the Paris Agreement {13, 14, 15, 16}; the UN 2030 Agenda for Sustainable Development including the Sustainable Development Goals (SDGs) {1, 3, 4, 17}; and the evolving roles of international cooperation {14}, finance {15} and innovation {16}.

- **Increasing diversity of actors and approaches to mitigation.** Recent literature highlights the growing role of non-state and sub-national actors including cities, businesses, Indigenous Peoples, citizens including local communities and youth, transnational initiatives, and public-private entities in the global effort to address climate change {5, 13, 14, 15, 16, 17}. Literature documents the global spread of climate policies and cost declines of existing and emerging low emission technologies, along with varied types and levels of mitigation efforts, and sustained reductions in greenhouse gas (GHG) emissions in some countries {2, 5, 6, 8, 12, 13, 16}, and the impacts of, and some lessons from, the COVID-19 pandemic. {1, 2, 3, 5, 13, 15, Box TS.1, Cross-Chapter Box 1 in Chapter 1}

- **Close linkages between climate change mitigation, adaptation and development pathways**. The development pathways taken by countries at all stages of economic development impact GHG emissions and hence shape mitigation challenges and opportunities, which vary across countries and regions. Literature explores how development choices and the establishment of enabling conditions for action and support influence the feasibility and the cost of limiting emissions {1, 3, 4, 5, 13, 15, 16}. Literature highlights that climate change mitigation action designed and conducted in the context of sustainable development, equity, and poverty eradication, and rooted in the development aspirations of the societies within which they take place, will be more acceptable, durable and effective {1, 3, 4, 5}. This report covers mitigation from both targeted measures, and from policies and governance with other primary objectives.

- **New approaches in the assessment**. In addition to the sectoral and systems chapters {3, 6, 7, 8, 9, 10, 11, 12}, the report includes, for the first time in a WG III report, chapters dedicated to demand for services, and social aspects of mitigation {5, Box TS.11}, and to innovation, technology development and transfer {16}. The assessment of future pathways in this report covers near term (to 2030), medium term (up to 2050), and long term (to 2100) timescales, combining assessment of existing pledges and actions {4, 5}, with an assessment of emissions reductions, and their implications, associated with long-term temperature outcomes up to the year 2100 {3}.[FOOTNOTE 4] The assessment of modelled global pathways addresses ways of shifting development pathways towards sustainability. Strengthened collaboration between IPCC Working Groups is reflected in Cross-Working Group boxes that integrate physical science, climate risks and adaptation, and the mitigation of climate change. [FOOTNOTE 5]

  FOOTNOTE 4: The term 'temperature' is used in reference to "global surface temperatures" throughout this SPM as defined in footnote 8 of WG I SPM. See FOOTNOTE 14 of Table SPM.1. Emission pathways and associated temperature changes are calculated using various forms of models, as summarised in Box SPM.1 and Chapter 3 and discussed in Annex III.

  FOOTNOTE 5: Namely: Economic Benefits from Avoided Climate Impacts along Long-Term Mitigation Pathways {Cross-Working Group Box 1 in Chapter 3}; Urban: Cities and Climate Change {Cross-Working Group Box 2 in Chapter 8}; and Mitigation and Adaptation via the Bioeconomy {Cross-Working Group Box 3 in Chapter 12}.

- **Increasing diversity of analytic frameworks from multiple disciplines including social sciences.** This report identifies multiple analytic frameworks to assess the drivers of, barriers to and options for, mitigation action. These include: economic efficiency including the benefits of avoided impacts; ethics and equity; interlinked technological and social transition processes; and socio-political frameworks, including institutions and governance {1, 3, 13, Cross-Chapter Box 12 in Chapter 16}. These help to identify risks and opportunities for action including co-benefits and just and equitable transitions at local, national and global scales. {1, 3, 4, 5, 13, 14, 16, 17}

Section B of this Summary for Policymakers (SPM) assesses *Recent developments and current trends*, including data uncertainties and gaps. Section C, *System transformations to limit global warming*, identifies emission pathways and alternative mitigation portfolios consistent with limiting global warming to different levels, and assesses specific mitigation options at the sectoral and system level. Section D addresses *Linkages between mitigation, adaptation, and sustainable development*. Section E, *Strengthening the response,* assesses knowledge of how enabling conditions of institutional design, policy, finance, innovation and governance arrangements can contribute to climate change mitigation in the context of sustainable development.

B. Recent developments and current trends

B.1 Total net anthropogenic GHG emissions [FOOTNOTE 6] have continued to rise during the period 2010–2019, as have cumulative net CO_2 emissions since 1850. Average annual GHG emissions during 2010-2019 were higher than in any previous decade, but the rate of growth between 2010 and 2019 was lower than that between 2000 and 2009. *(high confidence)* (Figure SPM.1) {Figure 2.2, Figure 2.5, Table 2.1, 2.2, Figure TS.2}

FOOTNOTE 6: Net GHG emissions in this report refer to releases of greenhouse gases from anthropogenic sources minus removals by anthropogenic sinks, for those species of gases that are reported under the common reporting format of the United Nations Framework Convention on Climate Change (UNFCCC): CO_2 from fossil fuel combustion and industrial processes (CO_2-FFI); net CO_2 emissions from land use, land use change and forestry (CO_2-LULUCF); methane (CH_4); nitrous oxide (N_2O); and fluorinated gases (F-gases) comprising hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6) as well as nitrogen trifluoride (NF3). Different datasets for GHG emissions exist, with varying time horizons and coverage of sectors and gases, including some that go back to 1850. In this report, GHG emissions are assessed from 1990, and CO_2 sometimes also from 1850. Reasons for this include data availability and robustness, scope of the assessed literature, and the differing warming impacts of non-CO_2 gases over time.

B.1.1 Global net anthropogenic GHG emissions were 59±6.6 $GtCO_2$-eq [FOOTNOTE 7, 8] in 2019, about 12% (6.5 $GtCO_2$-eq) higher than in 2010 and 54% (21 $GtCO_2$-eq) higher than in 1990. The annual average during the decade 2010–2019 was 56±6.0 $GtCO_2$-eq, 9.1 $GtCO_2$-eq yr^{-1} higher than in 2000-2009. This is the highest increase in average decadal emissions on record. The average annual rate of growth slowed from 2.1% yr^{-1} between 2000 and 2009 to 1.3% yr^{-1} between 2010 and 2019. (*high confidence*) (Figure SPM.1) {Figure 2.2, Figure 2.5, Table 2.1, 2.2, Figure TS.2}

FOOTNOTE 7: GHG emission metrics are used to express emissions of different greenhouse gases in a common unit. Aggregated GHG emissions in this report are stated in CO_2-equivalent (CO_2-eq) using the Global Warming Potential with a time horizon of 100 years (GWP100) with values based on the contribution of Working Group I to the AR6. The choice of metric depends on the purpose of the analysis and all GHG emission metrics have limitations and uncertainties, given that they simplify the complexity of the physical climate system and its response to past and future GHG emissions. {Chapter 2 SM 2.3, Cross-Chapter Box 2 in Chapter 2, Box TS.2, WG I Chapter 7 Supplementary Material}

FOOTNOTE 8: In this SPM, uncertainty in historic GHG emissions is reported using 90 % uncertainty intervals unless stated otherwise. GHG emission levels are rounded to two significant digits; as a consequence, small differences in sums due to rounding may occur.

B.1.2 Growth in anthropogenic emissions has persisted across all major groups of GHGs since 1990, albeit at different rates. By 2019, the largest growth in absolute emissions occurred in CO_2 from fossil fuels and industry followed by CH_4, whereas the highest relative growth occurred in fluorinated gases, starting from low levels in 1990 (*high confidence*). Net anthropogenic CO_2 emissions from land use, land-use change and forestry (CO_2-LULUCF) are subject to large uncertainties and high annual variability, with *low confidence* even in the direction of the long-term trend [FOOTNOTE 9]. (Figure SPM.1) {Figure 2.2, Figure 2.5, 2.2, Figure TS.2}

FOOTNOTE 9: Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Currently, net CO_2 fluxes from land reported by global book-keeping models used here are estimated to be about ~5.5 $GtCO_2$ yr^{-1} higher than the aggregate global net emissions based on national GHG inventories. This difference, which has been considered in the literature, mainly reflects differences in how anthropogenic forest sinks and areas of managed land are defined. Other reasons for this difference, which are more difficult to quantify, can arise from the limited representation of land management in global models and varying levels of accuracy and completeness of estimated LULUCF fluxes in national GHG inventories. Neither method is inherently preferable. Even when the same methodological approach is applied, the large uncertainty of CO_2-LULUCF emissions can lead to substantial revisions to estimated emissions. {Cross-Chapter Box 3 in Chapter 3, 7.2, SRCCL SPM A.3.3}

B.1.3 Historical cumulative net CO_2 emissions from 1850 to 2019 were 2400±240 $GtCO_2$ (*high confidence*). Of these, more than half (58%) occurred between 1850 and 1989 [1400±195 $GtCO_2$], and about 42% between 1990 and 2019 [1000±90 $GtCO_2$]. About 17% of historical cumulative net CO_2 emissions since 1850 occurred between 2010 and 2019 [410±30 $GtCO_2$]. [FOOTNOTE 10] By comparison, the current central estimate of the remaining carbon budget from 2020 onwards for limiting warming to 1.5°C with a probability of 50% has been assessed as 500 Gt CO_2, and as 1150 Gt CO_2 for a probability of 67% for limiting warming to 2°C. Remaining carbon budgets depend on the amount of non-CO_2 mitigation (±220 Gt CO_2) and are further subject to geophysical uncertainties. Based on central estimates only, cumulative net CO_2 emissions between 2010-2019 compare to about four fifths of the size of the remaining carbon budget from 2020 onwards for a 50% probability of limiting global warming to 1.5°C, and about one third of the remaining carbon budget for a 67% probability to limit global warming to 2°C. Even when taking uncertainties into account, historical emissions between 1850 and 2019 constitute a large share of total carbon budgets for these global warming levels [FOOTNOTE 11, 12]. Based on central estimates only, historical cumulative net CO_2 emissions between 1850-2019 amount to about four fifths [FOOTNOTE 12] of the total carbon budget for a 50% probability of limiting global warming to 1.5°C (central estimate about 2900 $GtCO_2$), and to about two thirds [FOOTNOTE 12] of the total carbon budget for a 67% probability to limit global warming to 2°C (central estimate about 3550 $GtCO_2$). {Figure 2.7, 2.2, Figure TS.3, WG I Table SPM.2}

FOOTNOTE 10: For consistency with WGI, historical cumulative CO_2 emissions from 1850-2019 are reported using 68% confidence intervals.

FOOTNOTE 11: The carbon budget is the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given likelihood, taking into account the effect of other anthropogenic climate forcers. This is referred to as the total carbon budget when expressed starting from the pre-industrial period, and as the remaining carbon budget when expressed from a recent specified date. The total carbon budgets reported here are the sum of historical emissions from 1850 to 2019 and the remaining carbon budgets from 2020 onwards, which extend until global net zero CO_2 emissions are reached. {Annex I: Glossary; WG I SPM}

FOOTNOTE 12: Uncertainties for total carbon budgets have not been assessed and could affect the specific calculated fractions.

B.1.4 Emissions of CO_2–FFI dropped temporarily in the first half of 2020 due to responses to the COVID-19 pandemic (*high confidence*), but rebounded by the end of the year (*medium confidence*). The annual average CO_2-FFI emissions reduction in 2020 relative to 2019 was about 5.8% [5.1-6.3%], or 2.2 [1.9-2.4] $GtCO_2$ (*high confidence*). The full GHG emissions impact of the COVID-19 pandemic could not be assessed due to a lack of data regarding non-CO_2 GHG emissions in 2020. {Cross-Chapter Box 1 in Chapter 1, Figure 2.6, 2.2, Box TS.1, Box TS.1 Figure 1}

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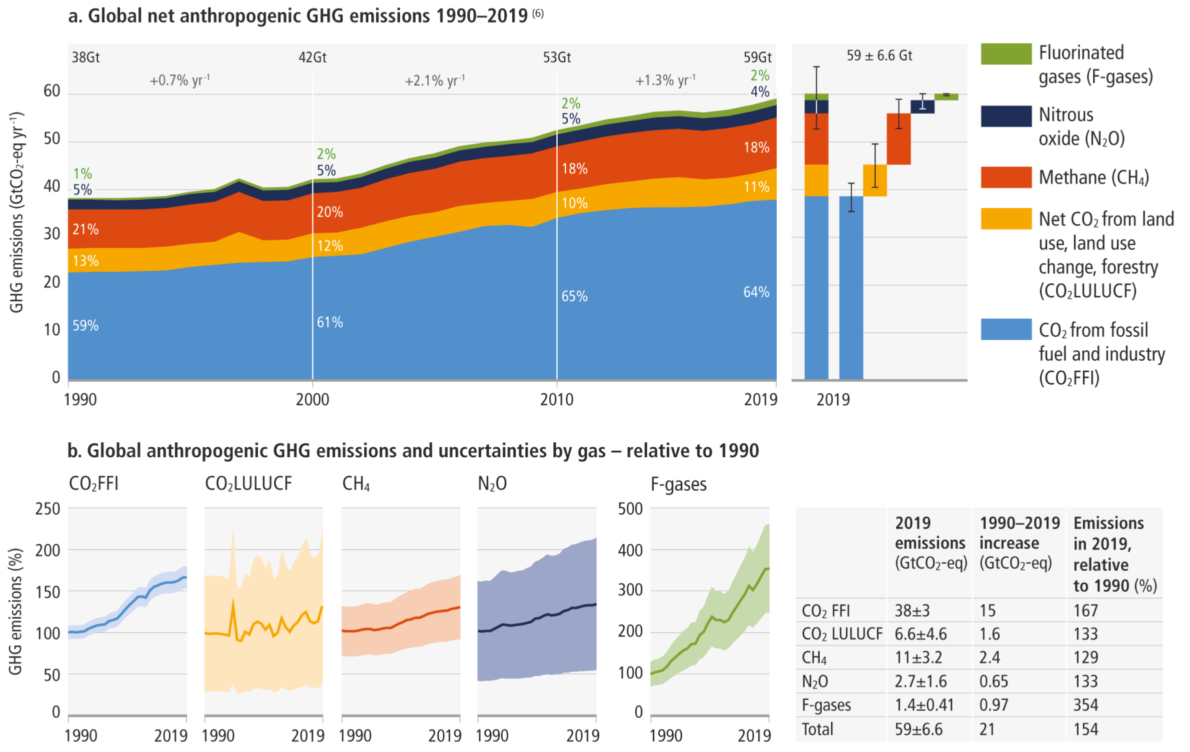
Global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases.



	2019 emissions ($GtCO_2$-eq)	1990–2019 increase ($GtCO_2$-eq)	Emissions in 2019, relative to 1990 (%)
CO_2 FFI	38±3	15	167
CO_2 LULUCF	6.6±4.6	1.6	133
CH_4	11±3.2	2.4	129
N_2O	2.7±1.6	0.65	133
F-gases	1.4±0.41	0.97	354
Total	59±6.6	21	154

Figure SPM.1: Global net anthropogenic GHG emissions ($GtCO_2$-eq yr^{-1}) 1990–2019

Global net anthropogenic GHG emissions include CO_2 from fossil fuel combustion and industrial processes (CO_2-FFI); net CO_2 from land use, land use change and forestry (CO_2-LULUCF) [FOOTNOTE 9]; methane (CH_4); nitrous oxide (N_2O); fluorinated gases (HFCs; PFCs, SF_6, NF_3). [FOOTNOTE 6]

Panel a shows aggregate annual global net anthropogenic GHG emissions by groups of gases from 1990 to 2019 reported in $GtCO_2$-eq converted based on global warming potentials with a 100-year time horizon (GWP100-AR6) from the IPCC Sixth Assessment Report Working Group I (Chapter 7). The fraction of global emissions for each gas is shown 1990, 2000, 2010, 2019; as well as the aggregate average annual growth rate between these decades. At the right side of Panel a, GHG emissions in 2019 are broken down into individual components with the associated uncertainties [90% confidence interval] indicated by the error bars: CO_2 FFI ±8%, CO_2-LULUCF ±70%, CH_4 ±30%, N_2O ±60%, F-gases ±30%, GHG ±11%. Uncertainties in GHG emissions are assessed in the Supplementary Material to Chapter 2. The single year peak of emissions in 1997 was due to higher CO_2-LULUCF emissions from a forest and peat fire event in South East Asia.

Panel b shows global anthropogenic CO_2-FFI, net CO_2-LULUCF, CH_4, N_2O and fluorinated gas emissions individually for the period 1990–2019, normalised relative to 100 in 1990. Note the different scale for the included fluorinated gas emissions compared to other gases, highlighting its rapid growth from a low base. Shaded areas indicate the uncertainty range. Uncertainty ranges as shown here are specific for individual groups of greenhouse gases and cannot be compared. The table shows the central estimate for: absolute emissions in 2019, the absolute change in emissions between 1990 and 2019, and emissions in 2019 expressed as a percentage of 1990 emissions. {2.2, Figure 2.5, Figure TS.2, Chapter 2 SM}

FOOTNOTE 9: Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Currently, net CO_2 fluxes from land reported by global book-keeping models used here are estimated to be about ~5.5 $GtCO_2$ yr^{-1} higher than the aggregate global net emissions based on national GHG inventories. This difference, which has been considered in the literature, mainly reflects differences in how anthropogenic forest sinks and areas of managed land are defined. Other reasons for this difference, which are more difficult to quantify, can arise from the limited representation of land management in global models and varying levels of accuracy and completeness of estimated LULUCF fluxes in national GHG inventories. Neither method is inherently preferable. Even when the same methodological approach is applied, the large uncertainty of CO_2-LULUCF emissions can lead to substantial revisions to estimated emissions. {Cross-Chapter Box 3 in Chapter 3, 7.2, SRCCL SPM A.3.3}

FOOTNOTE 6: Net GHG emissions in this report refer to releases of greenhouse gases from anthropogenic sources minus removals by anthropogenic sinks, for those species of gases that are reported under the common reporting format of the United Nations Framework Convention on Climate Change (UNFCCC): CO_2 from fossil fuel combustion and industrial processes (CO_2-FFI); net CO_2 emissions from land use, land use change and forestry (CO_2-LULUCF); methane (CH_4); nitrous oxide (N_2O); and fluorinated gases (F-gases) comprising hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6) as well as nitrogen trifluoride (NF3). Different datasets for GHG emissions exist, with varying time horizons and coverage of sectors and gases, including some that go back to 1850. In this report, GHG emissions are assessed from 1990, and CO_2 sometimes also from 1850. Reasons for this include data availability and robustness, scope of the assessed literature, and the differing warming impacts of non-CO_2 gases over time.

B.2 Net anthropogenic GHG emissions have increased since 2010 across all major sectors globally. An increasing share of emissions can be attributed to urban areas. Emissions reductions in CO_2 from fossil fuels and industrial processes, due to improvements in energy intensity of GDP and carbon intensity of energy, have been less than emissions increases from rising global activity levels in industry, energy supply, transport, agriculture and buildings. *(high confidence)* {2.2, 2.4, 6.3, 7.2, 8.3, 9.3, 10.1, 11.2}

B.2.1 In 2019, approximately 34% [20 $GtCO_2$-eq] of total net anthropogenic GHG emissions came from the energy supply sector, 24% [14 $GtCO_2$-eq] from industry, 22% [13 $GtCO_2$-eq]from agriculture, forestry and other land use (AFOLU), 15% [8.7 $GtCO_2$-eq] from transport and 6% [3.3 $GtCO_2$-eq] from buildings.[13] If emissions from electricity and heat production are attributed to the sectors that use the final energy, 90% of these indirect emissions are allocated to the industry and buildings sectors, increasing their relative GHG emissions shares from 24% to 34%, and from 6% to 16%, respectively. After reallocating emissions from electricity and heat production, the energy supply sector accounts for 12% of global net anthropogenic GHG emissions. (*high confidence*) {Figure 2.12, 2.2, 6.3, 7.2, 9.3, 10.1, 11.2, Figure TS.6}

FOOTNOTE 13: Sector definitions can be found in Annex II 9.1.

B.2.2 Average annual GHG emissions growth between 2010 and 2019 slowed compared to the previous decade in energy supply [from 2.3% to 1.0%] and industry [from 3.4% to 1.4%], but remained roughly constant at about 2% per year in the transport sector *(high confidence)*. Emissions growth in AFOLU, comprising emissions from agriculture (mainly CH_4 and N_2O) and forestry and other land use (mainly CO_2) is more uncertain than in other sectors due to the high share and uncertainty of CO_2-LULUCF emissions (*medium confidence*). About half of total net AFOLU emissions are from CO_2 LULUCF, predominantly from deforestation. [FOOTNOTE 14] (*medium confidence*). {Figure 2.13, 2.2, 6.3, 7.2, Figure 7.3, 9.3, 10.1, 11.2, TS.3}

FOOTNOTE 14: Land overall constituted a net sink of -6.6 (±4.6) $GtCO_2\ yr^{-1}$ for the period 2010-2019, comprising a gross sink of -12.5 (±3.2) $GtCO_2\ yr^{-1}$ resulting from responses of all land to both anthropogenic environmental change and natural climate variability, and net anthropogenic CO_2-LULUCF emissions +5.9 (±4.1) $GtCO_2\ yr^{-1}$ based on book-keeping models. {2.2, 7.2, Table 7.1}

B.2.3 The global share of emissions that can be attributed to urban areas is increasing. In 2015, urban emissions were estimated to be 25 $GtCO_2$-eq (about 62% of the global share) and in 2020, 29 $GtCO_2$-eq (67-72% of the global share).[15] The drivers of urban GHG emission are complex and include population size, income, state of urbanisation and urban form. (*high confidence*) {8.1, 8.3}

FOOTNOTE 15: This estimate is based on consumption-based accounting, including both direct emissions from within urban areas, and indirect emissions from outside urban areas related to the production of electricity, goods and services consumed in cities. These estimates include all CO_2 and CH_4 emission categories except for aviation and marine bunker fuels, land-use change, forestry and agriculture. {8.1, Annex I: Glossary}

B.2.4 Global energy intensity (total primary energy per unit GDP) decreased by 2% yr^{-1} between 2010 and 2019. Carbon intensity (CO_2 from fossil fuel combustion and industrial processes (CO_2 FFI) per unit primary energy) decreased by 0.3% yr^{-1}, with large regional variations, over the same period mainly due to fuel switching from coal to gas, reduced expansion of coal capacity, and increased use of renewables. This reversed the trend observed for 2000–2009. For comparison, the carbon intensity of primary energy is projected to decrease globally by about 3.5% yr^{-1} between 2020 and 2050 in modelled scenarios that limit warming to 2°C (>67%), and by about 7.7% yr^{-1} globally in scenarios that limit warming to 1.5°C (>50%) with no or limited overshoot.[16] (*high confidence*) {Figure 2.16, 2.2, 2.4, Table 3.4, 3.4, 6.3}

FOOTNOTE 16: See Box SPM.1 for the categorisation of modelled long-term emission scenarios based on projected temperature outcomes and associated probabilities adopted in this report.

B.3 Regional contributions [FOOTNOTE 17] to global GHG emissions continue to differ widely. Variations in regional, and national per capita emissions partly reflect different development stages, but they also vary widely at similar income levels. The 10% of households with the highest per capita emissions contribute a disproportionately large share of global household GHG emissions. At least 18 countries have sustained GHG emission reductions for longer than 10 years. (*high confidence*) (Figure SPM.2) {Figure 1.1, Figure 2.9, Figure 2.10, Figure 2.25, 2.2, 2.3, 2.4, 2.5, 2.6, Figure TS.4, Figure TS.5}

FOOTNOTE 17: See Working Group III Annex II, Part 1 for regional groupings adopted in this report.

B.3.1 GHG emissions trends over 1990-2019 vary widely across regions and over time, and across different stages of development as shown in Figure SPM.2. Average global per capita net anthropogenic GHG emissions increased from 7.7 to 7.8 tCO_2-eq, ranging from 2.6 tCO_2-eq to 19 tCO_2-eq across regions. Least Developed Countries (LDCs) and Small Island Developing States (SIDS) have much lower per capita emissions (1.7 tCO_2-eq, 4.6 tCO_2-eq, respectively) than the global average (6.9 tCO_2-eq), excluding CO_2-LULUCF [FOOTNOTE 18]. (*high confidence*) (Figure SPM.2) {Figure1.2, Figure 2.9, Figure 2.10, 2.2, Figure TS.4}

FOOTNOTE 18: In 2019, LDCs are estimated to have emitted 3.3% of global GHG emissions, and SIDS are estimated to have emitted 0.60% of global GHG emissions, excluding CO_2-LULUCF. These

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country groupings cut across geographic regions and are not depicted separately in Fig SPM2. {Figure 2.10}

B.3.2 Historical contributions to cumulative net anthropogenic CO_2 emissions between 1850 and 2019 vary substantially across regions in terms of total magnitude, but also in terms of contributions to CO_2-FFI (1650 +/- 73 $GtCO_2$-eq) and net CO_2-LULUCF (760 +/- 220 $GtCO_2$-eq) emissions.[FOOTNOTE 19] Globally, the major share of cumulative CO_2-FFI emissions is concentrated in a few regions, while cumulative CO_2-LULUCF [FOOTNOTE 9] emissions are concentrated in other regions. LDCs contributed less than 0.4% of historical cumulative CO_2-FFI emissions between 1850 and 2019, while SIDS contributed 0.5%. (*high confidence*) (Figure SPM.2) {Figure 2.10, 2.2, TS.3, Figure 2.7}

FOOTNOTE 9: Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Currently, net CO_2 fluxes from land reported by global book-keeping models used here are estimated to be about ~5.5 $GtCO_2$ yr^{-1} higher than the aggregate global net emissions based on national GHG inventories. This difference, which has been considered in the literature, mainly reflects differences in how anthropogenic forest sinks and areas of managed land are defined. Other reasons for this difference, which are more difficult to quantify, can arise from the limited representation of land management in global models and varying levels of accuracy and completeness of estimated LULUCF fluxes in national GHG inventories. Neither method is inherently preferable. Even when the same methodological approach is applied, the large uncertainty of CO_2-LULUCF emissions can lead to substantial revisions to estimated emissions. {Cross-Chapter Box 3 in Chapter 3, 7.2, SRCCL SPM A.3.3}

FOOTNOTE 19: For consistency with WGI, historical cumulative CO_2 emissions from 1850-2019 are reported using 68% confidence intervals.

B.3.3 In 2019, around 48% of the global population lives in countries emitting on average more than 6t CO_2-eq per capita, excluding CO_2-LULUCF. 35% live in countries emitting more than 9 tCO_2-eq per capita. Another 41% live in countries emitting less than 3 tCO_2-eq per capita. A substantial share of the population in these low emitting countries lack access to modern energy services (FOOTNOTE 20). Eradicating extreme poverty, energy poverty, and providing decent living standards (FOOTNOTE 21) to all in these regions in the context of achieving sustainable development objectives, in the near-term, can be achieved without significant global emissions growth. (*high confidence*) (Figure SPM.2) {Figure 1.2, 2.2, 2.4, 2.6, 3.7, 4.2, 6.7, Figure TS.4, Figure TS.5}

FOOTNOTE 20: In this report, access to modern energy services is defined as access to clean, reliable and affordable energy services for cooking and heating, lighting, communications, and productive uses (See Annex I: Glossary)

FOOTNOTE 21: In this report, decent living standards are defined as a set of minimum material requirements essential for achieving basic human well-being, including nutrition, shelter, basic living conditions, clothing, health care, education, and mobility. (See 5.1)

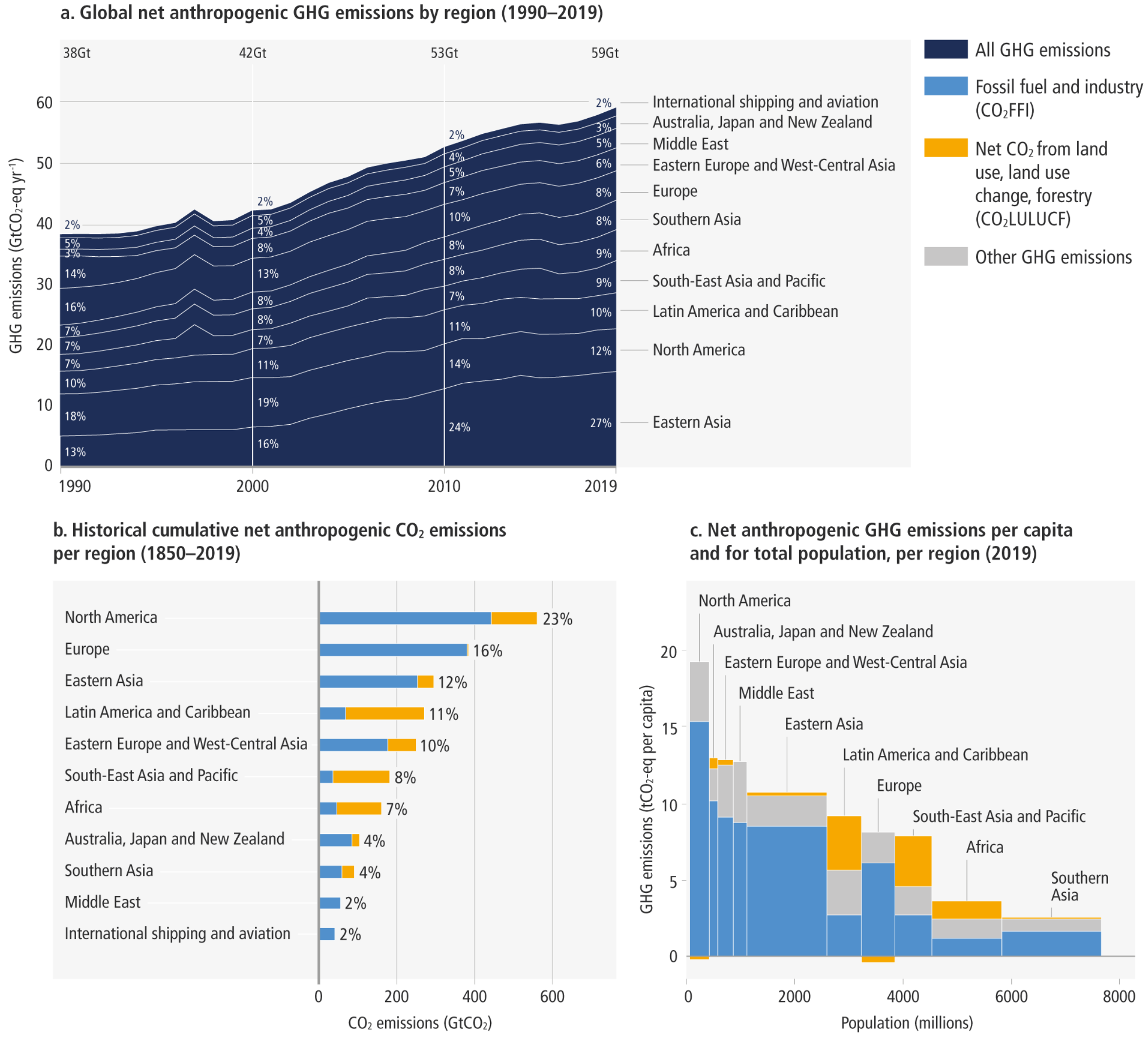
B.3.4 Globally, the 10% of households with the highest per capita emissions contribute 34-45% of global consumption-based household GHG emissions [**FOOTNOTE 22**], while the middle 40% contribute 40-53%, and the bottom 50% contribute 13-15%. (*high confidence*) {2.6, Figure 2.25}

FOOTNOTE 22: Consumption-based emissions refer to emissions released to the atmosphere to generate the goods and services consumed by a certain entity (e.g., a person, firm, country, or region).

The bottom 50% of emitters spend less than USD3PPP per capita per day. The top 10% of emitters (an open-ended category) spend more than USD23PPP per capita per day. The wide range of estimates for the contribution of the top 10% result from the wide range of spending in this category and differing methods in the assessed literature. {Annex I: Glossary; 2.6}

B.3.5 At least 18 countries have sustained production-based GHG and consumption-based CO_2 emission reductions for longer than 10 years. Reductions were linked to energy supply decarbonisation, energy efficiency gains, and energy demand reduction, which resulted from both policies and changes in economic structure. Some countries have reduced production-based GHG emissions by a third or more since peaking, and some have achieved several years of consecutive reduction rates of around 4 %/yr, comparable to global reductions in scenarios limiting warming to 2°C (>67%) or lower. These reductions have only partly offset global emissions growth. (*high confidence*) (Figure SPM.2) {Figure TS.4, 2.2, 1.3.2}

Emissions have grown in most regions but are distributed unevenly, both in the present day and cumulatively since 1850.



d. Regional indicators (2019) and regional production vs consumption accounting (2018)

	Africa	Australia, Japan, New Zealand	Eastern Asia	Eastern Europe, West-Central Asia	Europe	Latin America and Caribbean	Middle East	North America	South-East Asia and Pacific	Southern Asia
Population (million persons, 2019)	1292	157	1471	291	620	646	252	366	674	1836
GDP per capita ($USD1000_{ppp}2017$ per person)[1]	5.0	43	17	20	43	15	20	61	12	6.2
Net GHG 2019[2] (production basis)										
% GHG contributions	9%	3%	27%	6%	8%	10%	5%	12%	9%	8%
GHG emissions intensity (tCO_2-eq / $USD1000_{ppp}$ 2017)	0.78	0.30	0.62	0.64	0.18	0.61	0.64	0.31	0.65	0.42
GHG per capita (tCO_2-eq per person)	3.9	13	11	13	7.8	9.2	13	19	7.9	2.6
CO_2FFI, 2018, per person										
Production-based emissions (tCO_2FFI per person, based on 2018 data)	1.2	10	8.4	9.2	6.5	2.8	8.7	16	2.6	1.6
Consumption-based emissions (tCO_2FFI per person, based on 2018 data)	0.84	11	6.7	6.2	7.8	2.8	7.6	17	2.5	1.5

[1] GDP per capita in 2019 in USD2017 currency purchasing power basis.
[2] Includes CO_2FFI, CO_2LULUCF and Other GHGs, excluding international aviation and shipping.

The regional groupings used in this figure are for statistical purposes only and are described in Annex II, Part I.

Figure SPM.2: Regional GHG emissions, and the regional proportion of total cumulative production-based CO_2 emissions from 1850–2019

Panel a shows global net anthropogenic GHG emissions by region (in $GtCO_2$-eq yr-1 (GWP100 AR6)) for the time period 1990–2019 [FOOTNOTE 6]. Percentage values refer to the contribution of each region to total GHG emissions in each respective time period. The single year peak of emissions in 1997 was due to higher CO_2-LULUCF emissions from a forest and peat fire event in South East Asia. Regions are as grouped in Annex II.

Panel b shows the share of historical cumulative net anthropogenic CO_2 emissions per region from 1850 to 2019 in $GtCO_2$. This includes CO_2 from fossil fuel combustion and industrial processes (CO_2-FFI) and net CO_2 Land use, land use change, forestry (CO_2-LULUCF). Other GHG emissions are not included [FOOTNOTE 6]. CO_2-LULUCF emissions are subject to high uncertainties, reflected by a global uncertainty estimate of ± 70% (90% confidence interval).

Panel c shows the distribution of regional GHG emissions in tonnes CO_2-eq per capita by region in 2019. GHG emissions are categorised into: CO_2-FFI, net CO_2-LULUCF and other GHG emissions (methane, nitrous oxide, fluorinated gases, expressed in CO_2-eq using GWP100-AR6). The height of each rectangle shows per-capita emissions, the width shows the population of the region, so that the area of the rectangles refers to the total emissions for each region. Emissions from international aviation and shipping are not included. In the case of two regions, the area for CO_2-LULUCF is below the axis, indicating net CO_2 removals rather than emissions. CO_2-LULUCF emissions are subject to high uncertainties, reflected by a global uncertainty estimate of ± 70% (90% confidence interval).

Panel d shows population, GDP per person, emission indicators by region in 2019 for percentage GHG contributions, total GHG per person, and total GHG emissions intensity, together with production-based and consumption-based CO_2-FFI data, which is assessed in this report up to 2018. Consumption-based emissions are emissions released to the atmosphere in order to generate the goods and services consumed by a certain entity (e.g., region). Emissions from international aviation and shipping are not included.
{1.3, Figure 1.2, 2.2, Figure 2.9, Figure 2.10, Figure 2.11, Annex II}

B.4 The unit costs of several low-emission technologies have fallen continuously since 2010. Innovation policy packages have enabled these cost reductions and supported global adoption. Both tailored policies and comprehensive policies addressing innovation systems have helped overcome the distributional, environmental and social impacts potentially associated with global diffusion of low-emission technologies. Innovation has lagged in developing countries due to weaker enabling conditions. Digitalisation can enable emission reductions, but can have adverse side-effects unless appropriately governed. *(high confidence)* (Figure SPM.3) {2.2, 6.3, 6.4, 7.2, 12.2, 16.2, 16.4, 16.5, Cross-Chapter Box 11 in Chapter 16}

B.4.1 From 2010–2019, there have been sustained decreases in the unit costs of solar energy (85%), wind energy (55%), and lithium-ion batteries (85%), and large increases in their deployment, e.g., >10x for solar and >100x for electric vehicles (EVs), varying widely across regions (Figure SPM.3). The mix of policy instruments which reduced costs and stimulated adoption includes public R&D, funding for demonstration and pilot projects, and demand pull instruments such as deployment subsidies to attain scale. In comparison to modular small-unit size technologies, the empirical record shows that multiple large-scale mitigation technologies, with fewer opportunities for learning, have seen minimal cost reductions and their adoption has grown slowly. (*high confidence*) {1.3, 1.5, Figure 2.5, 2.5, 6.3, 6.4, 7.2, 11.3, 12.2, 12.3, 12.6, 13.6, 16.3, 16.4, 16.6}

B.4.2 Policy packages tailored to national contexts and technological characteristics have been effective in supporting low-emission innovation and technology diffusion. Appropriately designed policies and governance have helped address distributional impacts and rebound effects. Innovation has provided opportunities to lower emissions and reduce emission growth and created social and environmental co-benefits. (*high confidence*) 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. Low-emission innovation along with strengthened enabling conditions can reinforce development benefits, which can, in turn, create feedbacks towards greater public support for policy. *(medium confidence)* {9.9, 13.6, 13.7, 16.3, 16.4, 16.5, 16.6, Cross-Chapter Box 12 in Chapter 16, TS.3}

B.4.3 Digital technologies can contribute to mitigation of climate change and the achievement of several SDGs (*high confidence*). For example, sensors, Internet of Things, robotics, and artificial intelligence can improve energy management in all sectors, increase energy efficiency, and promote the adoption of many low-emission technologies, including decentralised renewable energy, while creating economic opportunities (*high confidence*). However, some of these climate change mitigation gains can be reduced or counterbalanced by growth in demand for goods and services due to the use of digital devices (*high confidence*). Digitalisation can involve trade-offs across several SDGs, e.g., increasing electronic waste, negative impacts on labour markets, and exacerbating the existing digital divide. Digital technology supports decarbonisation only if appropriately governed (*high confidence*). {5.3, 10, 12.6, 16.2, Cross-Chapter Box 11 in Chapter 16, TS.5, Box TS.14}

The unit costs of some forms of renewable energy and of batteries for passenger EVs have fallen, and their use continues to rise.

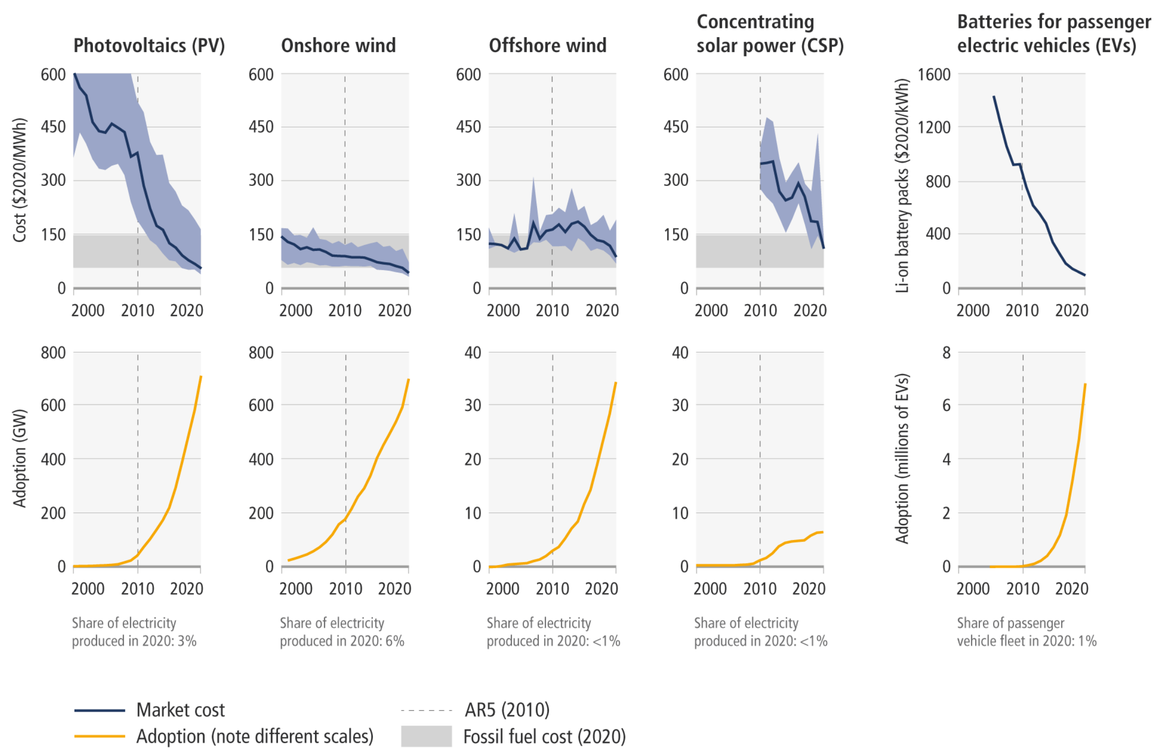


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Figure SPM.3: Unit cost reductions and use in some rapidly changing mitigation technologies

The top panel shows global costs per unit of energy (USD/MWh) for some rapidly changing mitigation technologies. Solid blue lines indicate average unit cost in each year. Light blue shaded areas show the range between the 5th and 95th percentiles in each year. Grey shading indicates the range of unit costs for new fossil fuel (coal and gas) power in 2020 (corresponding to USD55–148 per MWh). In 2020, the levelised costs of energy (LCOE) of the four renewable energy technologies could compete with fossil fuels in many places. For batteries, costs shown are for 1 kWh of battery storage capacity; for the others, costs are LCOE, which includes installation, capital, operations, and maintenance costs per MWh of electricity produced. The literature uses LCOE because it allows consistent comparisons of cost trends across a diverse set of energy technologies to be made. However, it does not include the costs of grid integration or climate impacts. Further, LCOE does not take into account other environmental and social externalities that may modify the overall (monetary and non-monetary) costs of technologies and alter their deployment.

The bottom panel shows cumulative global adoption for each technology, in GW of installed capacity for renewable energy and in millions of vehicles for battery-electric vehicles. A vertical dashed line is placed in 2010 to indicate the change since AR5. Shares of electricity produced and share of passenger vehicle fleet are indicated in text for 2020 based on provisional data, i.e., percentage of total electricity production (for PV, onshore wind, offshore wind, CSP) and of total stock of passenger vehicles (for electric vehicles). The electricity production share reflects different capacity factors; e.g., for the same amount of installed capacity, wind produces about twice as much electricity as solar PV. {2.5, 6.4}

Renewable energy and battery technologies were selected as illustrative examples because they have recently shown rapid changes in costs and adoption, and because consistent data are available. Other mitigation options assessed in the report are not included as they do not meet these criteria.

B.5 There has been a consistent expansion of policies and laws addressing mitigation since AR5. This has led to the avoidance of emissions that would otherwise have occurred and increased investment in low-GHG technologies and infrastructure. Policy coverage of emissions is uneven across sectors. Progress on the alignment of financial flows towards the goals of the Paris Agreement remains slow and tracked climate finance flows are distributed unevenly across regions and sectors. (*high confidence*) {5.6, 13.2, 13.4, 13.5, 13.6, 13.9, 14.3, 14.4, 14.5, Cross-Chapter Box 10 in Chapter 14, 15.3, 15.5}

B.5.1 The Kyoto Protocol led to reduced emissions in some countries and was instrumental in building national and international capacity for GHG reporting, accounting and emissions markets (*high confidence*). At least 18 countries that had Kyoto targets for the first commitment period have had sustained absolute emission reductions for at least a decade from 2005, of which two were countries with economies in transition (*very high confidence*). The Paris Agreement, with near universal participation, has led to policy development and target-setting at national and sub-national levels, in particular in relation to mitigation, as well as enhanced transparency of climate action and support (*medium confidence*). {14.3, 14.6}

B.5.2 The application of diverse policy instruments for mitigation at the national and sub-national levels has grown consistently across a range of sectors (*high confidence*). By 2020, over 20% of global GHG emissions were covered by carbon taxes or emissions trading systems, although coverage and prices have been insufficient to achieve deep reductions (*medium confidence*). By 2020, there were 'direct' climate laws focused primarily on GHG reductions in 56 countries covering 53% of global emissions (*medium confidence*). Policy coverage remains limited for emissions from agriculture and the production of industrial materials and feedstocks *(high confidence)*. {5.6, 7.6, 11.5, 11.6, 13.2, 13.6}

B.5.3 In many countries, policies have enhanced energy efficiency, reduced rates of deforestation and accelerated technology deployment, leading to avoided and in some cases reduced or removed emissions (*high confidence*). Multiple lines of evidence suggest that mitigation policies have led to avoided global emissions of several Gt CO_2-eq yr^{-1} (*medium confidence*). At least 1.8 Gt CO_2-eq yr^{-1} can be accounted for by aggregating separate estimates for the effects of economic and regulatory instruments. Growing numbers of laws and executive orders have impacted global emissions and were estimated to result in 5.9 Gt CO_2-eq yr^{-1} less in 2016 than they otherwise would have been. (*medium confidence*) (Figure SPM.3) {2.2, 2.8, 6.7, 7.6, 9.9, 10.8, 13.6, Cross-chapter Box 10 in Chapter 14}

B.5.4 Annual tracked total financial flows for climate mitigation and adaptation increased by up to 60% between 2013/14 and 2019/20 (in USD2015), but average growth has slowed since 2018[23] (*medium confidence*). These financial flows remained heavily focused on mitigation, are uneven, and have developed heterogeneously across regions and sectors (*high confidence*). In 2018, public and publicly mobilised private climate finance flows from developed to developing countries were below the collective goal under the UNFCCC and Paris Agreement to mobilize USD 100 billion per year by 2020 in the context of meaningful mitigation action and transparency on implementation (*medium confidence*). Public and private finance flows for fossil fuels are still greater than those for climate adaptation and mitigation (*high confidence*). Markets for green bonds, ESG (environmental, social and governance) and sustainable finance products have expanded significantly since AR5. Challenges remain, in particular around integrity and additionality, as well as the limited applicability of these markets to many developing countries. (*high confidence*) {Box 15.4, 15.3, 15.5, 15.6, Box 15.7}

FOOTNOTE 23: Estimates of financial flows (comprising both private and public, domestic and international flows) are based on a single report which assembles data from multiple sources and which has applied various changes to their methodology over the past years. Such data can suggest broad trends but is subject to uncertainties.

B.6 Global GHG emissions in 2030 associated with the implementation of nationally determined contributions (NDCs) announced prior to COP26 [FOOTNOTE 24] would make it *likely* that warming will exceed 1.5°C during the 21st century.[FOOTNOTE 25] *Likely* limiting warming to below 2°C would then rely on a rapid acceleration of mitigation efforts after 2030. Policies implemented by the end of 2020 [FOOTNOTE 26] are projected to result in higher global GHG emissions than those implied by NDCs. (*high confidence*) (Figure SPM.4) {3.3, 3.5, 4.2, Cross-Chapter Box 4 in Chapter 4}

FOOTNOTE 24: NDCs announced prior to COP26 refer to the most recent nationally determined contributions submitted to the UNFCCC up to the literature cut-off date of this report, 11 October 2021, and revised NDCs announced by China, Japan and the Republic of Korea prior to October 2021 but only submitted thereafter. 25 NDC updates were submitted between 12 October 2021 and prior to the start of COP26.

FOOTNOTE 25: This implies that mitigation after 2030 can no longer establish a pathway with less than 67% probability to exceed 1.5°C during the 21st century, a defining feature of the class of pathways that limit warming to 1.5°C (>50%) with no or limited overshoot assessed in this report (Category C1 in Table SPM.1). These pathways limit warming to 1.6°C or lower throughout the 21st century with a 50% likelihood.

FOOTNOTE 26: The policy cut-off date in studies used to project GHG emissions of "policies implemented by the end of 2020" varies between July 2019 and November 2020. {Table 4.2}

B.6.1 Policies implemented by the end of 2020 are projected to result in higher global GHG emissions than those implied by NDCs, indicating an implementation gap. A gap remains between global GHG emissions in 2030 associated with the implementation of NDCs announced prior to COP26 and those associated with modelled mitigation pathways assuming immediate action (for quantification see Table SPM.X). [FOOTNOTE 27] The magnitude of the emission gap depends on the global warming level considered and whether only unconditional or also conditional elements of NDCs [FOOTNOTE 28] are considered.[FOOTNOTE 29] (*high confidence*) {3.5, 4.2, Cross-Chapter Box 4 in Chapter 4}

Table SPM.X: Projected global emissions in 2030 associated with policies implemented by the end of 2020 and NDCs announced prior to COP26, and associated emission gaps. *Emissions projections for 2030 and absolute differences in emissions are based on emissions of 52-56 $GtCO_2$-eq yr^{-1} in 2019 as assumed in underlying model studies. (*medium confidence*){4.2, Table 4.3, Cross-Chapter Box 4 in Chapter 4}

$GtCO_2$-eq yr^{-1}	Implied by policies implemented by the end of 2020	Implied by NDCs announced prior to COP26	
		Unconditional elements	Inc. conditional elements
Median (Min–Max)*	57 (52–60)	53 (50–57)	50 (47–55)
Implementation gap between implemented policies and NDCs (Median)		4	7
Emission gap between NDCs and pathways that limit warming to 2°C (>67%) with immediate action		10–16	6–14
Emissions gap between NDCs and pathways that limit warming to 1.5°C (>50%) with no or limited overshoot with immediate action		19–26	16–23

FOOTNOTE 27: Immediate action in modelled global pathways refers to the adoption between 2020 and at latest before 2025 of climate policies intended to limit global warming to a given level. Modelled

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pathways that limit warming to 2°C (>67%) based on immediate action are summarised in Category C3a in Table SPM.1. All assessed modelled global pathways that limit warming to 1.5°C (>50%) with no or limited overshoot assume immediate action as defined here (Category C1 in Table SPM.1).

FOOTNOTE 28: In this report, "unconditional" elements of NDCs refer to mitigation efforts put forward without any conditions. "Conditional" elements refer to mitigation efforts that are contingent on international cooperation, for example bilateral and multilateral agreements, financing or monetary and/or technological transfers. This terminology is used in the literature and the UNFCCC's NDC Synthesis Reports, not by the Paris Agreement. {4.2.1, 14.3.2}

FOOTNOTE 29: Two types of gaps are assessed: The implementation gap is calculated as the difference between the median of global emissions in 2030 implied by policies implemented by the end of 2020 and those implied by NDCs announced prior to COP26. The emissions gap is calculated as the difference between GHG emissions implied by the NDCs (minimum/maximum emissions in 2030) and the median of global GHG emissions in modelled pathways limiting warming to specific levels based on immediate action and with stated likelihoods as indicated (Table SPM.1).

B.6.2 Global emissions in 2030 associated with the implementation of NDCs announced prior to COP26 are lower than the emissions implied by the original NDCs [FOOTNOTE 30] (*high confidence*). The original emission gap has fallen by about 20% to one third relative to pathways that limit warming to 2°C (>67%) with immediate action (Category C3a in Table SPM.1), and by about 15-20% relative to pathways limiting warming to 1.5°C (>50%) with no or limited overshoot (Category C1 in Table SPM.1) (*medium confidence*). (Figure SPM.4) {3.5, 4.2, Cross-Chapter Box 4 in Chapter 4}

FOOTNOTE 30: Original NDCs refer to those submitted to the UNFCCC in 2015 and 2016. Unconditional elements of NDCs announced prior to COP26 imply global GHG emissions in 2030 that are 3.8 [3.0–5.3] $GtCO_2$-eq yr^{-1} lower than those from the original NDCs, and 4.5 [2.7–6.3] $GtCO_2$-eq yr^{-1} lower when conditional elements of NDCs are included. NDC updates at or after COP26 could further change the implied emissions.

B.6.3 Modelled global emission pathways consistent with NDCs announced prior to COP26 that limit warming to 2°C (>67%) (Category C3b in Table SPM.1) imply annual average global GHG emissions reduction rates of 0–0.7 $GtCO_2$-eq per year during the decade 2020-2030, with an unprecedented acceleration to 1.4–2.0 $GtCO_2$-eq per year during 2030-2050 (*medium confidence*). Continued investments in unabated high emitting infrastructure and limited development and deployment of low emitting alternatives prior to 2030 would act as barriers to this acceleration and increase feasibility risks (*high confidence*). {3.3, 3.5, 3.8, Cross-Chapter Box 5 in Chapter 4}

B.6.4 Modelled global emission pathways consistent with NDCs announced prior to COP26 will *likely* exceed 1.5°C during the 21st century. Those pathways that then return warming to 1.5°C by 2100 with a likelihood of 50% or greater imply a temperature overshoot of 0.15-0.3°C (42 pathways in category C2 in Table SPM.1). In such pathways, global cumulative net-negative CO_2 emissions are -380 [-860 to -200] $GtCO_2$ [FOOTNOTE 31] in the second half of the century, and there is a rapid acceleration of other mitigation efforts across all sectors after 2030. Such overshoot pathways imply increased climate-related risk, and are subject to increased feasibility concerns[FOOTNOTE 32], and greater social and environmental risks, compared to pathways that limit warming to 1.5°C (>50%) with no or limited overshoot. (*high confidence*) (Figure SPM.4, Table SPM.1) {3.3, 3.5, 3.8, 12.3; WG II SPM.B.6}

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FOOTNOTE 31: Median and very likely range [5th to 95th percentile].

FOOTNOTE 32: Returning to below 1.5°C in 2100 from GHG emissions levels in 2030 associated with the implementation of NDCs is infeasible for some models due to model-specific constraints on the deployment of mitigation technologies and the availability of net negative CO_2 emissions.

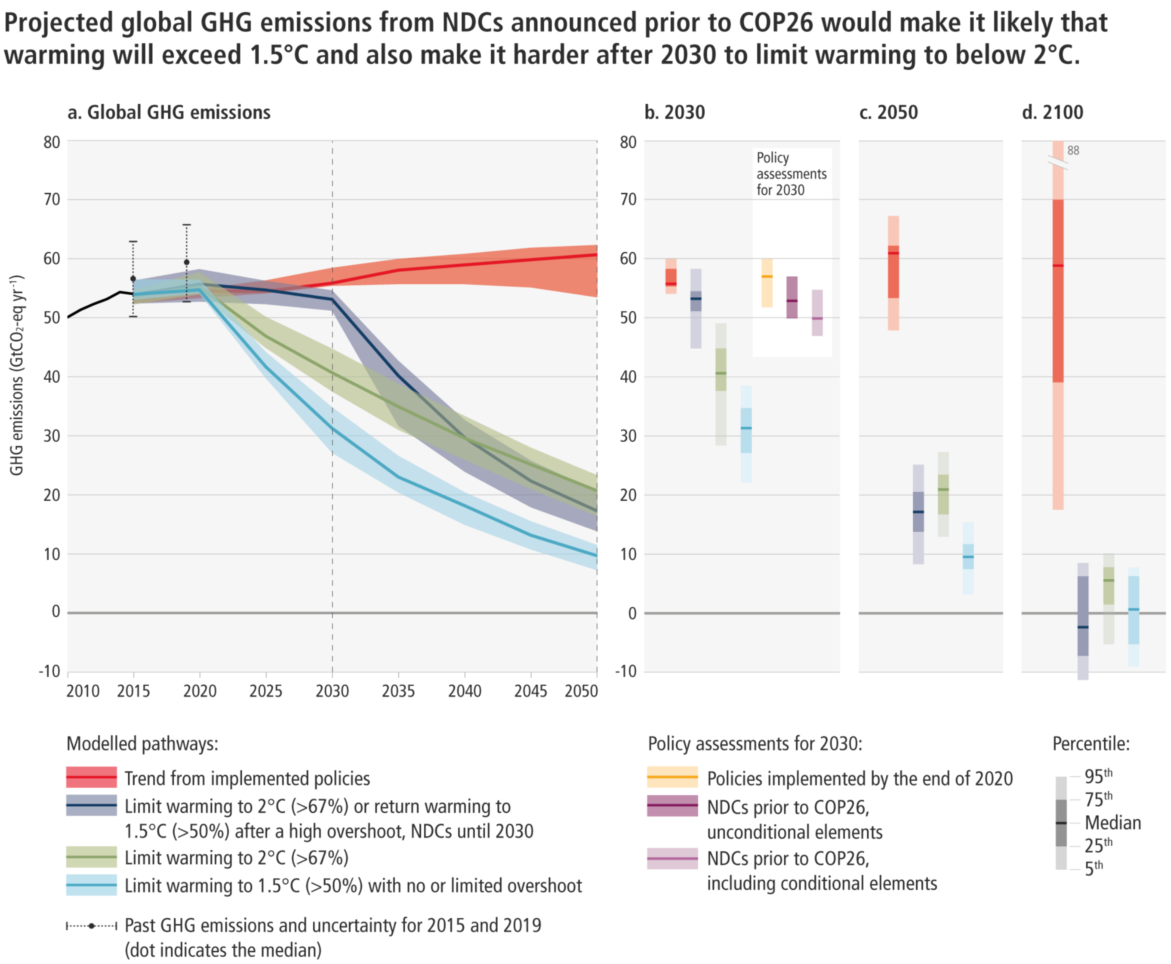

Figure SPM.4: Global GHG emissions of modelled pathways (funnels in Panel a. and associated bars in Panels b, c, d) and projected emission outcomes from near-term policy assessments for 2030 (Panel b).

Panel a shows global GHG emissions over 2015-2050 for four types of assessed modelled global pathways:

- Trend from implemented policies: Pathways with projected near-term GHG emissions in line with policies implemented until the end of 2020 and extended with comparable ambition levels beyond 2030 (29 scenarios across categories C5-C7, Table SPM.1)
- Limit to 2°C (>67%) or return warming to 1.5°C (>50%) after a high overshoot, NDCs until 2030: Pathways with GHG emissions until 2030 associated with the implementation of NDCs announced prior to COP26, followed by accelerated emissions reductions *likely* to limit warming to 2°C (C3b, Table SPM.1) or to return warming to 1.5°C with a probability of 50% or greater after high overshoot (subset of 42 scenarios from C2, Table SPM.1).

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- Limit to 2°C (>67%) with immediate action: Pathways that limit warming to 2°C (>67%) with immediate action after 2020[27] (C3a, Table SPM.1).
- Limit to 1.5°C (>50%) with no or limited overshoot: Pathways limiting warming to 1.5°C with no or limited overshoot (C1, Table SPM.1 C1). All these pathways assume immediate action after 2020.

Past GHG emissions for 2010-2015 used to project global warming outcomes of the modelled pathways are shown by a black line [FOOTNOTE 33] and past global GHG emissions in 2015 and 2019 as assessed in Chapter 2 are shown by whiskers.

FOOTNOTE 33: See the Box SPM.1 for a description of the approach to project global warming outcomes of modelled pathways and its consistency between the climate assessment in AR6 WG I.

Panels b, c and d show snapshots of the GHG emission ranges of the modelled pathways in 2030, 2050, and 2100, respectively. Panel b also shows projected emissions outcomes from near-term policy assessments in 2030 from Chapter 4.2 (Tables 4.2 and 4.3; median and full range). GHG emissions are in CO_2-equivalent using GWP100 from AR6 WG I. {3.5, 4.2, Tables 4.2 and 4.3, Cross-Chapter Box 4 in Chapter 4}

B.7 Projected cumulative future CO_2 emissions over the lifetime of existing and currently planned fossil fuel infrastructure without additional abatement exceed the total cumulative net CO_2 emissions in pathways that limit warming to 1.5°C (>50%) with no or limited overshoot. They are approximately equal to total cumulative net CO_2 emissions in pathways that limit warming to 2°C (>67%). (*high confidence*) {2.7, 3.3}

B.7.1 If historical operating patterns are maintained, [FOOTNOTE 34] and without additional abatement [FOOTNOTE 35], estimated cumulative future CO_2 emissions from existing fossil fuel infrastructure, the majority of which is in the power sector, would, from 2018 until the end of its lifetime, amount to 660 [460–890] $GtCO_2$. They would amount to 850 [600–1100] $GtCO_2$ when unabated emissions from currently planned infrastructure in the power sector is included. These estimates compare with cumulative global net CO_2 emissions from all sectors of 510 [330–710] $GtCO_2$ until the time of reaching net zero CO_2 emissions [FOOTNOTE 36] in pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and 890 [640–1160] $GtCO_2$ in pathways that limit warming to 2°C (>67%). (Table SPM.1) (*high confidence*) {2.7, Figure 2.26, Figure TS.8}

FOOTNOTE 34: Historical operating patterns are described by load factors and lifetimes of fossil fuel installations as observed in the past (average and range).

FOOTNOTE 35: Abatement here refers to human interventions that reduce the amount of greenhouse gases that are released from fossil fuel infrastructure to the atmosphere.

FOOTNOTE 36: Total cumulative CO_2 emissions up to the time of global net zero CO_2 emissions are similar but not identical to the remaining carbon budget for a given temperature limit assessed by Working Group I. This is because the modelled emission scenarios assessed by Working Group III cover a range of temperature levels up to a specific limit, and exhibit a variety of reductions in non-CO_2 emissions that also contribute to overall warming. {Box 3.4}

B.7.2 In modelled global pathways that limit warming to 2°C (>67%) or lower, most remaining fossil fuel CO_2 emissions until the time of global net zero CO_2 emissions are projected to occur outside the power sector, mainly in industry and transport. Decommissioning and reduced utilisation of existing

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fossil fuel based power sector infrastructure, retrofitting existing installations with CCS [FOOTNOTE 37] switches to low carbon fuels, and cancellation of new coal installations without CCS are major options that can contribute to aligning future CO_2 emissions from the power sector with emissions in the assessed global modelled least-cost pathways. The most appropriate strategies will depend on national and regional circumstances, including enabling conditions and technology availability. (*high confidence*) {Table 2.7, 2.7, 3.4, 6.3, 6.5, 6.7, Box SPM.1}

FOOTNOTE 37: In this context, capture rates of new installations with CCS are assumed to be 90-95% + {11.3.5}. Capture rates for retrofit installations can be comparable, if plants are specifically designed for CCS retrofits {11.3.6}.

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C. System transformations to limit global warming

C.1 Global GHG emissions are projected to peak between 2020 and at the latest before 2025 in global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot and in those that limit warming to 2°C (>67%) and assume immediate action. [Table SPM footnote [#9], FOOTNOTE 38] **In both types of modelled pathways, rapid and deep GHG emissions reductions follow throughout 2030, 2040 and 2050 (*high confidence*). Without a strengthening of policies beyond those that are implemented by the end of 2020, GHG emissions are projected to rise beyond 2025, leading to a median global warming of 3.2 [2.2 to 3.5] °C by 2100 [FOOTNOTE 39, 40] (*medium confidence*). (Table SPM.1, Figure SPM.4, Figure SPM.5) {3.3, 3.4}**

FOOTNOTE 38: All reported warming levels are relative to the period 1850–1900. If not otherwise specified, 'pathways' always refer to pathways computed with a model. Immediate action in the pathways refers to the adoption of climate policies between 2020 and at latest 2025 intended to limit global warming at a given level.

FOOTNOTE 39: Long-term warming is calculated from all modelled pathways assuming mitigation efforts consistent with national policies that were implemented by the end of 2020 (scenarios that fall into policy category P1b of Chapter 3) and that pass through the 2030 GHG emissions ranges of such pathways assessed in Chapter 4 (See FOOTNOTE 25) {3.2, Table 4.2}

FOOTNOTE 40: Warming estimates refer to the 50th and [5th–95th] percentile across the modelled pathways and the median temperature change estimate of the probabilistic WG I climate model emulators[Footnote 1] (Table SPM1).

C.1.1 Net global GHG emissions are projected to fall from 2019 levels by 27% [13–45%] by 2030 and 63% [52-76%] [FOOTNOTE 41] by 2050 in global modelled pathways that limit warming to 2°C (>67%) and assuming immediate action (category C3a, Table SPM.1). This compares with reductions of 43% [34–60%] by 2030 and 84% [73–98%] by 2050 in pathways that limit warming to 1.5°C (>50%) with no or limited overshoot (C1, Table SPM.1) (*high confidence*).[[FOOTNOTE 42] In modelled pathways that return warming to 1.5°C (>50%) after a high overshoot [FOOTNOTE 43], GHG emissions are reduced by 23 [0-44%] in 2030 and by 75 [62-91%] in 2050 (C2, Table SPM.1) (*high confidence*). Modelled pathways that are consistent with NDCs announced prior to COP26 until 2030 and assume no increase in ambition thereafter have higher emissions, leading to a median global warming of 2.8°C [2.1-3.4°C] by 2100 (*medium confidence*). [FOOTNOTE 24] (Figure SPM .4). {3.3}

FOOTNOTE 41: In this report, emissions reductions are reported relative to 2019 modelled emission levels, while in SR1.5 emissions reductions were calculated relative to 2010. Between 2010 and 2019 global GHG and global CO_2 emissions have grown by 12% (6.5 $GtCO_2eq$) and 13% (5.0 Gt CO_2) respectively. In global modelled pathways assessed in this report that limit warming to 1.5°C (>50%) with no or limited overshoot, GHG emissions are projected to be reduced by 37% [28-57%] in 2030 relative to 2010. In the same type of pathways assessed in SR1.5, GHG emissions are reduced by 45% (40-60% interquartile range) relative to 2010. In absolute terms, the 2030 GHG emissions levels of pathways that limit warming to 1.5°C (>50%) with no or limited overshoot are higher in AR6 (31 [21-36] $GtCO_2eq$) than in SR1.5 (28 (26-31 interquartile range) $GtCO_2eq$). (Figure SPM. 1, Table SPM.1) {3.3, SR1.5}

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FOOTNOTE 42: Scenarios in this category limit peak warming to 2°C throughout the 21st century with close to, or more than, 90% likelihood.

FOOTNOTE 43: This category contains 91 scenarios with immediate action and 42 scenarios that are consistent with the NDCs until 2030.

C.1.2 In modelled pathways that limit warming to 2°C (>67%) assuming immediate action, global net CO_2 emissions are reduced compared to modelled 2019 emissions by 27% [11–46%] in 2030 and by 52% [36-70%] in 2040; and global CH_4 emissions are reduced by 24% [9–53%] in 2030 and by 37% [20–60%] in 2040. In pathways that limit warming to 1.5°C (>50%) with no or limited overshoot global net CO_2 emissions are reduced compared to modelled 2019 emissions by 48% [36–69%] in 2030 and by 80% [61-109%] in 2040; and global CH_4 emissions are reduced by 34% [21–57%] in 2030 and 44% [31-63%] in 2040. There are similar reductions of non-CO_2 emissions by 2050 in both types of pathways: CH_4 is reduced by 45% [25–70%]; N_2O is reduced by 20% [-5 – 55%]; and F-Gases are reduced by 85% [20–90%]. [FOOTNOTE 44] Across most modelled pathways, this is the maximum technical potential for anthropogenic CH_4 reductions in the underlying models *(high confidence)*. Further emissions reductions, as illustrated by the IMP-SP pathway, may be achieved through changes in activity levels and/or technological innovations beyond those represented in the majority of the pathways *(medium confidence)*. Higher emissions reductions of CH_4 could further reduce peak warming. (*high confidence*) (Figure SPM.5) {3.3}

FOOTNOTE 44: These numbers for CH_4, N_2O, and F-gases are rounded to the nearest 5% except numbers below 5%.

C.1.3 In modelled pathways consistent with the continuation of policies implemented by the end of 2020, GHG emissions continue to rise, leading to global warming of 3.2 [2.2–3.5]°C by 2100 (within C5-C7, Table SPM 1) (*medium confidence*). Pathways that exceed warming of >4°C (≥50%) (C8, SSP5-8.5, Table SPM.1) would imply a reversal of current technology and/or mitigation policy trends (*medium confidence*). Such warming could occur in emission pathways consistent with policies implemented by the end of 2020 if climate sensitivity is higher than central estimates (*high confidence*). (Table SPM.1, Figure SPM.4) {3.3, Box 3.3}

C.1.4 Global modelled pathways falling into the lowest temperature category of the assessed literature (C1, Table SPM.1) are on average associated with a higher median peak warming in AR6 compared to pathways in the same category in SR1.5. In the modelled pathways in AR6, the likelihood of limiting warming to 1.5°C has on average declined compared to SR1.5. This is because GHG emissions have risen since 2017, and many recent pathways have higher projected emissions by 2030, higher cumulative net CO_2 emissions and slightly later dates for reaching net zero CO_2 or net zero GHG emissions. High mitigation challenges, for example, due to assumptions of slow technological change, high levels of global population growth, and high fragmentation as in the Shared Socioeconomic Pathway SSP3, may render modelled pathways that limit warming to 2°C (> 67%) or lower infeasible. (*medium confidence*) (Table SPM.1, Box SPM.1) {3.3, 3.8, Annex III Figure II.1, Annex III Figure II.3}

Table SPM.1 | Key characteristics of the modelled global emissions pathways: Summary of projected CO_2 and GHG emissions, projected net zero timings and the resulting global warming outcomes. Pathways are categorised (rows), according to their likelihood of limiting warming to different peak warming levels (if peak temperature occurs before 2100) and 2100 warming levels.

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Values shown are for the median [p50] and 5th-95th percentiles [p5-p95], noting that not all pathways achieve net zero CO_2 or GHGs.

p50 [p5-p95] [1]			GHG emissions Gt CO_2-eq/yr [7]			GHG emissions reductions from 2019 % [8]			Emissions milestones [9,10]				Cumulative CO_2 emissions Gt CO_2 [13]		Cumulative net-negative CO_2 emissions Gt CO_2	Global mean temperature change 50% probability [14] °C		Likelihood of peak global warming staying below (%) [15]		
Category [2,3,4] [# pathways]	Category / subset label	WG I SSP & WG III IPs/IMPs alignment [5,6]	2030	2040	2050	2030	2040	2050	Peak CO_2 emissions (% peak before 2100)	Peak GHG emissions (% peak before 2100)	Net-zero CO_2 (% net-zero pathways)	Net-zero GHGs [11,12] (% net-zero pathways)	2020 to net-zero CO_2	2020-2100	Year of net-zero CO_2 to 2100	at peak warming	2100	<1.5°C	<2.0°C	<3.0°C
Modelled global emissions pathways categorised by projected global warming levels (GWL). Detailed likelihood definitions are provided in SPM Box1. The five illustrative scenarios (SSPx-y) considered by AR6 WGI and the Illustrative (Mitigation) Pathways assessed in WGIII are aligned with the temperature categories and are indicated in a separate column. Global emission pathways contain regionally differentiated information. This assessment focuses on their global characteristics.			*Projected median annual GHG emissions in the year across the scenarios, with the 5th-95th percentile in brackets. Modelled GHG emissions in 2019: 55 [53-58] Gt CO_2-eq*			*Projected median GHG emissions reductions of pathways in the year across the scenarios compared to modelled 2019, with the 5th-95th percentile in brackets. Negative numbers indicate increase in emissions compared to 2019*			*Median 5-year intervals at which projected CO_2 & GHG emissions peak, with the 5th-95th percentile interval in square brackets. Percentage of peaking pathways is denoted in round brackets. Three dots (…) denotes emissions peak in 2100 or beyond for that percentile.*		*Median 5-year intervals at which projected CO_2 & GHG emissions of pathways in this category reach net-zero, with the 5th-95th percentile interval in square brackets. Percentage of net zero pathways is denoted in round brackets. Three dots (…) denotes net zero not reached for that percentile.*		*Median cumulative net CO_2 emissions across the projected scenarios in this category until reaching net-zero or until 2100, with the 5th-95th percentile interval in square brackets.*		*Median cumulative net-negative CO_2 emissions between the year of net-zero CO_2 and 2100. More net-negative results in greater temperature declines after peak.*	*Projected temperature change of pathways in this category (50% probability across the range of climate uncertainties), relative to 1850-1900, at peak warming and in 2100, for the median value across the scenarios and the 5th-95th percentile interval in square brackets.*		*Median likelihood that the projected pathways in this category stay below a given global warming level, with the 5th-95th percentile interval in square brackets.*		
C1 [97]	limit warming to 1.5°C (>50%) with no or limited overshoot		31 [21-36]	17 [6-23]	9 [1-15]	43 [34-60]	69 [58-90]	84 [73-98]				2095-2100 (52%) [2050-…]	510 [330-710]	320 [-210-570]	-220 [-660–-20]	1.6 [1.4-1.6]	1.3 [1.1-1.5]	38 [33-58]	90 [86-97]	100 [99-100]
C1a [50]	… with net-zero GHGs	SSP1-1.9, SP LD	33 [22-37]	18 [6-24]	8 [0-15]	41 [31-59]	66 [58-89]	85 [72-100]	2020-2025 (100%) [2020-2025]		2050-2055 (100%) [2035-2070]	2070-2075 (100%) [2050-2090]	550 [340-760]	160 [-220-620]	-360 [-680–-140]	1.6 [1.4-1.6]	1.2 [1.1-1.4]	38 [34-60]	90 [85-98]	100 [99-100]
C1b [47]	… without net-zero GHGs	Ren	29 [21-36]	16 [7-21]	9 [4-13]	48 [35-61]	70 [62-87]	84 [76-93]				…-… [0%] […-…]	460 [320-590]	360 [10-540]	-60 [-440-0]	1.6 [1.5-1.6]	1.4 [1.3-1.5]	37 [33-56]	89 [87-96]	100 [99-100]
C2 [133]	return warming to 1.5°C (>50%) after a high overshoot	Neg	42 [31-55]	25 [17-34]	14 [5-21]	23 [0-44]	55 [40-71]	75 [62-91]	2020-2025 (100%) [2020-2030]	[2020-2025]	2055-2060 (100%) [2045-2070]	2070-2075 (87%) [2055-…]	720 [530-930]	400 [-90-620]	-360 [-680–-60]	1.7 [1.5-1.8]	1.4 [1.2-1.5]	24 [15-42]	82 [71-93]	100 [99-100]
C3 [311]	limit warming to 2°C (>67%)		44 [32-55]	29 [20-36]	20 [13-26]	21 [1-42]	46 [34-63]	64 [53-77]	2020-2025 (100%) [2020-2030]	[2020-2025]	2070-2075 (93%) [2055-…]	…-… (30%) [2075-…]	890 [640-1160]	800 [510-1140]	-40 [-290-0]	1.7 [1.6-1.8]	1.6 [1.5-1.8]	20 [13-41]	76 [68-91]	99 [98-100]
C3a [204]	… with action starting in 2020	SSP1-2.6	40 [30-49]	29 [21-36]	20 [14-27]	27 [13-45]	47 [35-63]	63 [52-76]	2020-2025 (100%) [2020-2025]		2070-2075 (91%) [2055-…]	…-… (24%) [2080-…]	860 [640-1180]	790 [480-1150]	-30 [-280-0]	1.7 [1.6-1.8]	1.6 [1.5-1.8]	21 [14-42]	78 [69-91]	100 [98-100]
C3b [97]	… NDCs until 2030	GS	52 [47-56]	29 [20-36]	18 [10-25]	5 [0-14]	46 [34-63]	68 [56-82]			2065-2070 (97%) [2055-2090]	…-… (41%) [2075-…]	910 [720-1150]	800 [560-1050]	-60 [-300-0]	1.8 [1.6-1.8]	1.6 [1.5-1.7]	17 [12-35]	73 [67-87]	99 [98-99]
C4 [159]	limit warming to 2°C (>50%)		50 [41-56]	38 [28-44]	28 [19-35]	10 [0-27]	31 [20-50]	49 [35-65]	2020-2025 (100%) [2020-2030]		2080-2085 (86%) [2065-…]	…-… (31%) [2075-…]	1210 [970-1490]	1160 [700-1490]	-30 [-390-0]	1.9 [1.7-2.0]	1.8 [1.5-2.0]	11 [7-22]	59 [50-77]	98 [95-99]
C5 [212]	limit warming to 2.5°C (>50%)		52 [46-56]	45 [37-53]	39 [30-49]	6 [-1-18]	18 [4-33]	29 [11-48]			…-… (41%) [2080-…]	…-… (12%) [2090-…]	1780 [1400-2360]	1780 [1260-2360]	0 [-160-0]	2.2 [1.9-2.5]	2.1 [1.9-2.5]	4 [0-10]	37 [18-59]	91 [83-98]
C6 [97]	limit warming to 3°C (>50%)	SSP2-4.5 Mod-Act	54 [50-62]	53 [48-61]	52 [45-57]	2 [-10-11]	3 [-14-14]	5 [-2-18]	2030-2035 (96%) [2020-2090]	2020-2025 (97%)				2790 [2440-3520]			2.7 [2.4-2.9]	0 [0-0]	8 [2-18]	71 [53-88]
C7 [164]	limit warming to 4°C (>50%)	SSP3-7.0 Cur-Pol	62 [53-69]	67 [56-76]	70 [58-83]	-11 [-18-3]	-19 [-31-1]	-24 [-41–-2]	2085-2090 (57%) [2040-…]	2090-2095 (56%)	no net-zero		no net-zero	4220 [3160-5000]	no net-zero	temperature does not peak by 2100	3.5 [2.8-3.9]	0 [0-0]	0 [0-2]	22 [7-60]
C8 [29]	exceed warming of 4°C (>=50%)	SSP5-8.5	71 [69-81]	80 [78-96]	88 [82-112]	-20 [-34–-17]	-35 [-65–-29]	-46 [-92–-36]	2080-2085 (90%) [2070-…]					5600 [4910-7450]			4.2 [3.7-5.0]	0 [0-0]	0 [0-0]	4 [0-11]

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1 Values in the table refer to the 50th and [5th–95th] percentile values across the pathways falling within a given category as defined in Box SPM.1. For emissions-related columns these values relate to the distribution of all the pathways in that category. Harmonized emissions values are given for consistency with projected global warming outcomes using climate emulators. Based on the assessment of climate emulators in AR6 WG I (Chapter 7, Box 7.1), two climate emulators are used for the probabilistic assessment of the resulting warming of the pathways. For the 'Temperature Change' and 'Likelihood' columns, the single upper row values represent the 50th percentile across the pathways in that category and the median [50th percentile] across the warming estimates of the probabilistic MAGICC climate model emulator. For the bracketed ranges, the median warming for every pathway in that category is calculated for each of the two climate model emulators (MAGICC and FaIR). Subsequently, the 5th and 95th percentile values across all pathways for each emulator are calculated. The coolest and warmest outcomes (i.e. the lowest p5 of two emulators, and the highest p95, respectively) are shown in square brackets. These ranges therefore cover both the uncertainty of the emissions pathways as well as the climate emulators' uncertainty.
2 For a description of pathways categories see Box SPM.1.
3 All global warming levels are relative to 1850–1900. See Table SPM 1 Footnote 13 below and SPM Scenarios Box FOOTNOTE 46 for more details.
4 C3 pathways are sub-categorised according to the timing of policy action to match the emissions pathways in Figure SPM.4. Two pathways derived from a cost-benefit analysis have been added to C3a, whilst 10 pathways with specifically designed near-term action until 2030, whose emissions fall below those implied by NDCs announced prior to COP26, are not included in either of the two subsets.
5 Alignment with the categories of the illustrative SSP scenarios considered in AR6 WG I, and the Illustrative (Mitigation) Pathways (IPs/IMPs) of WG III. The IMPs have common features such as deep and rapid emissions reductions, but also different combinations of sectoral mitigation strategies. See SPM Box 1 for an introduction of the IPs and IMPs and Chapter 3 for full descriptions. {3.2, 3.3, Annex III.II.4}
6 The Illustrative Mitigation Pathway 'Neg' has extensive use of carbon dioxide removal (CDR) in the AFOLU, energy and the industry sectors to achieve net negative emissions. Warming peaks around 2060 and declines to below 1.5°C (50% likelihood) shortly after 2100. Whilst technically classified as C3, it strongly exhibits the characteristics of C2 high overshoot pathways, hence it has been placed in the C2 category. See SPM C3.1 for an introduction of the IPs and IMPs.
7 The 2019 range of harmonized GHG emissions across the pathways [53-58 $GtCO_2eq$] is within the uncertainty ranges of 2019 emissions assessed in Chapter 2 [53-66 $GtCO_2$-eq]. {Fig SPM 1, Fig SPM 2, Box SPM1 FOOTNOTE 50}
8 Rates of global emission reduction in mitigation pathways are reported on a pathway-by-pathway basis relative to harmonized modelled global emissions in 2019 rather than the global emissions reported in SPM Section B and Chapter 2; this ensures internal consistency in assumptions about emission sources and activities, as well as consistency with temperature projections based on the physical climate science assessment by WG I. {Annex III.II.2.5, FOOTNOTE 50} Negative values (e.g., in C7, C8) represent an increase in emissions.
9 Emissions milestones are provided for 5-year intervals in order to be consistent with the underlying 5-year time-step data of the modelled pathways. Peak emissions (CO_2 and GHGs) are assessed for 5 year reporting intervals starting in 2020. The interval 2020-2025 signifies that projected emissions peak as soon as possible between 2020 and at latest before 2025. The upper 5-year interval refers to the median interval within which the emissions peak or reach net zero. Ranges in square brackets underneath refer to the range across the pathways, comprising the lower bound of the 5th percentile 5-year interval and the upper bound of the 95th percentile 5-year interval. Numbers in round brackets signify the fraction of pathways that reach specific milestones.
10 Percentiles reported across all pathways in that category include those that do not reach net zero before 2100 (fraction of pathways reaching net zero is given in round brackets). If the fraction of pathways that reach net zero before 2100 is lower than the fraction of pathways covered by a percentile (e.g., 0.95 for the 95th percentile), the percentile is not defined and denoted with "…". The fraction of pathways reaching net zero includes all with reported non-harmonised, and / or harmonised emissions profiles that reach net zero. Pathways were counted when at least one of the two profiles fell below 100 $MtCO_2\ yr^{-1}$ until 2100.
11 The timing of net zero is further discussed in SPM C2.4 and the Cross-Chapter Box 3 in Chapter 3 on net zero CO_2 and net zero GHG emissions.
12 For cases where models do not report all GHGs, missing GHG species are infilled and aggregated into a Kyoto basket of GHG emissions in CO_2-eq defined by the 100 year global warming potential. For each pathway, reporting of CO_2, CH_4, and N_2O emissions was the minimum required for the assessment of the climate

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response and the assignment to a climate category. Emissions pathways without climate assessment are not included in the ranges presented here. See Annex III.II.5.

13 Cumulative emissions are calculated from the start of 2020 to the time of net zero and 2100, respectively. They are based on harmonized net CO_2 emissions, ensuring consistency with the WG I assessment of the remaining carbon budget. {Box 3.4, FOOTNOTE 51 in SPM C.2}.

14 Global mean temperature change for category (at peak, if peak temperature occurs before 2100, and in 2100) relative to 1850–1900, based on the median global warming for each pathway assessed using the probabilistic climate model emulators calibrated to the AR6 WG I assessment, see also SPM Scenarios Box. {SPM FOOTNOTE 12, WG I Cross Chapter Box 7.1, Annex III.II.2.5}.

15 Probability of staying below the temperature thresholds for the pathways in each category, taking into consideration the range of uncertainty from the climate model emulators consistent with the AR6 WG I assessment. The probabilities refer to the probability at peak temperature. Note that in the case of temperature overshoot (e.g., category C2 and some pathways in C1), the probabilities of staying below at the end of the century are higher than the probabilities at peak temperature.

<START BOX SPM.1 HERE>

Box SPM.1: Assessment of modelled global emission scenarios

A wide range of modelled global emission pathways and scenarios from the literature is assessed in this report, including pathways and scenarios with and without mitigation.[FOOTNOTE 45] Emissions pathways and scenarios project the evolution of GHG emissions based on a set of internally consistent assumptions about future socio-economic conditions and related mitigation measures.[FOOTNOTE 46] These are quantitative projections and are neither predictions nor forecasts. Around half of all modelled global emission scenarios assume cost-effective approaches that rely on least-cost emission abatement options globally. The other half looks at existing policies and regionally and sectorally differentiated actions. Most do not make explicit assumptions about global equity, environmental justice or intra-regional income distribution. Global emission pathways, including those based on cost effective approaches contain regionally differentiated assumptions and outcomes, and have to be assessed with the careful recognition of these assumptions. This assessment focuses on their global characteristics. The majority of the assessed scenarios (about 80%) have become available since the SR1.5, but some were assessed in that report. Scenarios with and without mitigation were categorised based on their projected global warming over the 21st century, following the same scheme as in the SR1.5 for warming up to and including 2°C. {1.5, 3.2, 3.3, Annex III.II.2, Annex III.II.3}

FOOTNOTE 45: In the literature, the terms pathways and scenarios are used interchangeably, with the former more frequently used in relation to climate goals. For this reason, this SPM uses mostly the term (emissions and mitigation) pathways. {Annex III.II.1.1}

FOOTNOTE 46: Key assumptions relate to technology development in agriculture and energy systems and socio-economic development, including demographic and economic projections. IPCC is neutral with regard to the assumptions underlying the scenarios in the literature assessed in this report, which do not cover all possible futures. Additional scenarios may be developed. The underlying population assumptions range from 8.5 to 9.7 billion in 2050 and 7.4 to 10.9 billion in 2100 (5-95th percentile) starting from 7.6 billion in 2019. The underlying assumptions on global GDP growth (ppp) range from 2.5 to 3.5% per year in the 2019-2050 period and 1.3 to 2.1% per year in the 2050-2100 (5-95th percentile). Many underlying assumptions are regionally differentiated. {1.5; 3.2; 3.3; Figure 3.9; Annex III.II.1.4; Annex III.II.3}

Scenario categories are defined by their likelihood of exceeding global warming levels (at peak and in 2100) and referred to in this report as follows [FOOTNOTE 47, 48]:

- Category C1 comprises modelled scenarios that limit warming to 1.5°C in 2100 with a likelihood of greater than 50%, and reach or exceed warming of 1.5°C during the 21st century with a likelihood of 67% or less. In this report, these scenarios are referred to as scenarios that limit warming to 1.5°C (>50%) with no or limited overshoot. Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C and for up to several decades. [FOOTNOTE 49]

- Category C2 comprises modelled scenarios that limit warming to 1.5°C in 2100 with a likelihood of greater than 50%, and exceed warming of 1.5°C during the 21st century with a likelihood of greater than 67%. In this report, these scenarios are also referred to as scenarios

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that return warming to 1.5°C (>50%) after a high overshoot. High overshoot refers to temporarily exceeding 1.5°C global warming by 0.1-0.3°C for up to several decades.

- Category C3 comprises modelled scenarios that limit peak warming to 2°C throughout the 21st century with a likelihood of greater than 67%. In this report, these scenarios are also referred to as scenarios that limit warming to 2°C (>67%).

- Categories C4-C7 comprise modelled scenarios that limit warming to 2°C, 2.5°C, 3°C, 4°C, respectively, throughout the 21st century with a likelihood of greater than 50%. In some scenarios in C4 and many scenarios in C5-C7, warming continues beyond the 21st century.

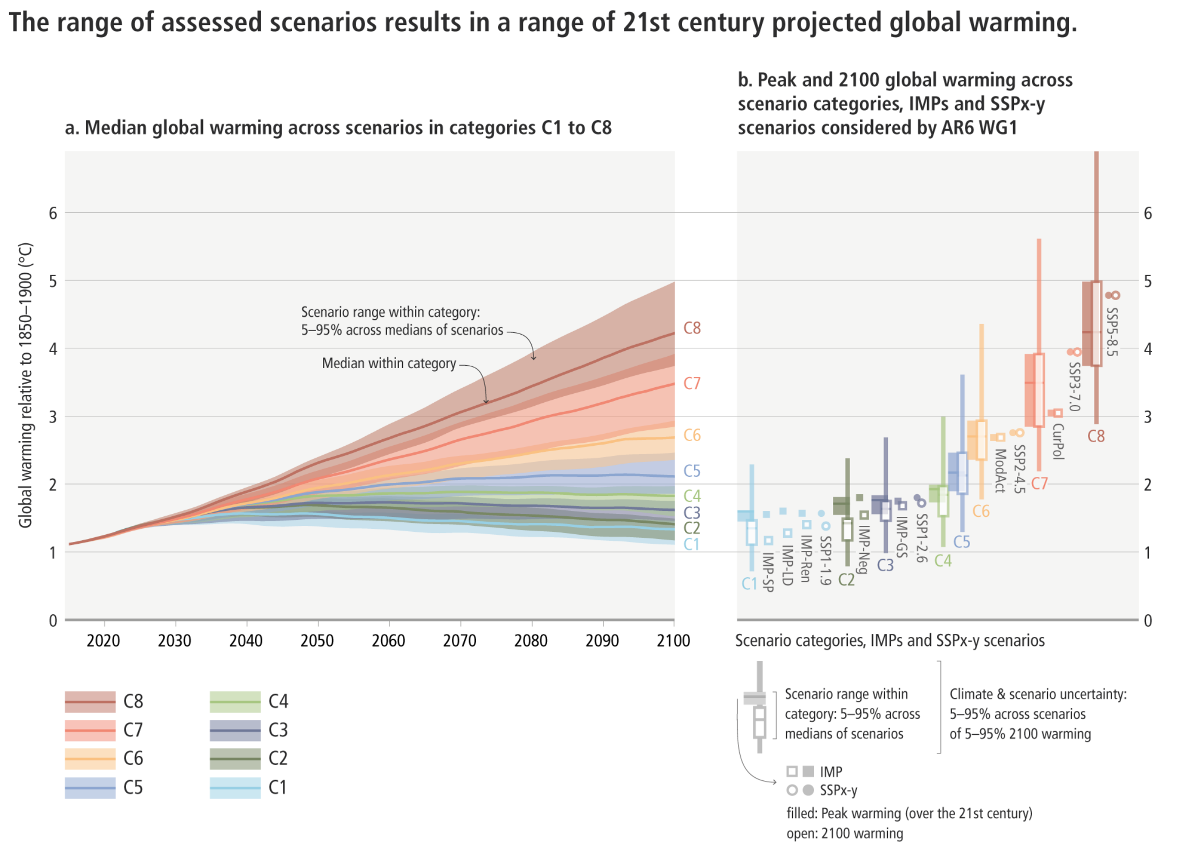
- Category C8 comprises modelled scenarios that exceed warming of 4°C during the 21st century with a likelihood of 50% or greater. In these scenarios warming continues to rise beyond the 21st century.

Categories of modelled scenarios are distinct and do not overlap; they do not contain categories consistent with lower levels of global warming, e.g., the category of C3 scenarios that limit warming to 2°C (>67%) does not include the C1 and C2 scenarios that limit or return warming to 1.5°C (>50%). Where relevant, scenarios belonging to the group of categories C1-C3 are referred to in this report as scenarios that limit warming to 2°C (>67%) or lower.

FOOTNOTE 47: The future scenario projections presented here are consistent with the total observed increase in global surface temperature between 1850-1900 and 1995-2014 as well as to 2011-2020 (with best estimates of 0.85 and 1.09°C, respectively) assessed in WGI. The largest contributor to historical human-induced warming is CO_2, with historical cumulative CO_2 emissions from 1850 to 2019 being 2400 ± 240 ($GtCO_2$). {WGI SPM A.1.2,WGI Table SPM.2, WGI Table 5.1, Section B}

FOOTNOTE 48: In case no explicit likelihood is provided, the reported warming levels are associated with a likelihood of >50%.

FOOTNOTE 49: Scenarios in this category are found to have simultaneous likelihood to limit peak global warming to 2°C throughout the 21st century of close to and more than 90%.



Box SPM.1, Figure 1

Projected global mean warming of the ensemble of modelled scenarios included in the climate categories C1-C8 and IMPs (based on emulators calibrated to the WGI assessment), as well as five illustrative scenarios (SSPx-y) as considered by AR6 WG I. The left panel shows the p5-p95 range of projected median warming across global modelled pathways within a category, with the category medians (line). The right panel shows the peak and 2100 emulated temperature outcomes for the categories C1 to C8 and for IMPs, and the five illustrative scenarios (SSPx-y) as considered by AR6 WG I. The boxes show the p5-p95 range within each scenario category as in panel-a. The combined p5-p95 range across scenarios and the climate uncertainty for each category C1- C8 is also shown for 2100 warming (thin vertical lines). {Table SPM.1, Figure 3.11, WGI Figure SPM.8}

Methods to project global warming associated with the scenarios were updated to ensure consistency with the AR6 WG1 assessment of physical climate science [FOOTNOTE 50]· {3.2, Annex III.II.2.5, WG I Cross-chapter box 7.1}

FOOTNOTE 50: This involved improved methodologies to use climate emulators (MAGICC7 and FAIR v1.6), which were evaluated and calibrated to closely match the global warming response to emissions as assessed in AR6 WGI. It included harmonisation of global GHG emissions in 2015 in modelled scenarios (51-56 $GtCO_2$-eq; 5th to 95th percentiles) with the corresponding emission value underlying the CMIP6 projected climate response assessed by WG I (54 $GtCO_2$-eq), based on similar data sources of historical emissions that are updated over time. The assessment of past GHG emissions in Chapter 2 of the report is based on a more recent dataset providing emissions of 57 [±6.3] $GtCO_2$-eq in 2015 (B.1). Differences are well within the assessed uncertainty range, and arise mainly from differences in estimated CO_2-LULUCF emissions, which are subject to large uncertainties, high annual variability and revisions over time. Projected rates of global emission reduction in mitigation scenarios are reported relative to modelled global emissions in 2019 rather than the global emissions reported in Chapter 2; this ensures internal consistency in assumptions about emission sources and activities, as well as consistency with temperature projections based on the physical climate science assessment by WG I. {Annex III.II.2.5}

These updated methods affect the categorisation of some scenarios. On average across scenarios, peak global warming is projected to be lower by up to about 0.05[±0.1]°C than if the same scenarios were evaluated using the SR1.5 methodology, and global warming in 2100 is projected to be lower by about 0.1[±0.1]°C. {Annex III.II.2.5.1, Annex III, Figure II.3}

Resulting changes to the emission characteristics of scenario categories described in Table SPM.1 interact with changes in the characteristics of the wider range of emission scenarios published since the SR1.5. Proportionally more scenarios assessed in AR6 are designed to limit temperature overshoot and more scenarios limit large-scale net negative CO_2 emissions than in SR1.5. As a result, AR6 scenarios in the lowest temperature category (C1) generally reach net zero GHG emissions later in the 21st century than scenarios in the same category assessed in SR1.5, and about half do not reach net zero GHG by 2100. The rate of decline of GHG emissions in the near term by 2030 in category C1 scenarios is very similar to the assessed rate in SR1.5, but absolute GHG emissions of category C1 scenarios in AR6 are slightly higher in 2030 than in SR1.5, since the reductions start from a higher emissions level in 2020. (Table SPM.1) {Annex III 2.5, 3.2, 3.3}

The large number of global emissions scenarios assessed, including 1202 scenarios with projected global warming outcomes using climate emulators, come from a wide range of modelling approaches. They include the five illustrative scenarios (Shared Socioeconomic Pathways; SSPs) assessed by WG I for their climate outcomes but cover a wider and more varied set in terms of assumptions and modelled outcomes. For this assessment, Illustrative Mitigation Pathways (IMPs) were selected from this larger set to illustrate a range of different mitigation strategies that would be consistent with different warming levels. The IMPs illustrate pathways that achieve deep and rapid emissions reductions through different combinations of mitigation strategies. The IMPs are not intended to be comprehensive and do not address all possible themes in the underlying report. They differ in terms of their focus, for example, placing greater emphasis on renewables (IMP-Ren), deployment of carbon dioxide removal that result in net negative global GHG emissions (IMP-Neg) and efficient resource use as well as shifts in consumption patterns globally, leading to low demand for resources, while ensuring a high level of services and satisfying basic needs (IMP-LD) (Figure SPM.5). Other IMPs illustrate the implications of a less rapid introduction of mitigation measures followed by a subsequent gradual strengthening (IMP-GS), and how shifting global pathways towards sustainable development, including by reducing inequality, can lead to mitigation (IMP-SP). The IMPs reach different climate goals as indicated in Table SPM.1 and Figure Box SPM.1.{1.5, 3.1, 3.2, 3.3, 3.6, Figure 3.7, Figure 3.8, Box 3.4, Annex III.II.2.4}

<END BOX SPM.1 HERE>

C.2 Global net zero CO_2 emissions are reached in the early 2050s in modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and around the early 2070s in modelled pathways that limit warming to 2°C (>67%). Many of these pathways continue to net negative CO_2 emissions after the point of net zero. These pathways also include deep reductions in other GHG emissions. The level of peak warming depends on cumulative CO_2 emissions until the time of net zero CO_2 and the change in non-CO_2 climate forcers by the time of peaking. Deep

GHG emissions reductions by 2030 and 2040, particularly reductions of methane emissions, lower peak warming, reduce the likelihood of overshooting warming limits and lead to less reliance on net negative CO_2 emissions that reverse warming in the latter half of the century. Reaching and sustaining global net zero GHG emissions results in a gradual decline in warming. (*high confidence)* (Table SPM.1) {3.3, 3.5, Box 3.4, Cross-Chapter Box 3 in Chapter 3, AR6 WG I SPM D1.8}

C.2.1 Modelled global pathways limiting warming to 1.5°C (>50%) with no or limited overshoot are associated with projected cumulative net CO_2 emissions [FOOTNOTE 51] until the time of net zero CO_2 of 510 [330–710] $GtCO_2$. Pathways limiting warming to 2°C (>67%) are associated with 890 [640–1160] $GtCO_2$ (Table SPM.1) . (*high confidence*). {3.3, Box 3.4}

FOOTNOTE 51: Cumulative net CO_2 emissions from the beginning of the year 2020 until the time of net zero CO_2 in assessed pathways are consistent with the remaining carbon budgets assessed by WG I, taking account of the ranges in the WG III temperature categories and warming from non-CO_2 gases. {Box 3.4}

C.2.2 Modelled global pathways that limit warming to 1.5°C (>50%) with no or limited overshoot involve more rapid and deeper near-term GHG emissions reductions through to 2030, and are projected to have less net negative CO_2 emissions and less carbon dioxide removal (CDR) in the longer term, than pathways that return warming to 1.5°C (>50%) after a high overshoot (C2 category). Modelled pathways that limit warming to 2°C (>67%) have on average lower net negative CO_2 emissions compared to pathways that limit warming to 1.5°C (>50%) with no or limited overshoot and pathways that return warming to 1.5°C (>50%) after a high overshoot (C1 and C2 categories respectively). Modelled pathways that return warming to 1.5°C (>50%) after a high overshoot (C2 category) show near-term GHG emissions reductions similar to pathways that limit warming to 2°C (>67%) (C3 category). For a given peak global warming level, greater and more rapid near-term GHG emissions reductions are associated with later net zero CO_2 dates. (*high confidence*) (Table SPM.1) {3.3, Table 3.5, Cross-Chapter Box 3 in Chapter 3, Annex I: Glossary}

C.2.3 Future non-CO_2 warming depends on reductions in non-CO_2 GHG, aerosol and their precursor, and ozone precursor emissions. In modelled global low emission pathways, the projected reduction of cooling and warming aerosol emissions over time leads to net warming in the near- to mid-term. In these mitigation pathways, the projected reductions of cooling aerosols are mostly due to reduced fossil fuel combustion that was not equipped with effective air pollution controls. Non-CO_2 GHG emissions at the time of net zero CO_2 are projected to be of similar magnitude in modelled pathways that limit warming to 2°C (>67%) or lower. These non-CO_2 GHG emissions are about 8 [5–11] $GtCO_2$-eq per year, with the largest fraction from CH_4 (60% [55–80%]), followed by N_2O (30% [20–35%]) and F-gases (3% [2–20%]). [FOOTNOTE 52] Due to the short lifetime of CH_4 in the atmosphere, projected deep reduction of CH_4 emissions up until the time of net zero CO_2 in modelled mitigation pathways effectively reduces peak global warming. (*high confidence*) {3.3, AR6 WG I SPM D1.7}

FOOTNOTE 52: All numbers here rounded to the closest 5%, except values below 5% (for F-gases).

C.2.4 At the time of global net zero GHG emissions, net negative CO_2 emissions counterbalance metric-weighted non-CO_2 GHG emissions. Typical emissions pathways that reach and sustain global net zero GHG emissions based on the 100 year global warming potential (GWP100) [FOOTNOTE 7] are projected to result in a gradual decline of global warming. About half of the assessed pathways that limit warming to 1.5°C (>50%) with no or limited overshoot (C1 category) reach net zero GHG emissions during the second half of the 21st century. These pathways show greater reduction in global warming after the peak to 1.2 [1.1-1.4]°C by 2100 than modelled pathways in the same category that

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do not reach net zero GHG emissions before 2100 and that result in warming of 1.4 [1.3–1.5]°C by 2100. In modelled pathways that limit warming to 2°C (>67%) (C3 category), there is no significant difference in warming by 2100 between those pathways that reach net zero GHGs (around 30%) and those that do not (*high confidence*). In pathways that limit warming to 2°C (>67%) or lower and that do reach net zero GHG, net zero GHG occurs around 10–40 years later than net zero CO_2 emissions (*medium confidence*). {3.3, Cross-Chapter Box 3 in Chapter 3, Cross-Chapter Box 2 in Chapter 2; AR6 WG I SPM D1.8}

C.3 All global modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and those that limit warming to 2°C (>67%) 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. Illustrative Mitigation Pathways (IMPs) show different combinations of sectoral mitigation strategies consistent with a given warming level. (*high confidence*) (Figure SPM.5) {3.2, 3.3, 3.4, 6.4, 6.6}

C.3.1 There is a variation in the contributions of different sectors in modelled mitigation pathways, as illustrated by the Illustrative Mitigation Pathways. However, modelled pathways that limit warming to 2°C (>67%) or lower share common characteristics, including rapid and deep GHG emission reductions. Doing less in one sector needs to be compensated by further reductions in other sectors if warming is to be limited. (*high confidence*) (Figure SPM.5) {3.2, 3.3, 3.4}

C.3.2 In modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, the global use of coal, oil and gas in 2050 is projected to decline with median values of about 95%, 60% and 45% compared to 2019. The interquartile ranges are (80 to 100%), (40 to 75%) and (20 to 60%) and the p5-p95 ranges are [60 to 100%], [25 to 90%] and [-30 to 85%], respectively. In modelled pathways that limit warming to 2°C (>67%), these projected declines have a median value and interquartile range of 85% (65 to 95%), 30% (15 to 50%) and 15% (-10 to 40%) respectively by 2050. The use of coal, oil and gas without CCS in modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot is projected to be reduced to a greater degree, with median values of about 100%, 60% and 70% in 2050 compared to 2019. The interquartile ranges are (95 to 100%), (45 to 75%) and (60 to 80%) and the p5-p95 range of about [85 to 100%], [25 to 90%], and [35 to 90%] for coal, oil and gas respectively. In these global modelled pathways, in 2050 almost all electricity is supplied from zero or low-carbon sources, such as renewables or fossil fuels with CCS, combined with increased electrification of energy demand. As indicated by the ranges, choices in one sector can be compensated for by choices in another while being consistent with assessed warming levels. [FOOTNOTE 53] (*high confidence*) {3.4, 3.5, Table 3.6, Figure 3.22, Figure 6.35}

FOOTNOTE 53: Most but not all models include the use of fossil fuels for feedstock with varying underlying standards.

C.3.3 In modelled pathways that reach global net zero CO_2 emissions, at the point they reach net zero, 5-16 $GtCO_2$ of emissions from some sectors are compensated for by net negative CO_2 emissions in other sectors. In most global modelled pathways that limit warming to 2°C (>67%) or lower, the AFOLU sector, via reforestation and reduced deforestation, and the energy supply sector reach net zero CO_2 emissions earlier than the buildings, industry and transport sectors. (*high confidence*) (Figure SPM.5, panel e and f) {3.4}

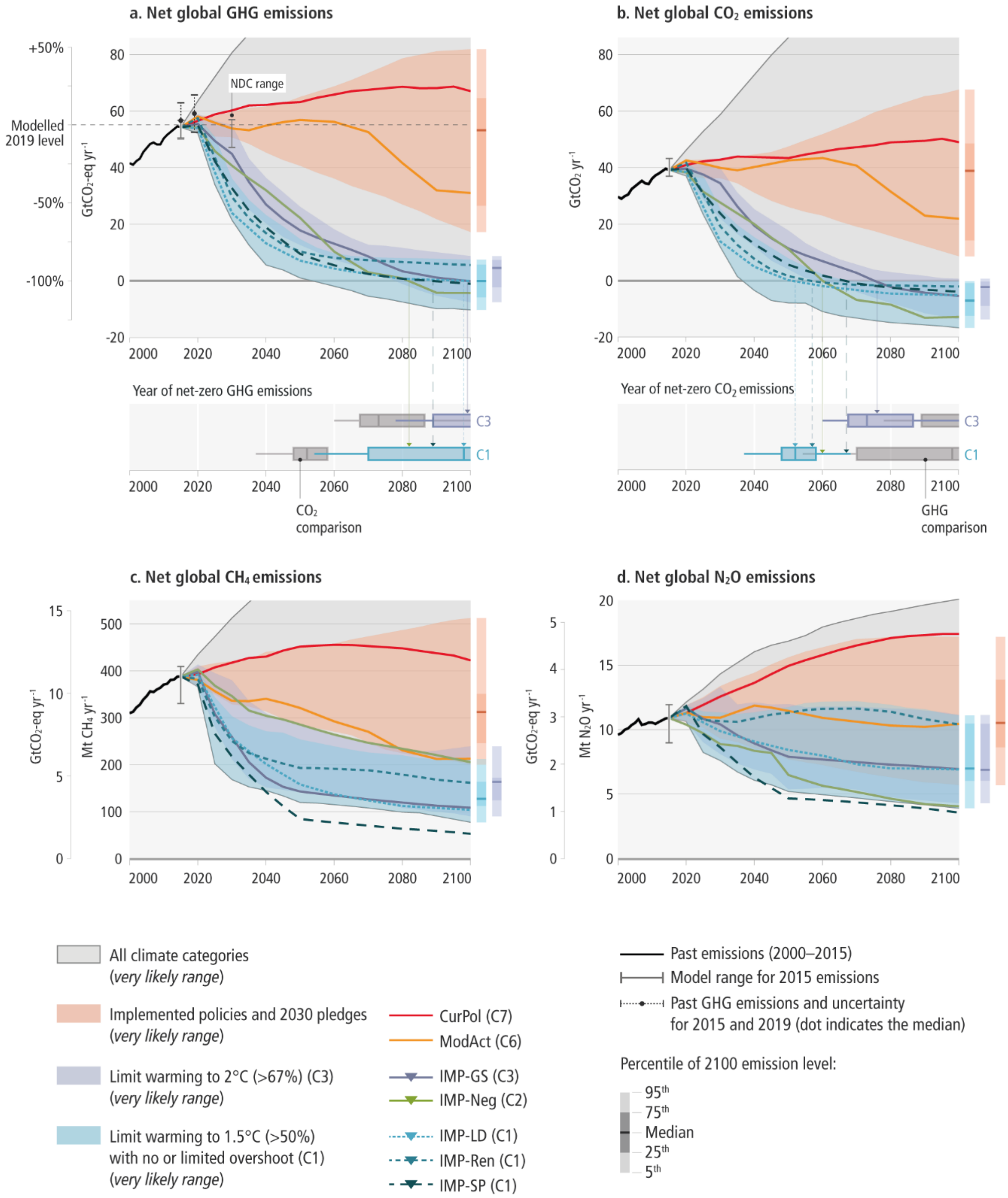
C.3.4 In modelled pathways that reach global net zero GHG emissions, at the point they reach net zero GHG, around 74% [54 to 90%] of global emissions reductions are achieved by CO_2 reductions in energy supply and demand, 13% [4 to20%] by CO_2 mitigation options in the AFOLU sector, and 13% [10 to18%] through the reduction of non-CO_2 emissions from land-use, energy and industry (*medium confidence*). (Figure SPM.5f) {3.3, 3.4}

C.3.5 Methods and levels of CDR deployment in global modelled mitigation pathways vary depending on assumptions about costs, availability and constraints. [FOOTNOTE 54] In modelled pathways that report CDR and that limit warming to 1.5°C (>50%) with no or limited overshoot, global cumulative CDR during 2020-2100 from Bioenergy with Carbon Dioxide Capture and Storage (BECCS) and Direct Air Carbon Dioxide Capture and Storage (DACCS) is 30-780 $GtCO_2$ and 0-310 $GtCO_2$, respectively. In these modelled pathways, the AFOLU sector contributes 20-400 $GtCO_2$ net negative emissions. Total cumulative net negative CO_2 emissions including CDR deployment across all options represented in these modelled pathways are 20–660 $GtCO_2$. In modelled pathways that limit warming to 2°C (>67%), global cumulative CDR during 2020–2100 from BECCS and DACCS is 170–650 and 0–250 $GtCO_2$ respectively, the AFOLU sector contributes 10–250 $GtCO_2$ net negative emissions, and total cumulative net negative CO_2 emissions are around 40 [0–290] $GtCO_2$. (Table SPM.1) (*high confidence*) {Table 3.2, 3.3, 3.4}

FOOTNOTE 54: Aggregate levels of CDR deployment are higher than total net negative CO_2 emissions given that some of the deployed CDR is used to counterbalance remaining gross emissions. Total net negative CO_2 emissions in modelled pathways might not match the aggregated net negative CO_2 emissions attributed to individual CDR methods. Ranges refer to the 5-95th percentile across modelled pathways that include the specific CDR method. Cumulative levels of CDR from AFOLU cannot be quantified precisely given that: a) some pathways assess CDR deployment relative to a baseline; and b) different models use different reporting methodologies that in some cases combine gross emissions and removals in AFOLU. Total CDR from AFOLU equals or exceeds the net negative emissions mentioned.

C.3.6 All mitigation strategies face implementation challenges, including technology risks, scaling, and costs. Many challenges, such as dependence on CDR, pressure on land and biodiversity (e.g., bioenergy) and reliance on technologies with high upfront investments (e.g., nuclear), are significantly reduced in modelled pathways that assume using resources more efficiently (e.g., IMP-LD) or shift global development towards sustainability (e.g., IMP-SP). (*high confidence*) (Figure SPM 5) {3.2, 3.4, 3.7, 3.8, 4.3, 5.1}

Modelled mitigation pathways that limit warming to 1.5°C, and 2°C, involve deep, rapid and sustained emissions reductions.



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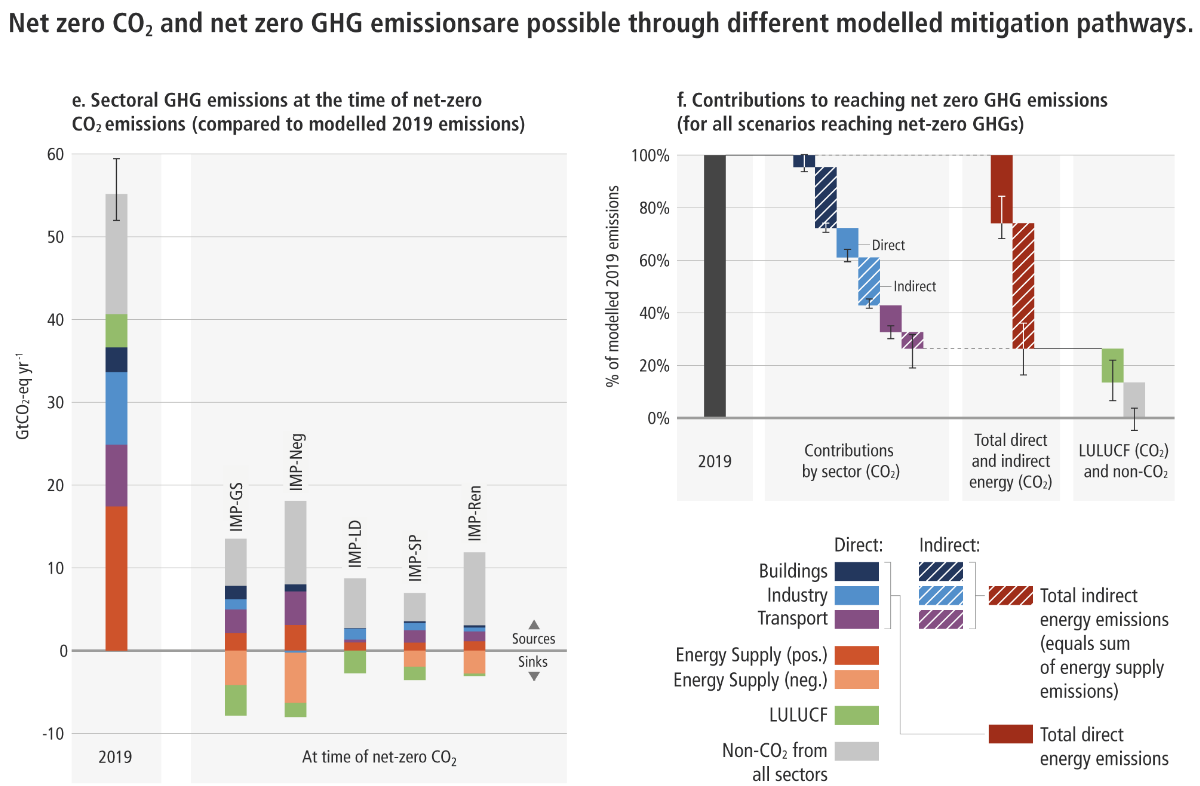

Figure SPM.5: Illustrative Mitigation Emissions Pathways (IMPs) and net zero CO_2 and GHG emissions strategies

Panel a and b show the development of global GHG and CO_2 emissions in modelled global pathways (upper sub-panels) and the associated timing of when GHG and CO_2 emissions reach net zero (lower sub-panels). Panels c and d show the development of global CH_4 and N_2O emissions, respectively. Coloured ranges denote the 5th to 95th percentile across pathways. The red ranges depict emissions pathways assuming policies that were implemented by the end of 2020 and pathways assuming implementation of NDCs (announced prior to COP26). Ranges of modelled pathways that limit warming to 1.5ºC (>50%) with no or limited overshoot are shown in light blue (category C1) and pathways that limit warming to 2ºC (>67%) are shown in light purple (category C3). The grey range comprises all assessed pathways (C1-C8) from the 5th percentile of the lowest warming category (C1) to the 95th percentile of the highest warming category (C8). The modelled pathway ranges are compared to the emissions from two pathways illustrative of high emissions (CurPol and ModAct) and five Illustrative Mitigation Pathways (IMPs): IMP-LD, IMP-Ren, IMP-SP, IMP-Neg and IMP-GS. Emissions are harmonised to the same 2015 base year. The vertical error bars in 2015 show the 5-95th percentile uncertainty range of the non-harmonised emissions across the pathways, and the uncertainty range, and median value, in emission estimates for 2015 and 2019. The vertical error bars in 2030 (panel a) depict the assessed range of the NDCs,as announced prior to COP26 (see Figure SPM.4, FOOTNOTE 24) .

Panel e shows the sectoral contributions of CO_2 and non-CO_2 emissions sources and sinks at the time when net zero CO_2 emissions are reached in the IMPs. Positive and negative emissions for different IMPs are compared to the GHG emissions from the year 2019. Energy supply (neg.) includes BECCS and DACCS. DACCS features in only two of the five IMPs (IMP-REN, IMP-GS) and contributes <1 % and 64%, respectively, to the net negative emissions in Energy Supply (neg.).

Panel f shows the contribution of different sectors and sources to the emissions reductions from a 2019 baseline for reaching net zero GHG emissions. Bars denote the median emissions reductions for all pathways that reach net zero GHG emissions. The whiskers indicate the p5-p95 range. The contributions of the service sectors (transport, buildings, industry) are split into direct (demand-side) as well as indirect (supply-side) CO_2 emissions

reductions. Direct emissions represent demand-side emissions due to the fuel use in the respective demand sector. Indirect emissions represent upstream emissions due to industrial processes and energy conversion, transmission and distribution. In addition, the contributions from the LULUCF sector and reductions from non-CO_2 emissions sources (green and grey bars) are displayed.
{3.3, 3.4}

C.4 Reducing GHG emissions across the full energy sector requires major transitions, including a substantial reduction in overall fossil fuel use, the deployment of low-emission energy sources, switching to alternative energy carriers, and energy efficiency and conservation. The continued installation of unabated fossil fuel [FOOTNOTE 55] infrastructure will 'lock-in' GHG emissions. (*high confidence*) {2.7, 6.6, 6.7, 16.4}

C.4.1 Net-zero CO_2 energy systems entail: a substantial reduction in overall fossil fuel use, minimal use of unabated fossil fuels, and use of CCS in the remaining fossil system [FOOTNOTE 55]; electricity systems that emit no net CO_2; widespread electrification of the energy system including end uses; energy carriers such as sustainable biofuels, low-emissions hydrogen, and derivatives in applications less amenable to electrification; energy conservation and efficiency; and greater physical, institutional, and operational integration across the energy system. CDR will be needed to counter-balance residual emissions in the energy sector. The most appropriate strategies depend on national and regional circumstances, including enabling conditions and technology availability. (*high confidence*) {3.4, 6.6, 11.3, 16.4}

FOOTNOTE 55: In this context, 'unabated fossil fuels' refers to fossil fuels produced and used without interventions that substantially reduce the amount of GHG emitted throughout the life-cycle; for example, capturing 90% or more from power plants, or 50-80% of fugitive methane emissions from energy supply. {Box 6.5, 11.3}

C.4.2 Unit cost reductions in key technologies, notably wind power, solar power, and storage, have increased the economic attractiveness of low-emission energy sector transitions through 2030. Maintaining emission-intensive systems may, in some regions and sectors, be more expensive than transitioning to low emission systems. Low-emission energy sector transitions will have multiple co-benefits, including improvements in air quality and health. The long-term economic attractiveness of deploying energy system mitigation options depends, *inter alia*, on policy design and implementation, technology availability and performance, institutional capacity, equity, access to finance, and public and political support. (*high confidence*) {Figure SPM3, 3.4, 6.4, 6.6, 6.7, 13.7}

C.4.3 Electricity systems powered predominantly by renewables are becoming increasingly viable. Electricity systems in some countries and regions are already predominantly powered by renewables. It will be more challenging to supply the entire energy system with renewable energy. Even though operational, technological, economic, regulatory, and social challenges remain, a variety of systemic solutions to accommodate large shares of renewables in the energy system have emerged. A broad portfolio of options such as, integrating systems, coupling sectors, energy storage, smart grids, demand-side management, sustainable biofuels, electrolytic hydrogen and derivatives, and others will ultimately be needed to accommodate large shares of renewables in energy systems. (*high confidence*) {Box 6.8, 6.4, 6.6}

C.4.4 Limiting global warming to 2ºC or below will leave a substantial amount of fossil fuels unburned and could strand considerable fossil fuel infrastructure *(high confidence)*. Depending on its availability, CCS could allow fossil fuels to be used longer, reducing stranded assets (*high confidence*). The combined global discounted value of the unburned fossil fuels and stranded fossil fuel infrastructure has been projected to be around 1–4 trillion dollars from 2015 to 2050 to limit global warming to approximately 2ºC, and it will be higher if global warming is limited to approximately 1.5ºC *(medium confidence)*. In this context, coal assets are projected to be at risk of being stranded before 2030, while oil and gas assets are projected to be more at risk of being stranded toward mid-century. A low-emission energy sector transition is projected to reduce international trade in fossil fuels. (*high confidence*) {6.7, Figure 6.35}

C.4.5 Global methane emissions from energy supply, primarily fugitive emissions from production and transport of fossil fuels, accounted for about 18% [13%-23%] of global GHG emissions from energy supply, 32% [22%-42%] of global methane emissions, and 6% [4%-8%] of global GHG emissions in 2019 (*high confidence*). About 50–80% of CH_4 emissions from these fossil fuels could be avoided with currently available technologies at less than USD50 tCO_2-eq^{-1} (*medium confidence*). {6.3, 6.4.2, Box 6.5, 11.3, 2.2.2, Table 2.1, Figure 2.5; Annex1 Glossary}

C.4.6 CCS is an option to reduce emissions from large-scale fossil-based energy and industry sources, provided geological storage is available. When CO_2 is captured directly from the atmosphere (DACCS), or from biomass (BECCS), CCS provides the storage component of these CDR methods. CO_2 capture and subsurface injection is a mature technology for gas processing and enhanced oil recovery. In contrast to the oil and gas sector, CCS is less mature in the power sector, as well as in cement and chemicals production, where it is a critical mitigation option. The technical geological CO_2 storage capacity is estimated to be on the order of 1000 gigatonnes of CO_2, which is more than the CO_2 storage requirements through 2100 to limit global warming to 1.5°C, although the regional availability of geological storage could be a limiting factor. If the geological storage site is appropriately selected and managed, it is estimated that the CO_2 can be permanently isolated from the atmosphere. Implementation of CCS currently faces technological, economic, institutional, ecological-environmental and socio-cultural barriers. Currently, global rates of CCS deployment are far below those in modelled pathways limiting global warming to 1.5°C or 2°C. Enabling conditions such as policy instruments, greater public support and technological innovation could reduce these barriers. (*high confidence*) {2.5, 6.3, 6.4, 6.7, 11.3, 11.4, Cross-Chapter Box 8 in Chapter 12, Figure TS.31, SRCCS Chapter 5}

C.5 Net-zero CO_2 emissions from the industrial sector are challenging but possible. Reducing industry emissions will entail coordinated action throughout value chains to promote all mitigation options, including demand management, energy and materials efficiency, circular material flows, as well as abatement technologies and transformational changes in production processes. Progressing towards net zero GHG emissions from industry will be enabled by the adoption of new production processes using low and zero GHG electricity, hydrogen, fuels, and carbon management. (*high confidence*) {11.2, 11.3, 11.4, Box TS.4}

C.5.1 The use of steel, cement, plastics, and other materials is increasing globally, and in most regions. There are many sustainable options for demand management, materials efficiency, and circular material flows that can contribute to reduced emissions, but how these can be applied will vary across regions and different materials. These options have a potential for being more used in industrial practice and would need more attention from industrial policy. These options, as well as new production technologies, are generally not considered in recent global scenarios nor in national economy-wide scenarios due to relative newness. As a consequence, the mitigation potential in some scenarios is underestimated compared to bottom-up industry-specific models. (*high confidence*) {3.4, 5.3, Figure 5.7, 11.2, Box 11.2, 11.3, 11.4, 11.5.2, 11.6}

C.5.2 For almost all basic materials – primary metals [FOOTNOTE 56], building materials and chemicals – many low- to zero- GHG intensity production processes are at the *pilot* to *near-commercial* and in some cases *commercial* stage but not yet established industrial practice. Introducing new sustainable basic materials production processes could increase production costs but, given the small fraction of consumer cost based on materials, are expected to translate into minimal cost increases for final consumers. Hydrogen direct reduction for primary steelmaking is *near-commercial* in some regions. Until new chemistries are mastered, deep reduction of cement process emissions will rely on already commercialised cementitious material substitution and the availability of CCS. Reducing emissions from the production and use of chemicals would need to rely on a life cycle approach, including increased plastics recycling, fuel and feedstock switching, and carbon sourced through biogenic sources, and, depending on availability, CCU, direct air CO_2 capture, as well as CCS. Light industry, mining and manufacturing have the potential to be decarbonised through available abatement technologies (e.g., material efficiency, circularity), electrification (e.g., electrothermal heating, heat pumps) and low- or zero- GHG emitting fuels (e.g., hydrogen, ammonia, and bio-based & other synthetic fuels). (*high confidence*) {Table 11.4, Box 11.2, 11.3, 11.4}

FOOTNOTE 56: Primary metals refers to virgin metals produced from ore.

C.5.3 Action to reduce industry sector emissions may change the location of GHG intensive industries and the organisation of value chains. Regions with abundant low GHG energy and feedstocks have the potential to become exporters of hydrogen-based chemicals and materials processed using low-carbon electricity and hydrogen. Such reallocation will have global distributional effects on employment and economic structure. (*medium confidence*) {Box 11.1}

C.5.4 Emissions intensive and highly traded basic materials industries are exposed to international competition, and international cooperation and coordination may be particularly important in enabling change. For sustainable industrial transitions, broad and sequential national and sub-national policy strategies reflecting regional contexts will be required. These may combine policy packages including: transparent GHG accounting and standards; demand management; materials and energy efficiency policies; R&D and niche markets for commercialisation of low emission materials and products; economic and regulatory instruments to drive market uptake; high quality recycling, low-emissions energy and other abatement infrastructure (e.g., for CCS); and socially inclusive phase-out plans of emissions intensive facilities within the context of just transitions. The coverage of mitigation policies could be expanded nationally and sub-nationally to include all industrial emission sources, and both available and emerging mitigation options. (*high confidence*) {11.6}

C.6 Urban areas can create opportunities to increase resource efficiency and significantly reduce GHG emissions through the systemic transition of infrastructure and urban form through low-emission development pathways towards net-zero emissions. Ambitious mitigation efforts for established, rapidly growing and emerging cities will encompass 1) reducing or changing energy and material consumption, 2) electrification, and 3) enhancing carbon uptake and storage in the urban environment. Cities can achieve net-zero emissions, but only if emissions are reduced within and outside of their administrative boundaries through supply chains, which will have beneficial cascading effects across other sectors. (*very high confidence*) {8.2, 8.3, 8.4, 8.5, 8.6, Figure 8.21, 13.2}

C.6.1 In modelled scenarios, global consumption-based urban CO_2 and CH_4 emissions [FOOTNOTE 15] are projected to rise from 29 $GtCO_2$-eq in 2020 to 34 $GtCO_2$-eq in 2050 with moderate mitigation efforts (intermediate GHG emissions, SSP2-4.5), and up to 40 $GtCO_2$-eq in 2050 with low mitigation efforts (high GHG emissions, SSP 3-7.0). With ambitious and immediate mitigation efforts, including high levels of electrification and improved energy and material efficiency, global consumption-based urban CO_2 and CH_4 emissions could be reduced to 3 $GtCO_2$-eq in 2050 in the modelled scenario with very low GHG emissions (SSP1-1.9). [FOOTNOTE 57] (*medium confidence*) {8.3}

FOOTNOTE 15: This estimate is based on consumption-based accounting, including both direct emissions from within urban areas, and indirect emissions from outside urban areas related to the production of electricity, goods and services consumed in cities. These estimates include all CO_2 and CH_4 emission categories except for aviation and marine bunker fuels, land-use change, forestry and agriculture. {8.1, Annex I: Glossary}

FOOTNOTE 57: These scenarios have been assessed by WGI to correspond to intermediate, high and very low GHG emissions.

C.6.2 The potential and sequencing of mitigation strategies to reduce GHG emissions will vary depending on a city's land use, spatial form, development level, and state of urbanisation (*high confidence*). Strategies for established cities to achieve large GHG emissions savings include efficiently improving, repurposing or retrofitting the building stock, targeted infilling, and supporting non-motorised (e.g., walking, bicycling) and public transport. Rapidly growing cities can avoid future emissions by co-locating jobs and housing to achieve compact urban form, and by leapfrogging or transitioning to low-emissions technologies. New and emerging cities will have significant infrastructure development needs to achieve high quality of life, which can be met through energy efficient infrastructures and services, and people-centred urban design. (*high confidence*). For cities, three broad mitigation strategies have been found to be effective when implemented concurrently: i) reducing or changing energy and material use towards more sustainable production and consumption; ii) electrification in combination with switching to low-emission energy sources; and iii) enhancing carbon uptake and storage in the urban environment, for example through bio-based building materials, permeable surfaces, green roofs, trees, green spaces, rivers, ponds and lakes [FOOTNOTE 58]. (*very high confidence*) {5.3, Figure 5.7, Table SM5.2, 8.2, 8.4, 8.6, Figure 8.21, 9.4, 9.6, 10.2}

FOOTNOTE 58: These examples are considered to be a subset of nature-based solutions or ecosystem-based approaches.

C.6.3 The implementation of packages of multiple city-scale mitigation strategies can have cascading effects across sectors and reduce GHG emissions both within and outside a city's administrative boundaries. The capacity of cities to develop and implement mitigation strategies varies with the broader regulatory and institutional settings, as well as enabling conditions, including access to financial and technological resources, local governance capacity, engagement of civil society, and municipal budgetary powers. (*very high confidence*). {Figure 5.7, Table SM5.2, 8.4, 8.5, 8.6, 13.2, 13.3, 13.5, 13.7, Cross-Chapter Box 9}

C.6.4 A growing number of cities are setting climate targets, including net-zero GHG targets. Given the regional and global reach of urban consumption patterns and supply chains, the full potential for reducing consumption-based urban emissions to net-zero GHG can be met only when emissions beyond cities' administrative boundaries are also addressed. The effectiveness of these strategies depends on cooperation and coordination with national and sub-national governments, industry, and civil society, and whether cities have adequate capacity to plan and implement mitigation strategies. Cities can play a positive role in reducing emissions across supply chains that extend beyond cities' administrative boundaries, for example through building codes and the choice of construction materials. (*very high confidence*) {8.4, Box 8.4, 8.5, 9.6, 9.9, 13.5, 13.9}

C.7. In modelled global scenarios, existing buildings, if retrofitted, and buildings yet to be built, are projected to approach net zero GHG emissions in 2050 if policy packages, which combine ambitious sufficiency, efficiency, and renewable energy measures, are effectively implemented and barriers to decarbonisation are removed. Low ambitious policies increase the risk of lock-in buildings in carbon for decades while well-designed and effectively implemented mitigation interventions, in both new buildings and existing ones if retrofitted, have significant potential to contribute to achieving SDGs in all regions while adapting buildings to future climate. (*high confidence*) {9.1, 9.3, 9.4, 9.5, 9.6, 9.9}

C.7.1 In 2019, global direct and indirect GHG emissions from buildings and emissions from cement and steel use for building construction and renovation were 12 $GtCO_2$-eq. These emissions include indirect emissions from offsite generation of electricity and heat, direct emissions produced onsite and emissions from cement and steel used for building construction and renovation. In 2019, global direct and indirect emissions from non-residential buildings increased by about 55% and those from residential buildings increased by about 50% compared to 1990. The latter increase, according to the decomposition analysis, was mainly driven by the increase of the floor area per capita, population growth and the increased use of emission-intensive electricity and heat while efficiency improvements have partly decreased emissions. There are great differences in the contribution of each of these drivers to regional emissions. (*high confidence*) {9.3}

C.7.2 Integrated design approaches to the construction and retrofit of buildings have led to increasing examples of zero energy or zero carbon buildings in several regions. However, the low renovation rates and low ambition of retrofitted buildings have hindered the decrease of emissions. Mitigation interventions at the design stage include buildings typology, form, and multi-functionality to allow for adjusting the size of buildings to the evolving needs of their users and repurposing unused existing buildings to avoid using GHG-intensive materials and additional land. Mitigation interventions include: at the construction phase, low-emission construction materials, highly efficient building envelope and the integration of renewable energy solutions[FOOTNOTE 59]; at the use phase, highly efficient appliances/ equipment, the optimisation of the use of buildings and the supply with low-emission energy

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sources; and at the disposal phase, recycling and re-using construction materials. (*high confidence*) {9.4, 9.5, 9.6, 9.7}

FOOTNOTE 59: Integration of renewable energy solutions refers to the integration of solutions such as solar photovoltaics, small wind turbines, solar thermal collectors, and biomass boilers.

C.7.3 By 2050, bottom-up studies show that up to 61% (8.2 $GtCO_2$) of global building emissions could be mitigated. Sufficiency policies [FOOTNOTE 60] that avoid the demand for energy and materials contribute 10% to this potential, energy efficiency policies contribute 42%, and renewable energy policies 9%. The largest share of the mitigation potential of new buildings is available in developing countries while in developed countries the highest mitigation potential is within the retrofit of existing buildings. The 2020-2030 decade is critical for accelerating the learning of know-how, building the technical and institutional capacity, setting the appropriate governance structures, ensuring the flow of finance, and in developing the skills needed to fully capture the mitigation potential of buildings. *(high confidence)* {9.3, 9.4, 9.5, 9.6, 9.7, 9.9}

FOOTNOTE 60: Sufficiency policies are a set of measures and daily practices that avoid demand for energy , materials, land and water while delivering human wellbeing for all within planetary boundaries.

C.8 Demand-side options and low-GHG emissions technologies can reduce transport sector emissions in developed countries and limit emissions growth in developing countries (*high confidence*). Demand-focused interventions can reduce demand for all transport services and support the shift to more energy efficient transport modes (*medium confidence*). Electric vehicles powered by low emissions electricity offer the largest decarbonisation potential for land-based transport, on a life cycle basis (*high confidence*). Sustainable biofuels can offer additional mitigation benefits in land-based transport in the short and medium term (*medium confidence*). Sustainable biofuels, low emissions hydrogen, and derivatives (including synthetic fuels) can support mitigation of CO_2 emissions from shipping, aviation, and heavy-duty land transport but require production process improvements and cost reductions (*medium confidence*). Many mitigation strategies in the transport sector would have various co-benefits, including air quality improvements, health benefits, equitable access to transportation services, reduced congestion, and reduced material demand *(high confidence)*. {10.2, 10.4, 10.5, 10.6, 10.7}

C.8.1 In scenarios that limit warming to 1.5°C (>50%) with no or limited overshoot, global transport-related CO_2 emissions fall by 59% [42–68% interquartile range] by 2050 relative to modelled 2020 emissions, but with regionally differentiated trends (*high confidence*). In global modelled scenarios that limit warming to 2°C (>67%), transport related CO_2 emissions are projected to decrease by 29% [14-44% interquartile range] by 2050 compared to modelled 2020 emissions. In both categories of scenarios, the transport sector *likely* does not reach zero CO_2 emissions by 2100 so negative emissions are *likely* needed to counterbalance residual CO_2 emissions from the sector *(high confidence)*. {3.4, 10.7}

C.8.2 Changes in urban form (e.g., density, land use mix, connectivity, and accessibility) in combination with programmes that encourage changes in consumer behaviour (e.g., transport pricing) could reduce transport related greenhouse gas emissions in developed countries and slow growth in emissions in developing countries (*high confidence*). Investments in public inter- and intra-city transport and active transport infrastructure (e.g., bike and pedestrian pathways) can further support the shift to less GHG-intensive transport modes (*high confidence*). Combinations of systemic changes including, teleworking, digitalisation, dematerialisation, supply chain management, and smart and shared mobility may reduce demand for passenger and freight services across land, air, and sea (*high confidence*). Some of these changes could lead to induced demand for transport and energy services, which may decrease their GHG emissions reduction potential (*medium confidence*). {5.3, 10.2, 10.8}

C.8.3 Electric vehicles powered by low-GHG emissions electricity have large potential to reduce land-based transport GHG emissions, on a life cycle basis (*high confidence*). Costs of electrified vehicles, including automobiles, two and three wheelers, and buses are decreasing and their adoption is accelerating, but they require continued investments in supporting infrastructure to increase scale of deployment (*high confidence*). Advances in battery technologies could facilitate the electrification of heavy-duty trucks and complement conventional electric rail systems (*medium confidence*). There are growing concerns about critical minerals needed for batteries. Material and supply diversification strategies, energy and material efficiency improvements, and circular material flows can reduce the environmental footprint and material supply risks for battery production (*medium confidence*). Sourced sustainably and with low-GHG emissions feedstocks, bio-based fuels, blended or unblended with fossil fuels, can provide mitigation benefits, particularly in the short- and medium-term (*medium confidence*). Low-GHG emissions hydrogen and hydrogen derivatives, including synthetic fuels, can offer mitigation potential in some contexts and land-based transport segments (*medium confidence*). {3.4, 6.3, 10.3, 10.4, 10.7, 10.8, Box 10.6}

C.8.4 While efficiency improvements (e.g., optimised aircraft and vessel designs, mass reduction, and propulsion system improvements) can provide some mitigation potential, additional CO_2 emissions mitigation technologies for aviation and shipping will be required (*high confidence*). For aviation, such technologies include high energy density biofuels (*high confidence*), and low-emission hydrogen and synthetic fuels (*medium confidence*). Alternative fuels for shipping include low-emission hydrogen, ammonia, biofuels, and other synthetic fuels (*medium confidence*). Electrification could play a niche role for aviation and shipping for short trips (*medium confidence*) and can reduce emissions from port and airport operations (*high confidence*). Improvements to national and international governance structures would further enable the decarbonisation of shipping and aviation (*medium confidence*). Such improvements could include, for example, the implementation of stricter efficiency and carbon intensity standards for the sectors (*medium confidence*). {10.3. 10.5, 10.6, 10.7, 10.8, Box 10.5}

C.8.5 Substantial potential for GHG reductions, both direct and indirect, for the transport sector largely depends on power sector decarbonisation, and low emissions feedstocks and production chains *(high confidence)*. Integrated transport and energy infrastructure planning and operations can enable sectoral synergies and reduce the environmental, social, and economic impacts of decarbonising the transport and energy sectors *(high confidence)*. Technology transfer and financing can support developing countries leapfrogging or transitioning to low emissions transport systems thereby providing multiple co-benefits (*high confidence*). {10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8}

C.9 AFOLU mitigation options, when sustainably implemented, can deliver large-scale GHG emission reductions and enhanced removals, but cannot fully compensate for delayed action in other sectors. In addition, sustainably sourced agricultural and forest products can be used instead of more GHG intensive products in other sectors. Barriers to implementation and trade-offs may result from the impacts of climate change, competing demands on land, conflicts with food security and livelihoods, the complexity of land ownership and management systems, and cultural aspects. There are many country-specific opportunities to provide co-benefits (such as biodiversity conservation, ecosystem services, and livelihoods) and avoid risks (for example, through adaptation to climate change). (*high confidence*) {7.4, 7.6, 7.7, 12.5, 12.6}

C.9.1 The projected economic mitigation potential of AFOLU options between 2020 and 2050, at costs below USD100 tCO_2-eq^{-1}, is 8-14 $GtCO_2$-eq yr^{-1} [FOOTNOTE 61] (*high confidence*). 30-50% of this potential is available at less than USD20/tCO_2-eq and could be upscaled in the near term across most regions (*high confidence*). The largest share of this economic potential [4.2-7.4 $GtCO_2$-eq yr^{-1}] comes from the conservation, improved management, and restoration of forests and other ecosystems (coastal wetlands, peatlands, savannas and grasslands), with reduced deforestation in tropical regions having the highest total mitigation. Improved and sustainable crop and livestock management, and carbon sequestration in agriculture, the latter includes soil carbon management in croplands and grasslands, agroforestry and biochar, can contribute 1.8-4.1 $GtCO_2$-eq yr^{-1} reduction. Demand-side and material substitution measures, such as shifting to balanced, sustainable healthy diets [FOOTNOTE 62], reducing food loss and waste, and using bio-materials, can contribute 2.1 [1.1-3.6]$GtCO_2$-eq yr^{-1} reduction. In addition, demand-side measures together with the sustainable intensification of agriculture can reduce ecosystem conversion and CH_4 and N_2O emissions, and free-up land for reforestation and restoration, and the producing of renewable energy. The improved and expanded use of wood products sourced from sustainably managed forests also has potential through the allocation of harvested wood to longer-lived products, increasing recycling or material substitution. AFOLU mitigation measures cannot compensate for delayed emission reductions in other sectors. Persistent and region-specific barriers continue to hamper the economic and political feasibility of deploying AFOLU mitigation options. Assisting countries to overcome barriers will help to achieve significant mitigation (*medium confidence*). (Figure SPM.6) {7.1, 7.4, 7.5, 7.6}

FOOTNOTE 61: The global top-down estimates and sectoral bottom-up estimates described here do not include the substitution of emissions from fossil fuels and GHG-intensive materials. 8-14 $GtCO_2$-eq yr^{-1} represents the mean of the AFOLU economic mitigation potential estimates from top-down estimates (lower bound of range) and global sectoral bottom-up estimates (upper bound of range). The full range from top-down estimates is 4.1-17.3 $GtCO_2$-eq yr^{-1} using a "no policy" baseline. The full range from global sectoral studies is 6.7-23.4 $GtCO_2$-eq yr^{-1} using a variety of baselines. (*high confidence*)

FOOTNOTE 62: 'Sustainable healthy diets' promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable, as described in FAO and WHO. The related concept of balanced diets refers to diets that feature plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission systems, as described in SRCCL.

C.9.2 AFOLU carbon sequestration and GHG emission reduction options have both co-benefits and risks in terms of biodiversity and ecosystem conservation, food and water security, wood supply, livelihoods and land tenure and land-use rights of Indigenous Peoples, local communities and small land owners. Many options have co-benefits but those that compete for land and land-based resources can pose risks. The scale of benefit or risk largely depends on the type of activity undertaken, deployment strategy (e.g., scale, method), and context (e.g., soil, biome, climate, food system, land ownership) that vary geographically and over time. Risks can be avoided when AFOLU mitigation is pursued in response to the needs and perspectives of multiple stakeholders to achieve outcomes that maximize co-benefits while limiting trade-offs. (*high confidence)* {7.4, 7.6, 12.3}

C.9.3 Realising the AFOLU potential entails overcoming institutional, economic and policy constraints and managing potential trade-offs (*high confidence*). Land-use decisions are often spread across a wide range of landowners; demand-side measures depend on billions of consumers in diverse contexts. Barriers to the implementation of AFOLU mitigation include insufficient institutional and financial support, uncertainty over long-term additionality and trade-offs, weak governance, insecure land ownership, the low incomes and the lack of access to alternative sources of income, and the risk of reversal. Limited access to technology, data, and know-how is a barrier to implementation. Research and development are key for all measures. For example, measures for the mitigation of agricultural CH_4 and N_2O emissions with emerging technologies show promising results. However the mitigation of agricultural CH_4 and N_2O emissions is still constrained by cost, the diversity and complexity of agricultural systems, and by increasing demands to raise agricultural yields, and increasing demand for livestock products. (*high confidence*) {7.4, 7.6}

C.9.4 Net costs of delivering 5-6 Gt CO_2 yr^{-1} of forest related carbon sequestration and emission reduction as assessed with sectoral models are estimated to reach to ~USD400 billion yr^{-1} by 2050. The costs of other AFOLU mitigation measures are highly context specific. Financing needs in AFOLU, and in particular in forestry, include both the direct effects of any changes in activities as well as the opportunity costs associated with land use change. Enhanced monitoring, reporting and verification capacity and the rule of law are crucial for land-based mitigation, in combination with policies also recognising interactions with wider ecosystem services, could enable engagement by a wider array of actors, including private businesses, NGOs, and Indigenous Peoples and local communities. (*medium confidence*) {7.6, 7.7}

C.9.5 Context specific policies and measures have been effective in demonstrating the delivery of AFOLU carbon sequestration and GHG emission reduction options but the above-mentioned constraints hinder large scale implementation (*medium confidence*). Deploying land-based mitigation can draw on lessons from experience with regulations, policies, economic incentives, payments (e.g., for biofuels, control of nutrient pollution, water regulations, conservation and forest carbon, ecosystem services, and rural livelihoods), and from diverse forms of knowledge such as Indigenous knowledge, local knowledge and scientific knowledge. Indigenous Peoples, private forest owners, local farmers and communities manage a significant share of global forests and agricultural land and play a central role in land-based mitigation options. Scaling successful policies and measures relies on governance that emphasises integrated land use planning and management framed by SDGs, with support for implementation. (*high confidence*) {7.4, Box 7.2, 7.6}

C.10 Demand-side mitigation encompasses changes in infrastructure use, end-use technology adoption, and socio-cultural and behavioural change. Demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end use sectors by 40-70% by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources. Demand side mitigation response options are consistent with improving basic wellbeing for all. (*high confidence*) (Figure SPM.6) {5.3, 5.4, Figure 5.6, Figure 5.14, 8.2, 9.4, 10.2, 11.3, 11.4, 12.4, Figure TS.22}

C.10.1 Infrastructure design and access, and technology access and adoption, including information and communication technologies, influence patterns of demand and ways of providing services, such as mobility, shelter, water, sanitation, and nutrition. Illustrative global low demand scenarios, accounting for regional differences, indicate that more efficient end-use energy conversion can improve services while reducing the need for upstream energy by 45% by 2050 compared to 2020. Demand-side mitigation potential differs between and within regions, and some regions and populations require additional energy, capacity, and resources for human wellbeing. The lowest population quartile by

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income worldwide faces shortfalls in shelter, mobility, and nutrition. (*high confidence*) {5.2, 5.3, 5.4, 5.5, Figure 5.6, Figure 5.10, Figure TS.20, Figure TS.22, Table 5.2}

C.10.2 By 2050, comprehensive demand-side strategies across all sectors could reduce CO_2 and non-CO_2 GHG emissions globally by 40–70% compared to the 2050 emissions projection of two scenarios consistent with policies announced by national governments until 2020. With policy support, socio-cultural options, and behavioural change can reduce global GHG emissions of end-use sectors by at least 5% rapidly, with most of the potential in developed countries, and more until 2050, if combined with improved infrastructure design and access. Individuals with high socio-economic status contribute disproportionately to emissions and have the highest potential for emissions reductions, e.g., as citizens, investors, consumers, role models, and professionals. (*high confidence*) (Figure SPM.6){5.2, 5.3, 5.4, 5.5, 5.6, Table SM5.2, 8.4, 9.9, 13.2, 13.5, 13.8, Figure TS.20}

C.10.3 A range of 5-30% of global annual GHG emissions from end-use sectors are avoidable by 2050, compared to 2050 emissions projection of two scenarios consistent with policies announced by national governments until 2020, through changes in the built environment, new and repurposed infrastructures and service provision through compact cities, co-location of jobs and housing, more efficient use of floor space and energy in buildings, and reallocation of street space for active mobility (*high confidence*). (Figure SPM.6) {5.3.1, 5.3.3, 5.4, Figure 5.7, Figure 5.13, Table 5.1, Table 5.5, Table SM5.2, 8.4, 9.5, 10.2, 11.3, 11.4, Table 11.6, Box TS.12}

C.10.4 Choice architecture [FOOTNOTE 63] can help end-users adopt, as relevant to consumers, culture and country contexts, low GHG intensive options such as balanced, sustainable healthy diets[FOOTNOTE 62] acknowledging nutritional needs; food waste reduction; adaptive heating and cooling choices for thermal comfort; integrated building renewable energy; and electric light-duty vehicles, and shifts to walking, cycling, shared pooled and public transit; sustainable consumption by intensive use of longer-lived repairable products (*high confidence*). Addressing inequality and many forms of status consumption [FOOTNOTE 64] and focusing on wellbeing supports climate change mitigation efforts (*high confidence*). (Figure SPM.6) {2.4.3, 2.6.2, 4.2.5, 5.1, 5.2, 5.3, 5.4, Figure 5.4, Figure 5.10, Table 5.2, Table SM5.2, 7.4.5, 8.2, 8.4, 9.4, 10.2, 12.4, Figure TS.20}

FOOTNOTE 63: Choice architecture describes the presentation of choices to consumers, and the impact that presentation has on consumer decision-making.

FOOTNOTE 64: Status consumption refers to the consumption of goods and services which publicly demonstrates social prestige.

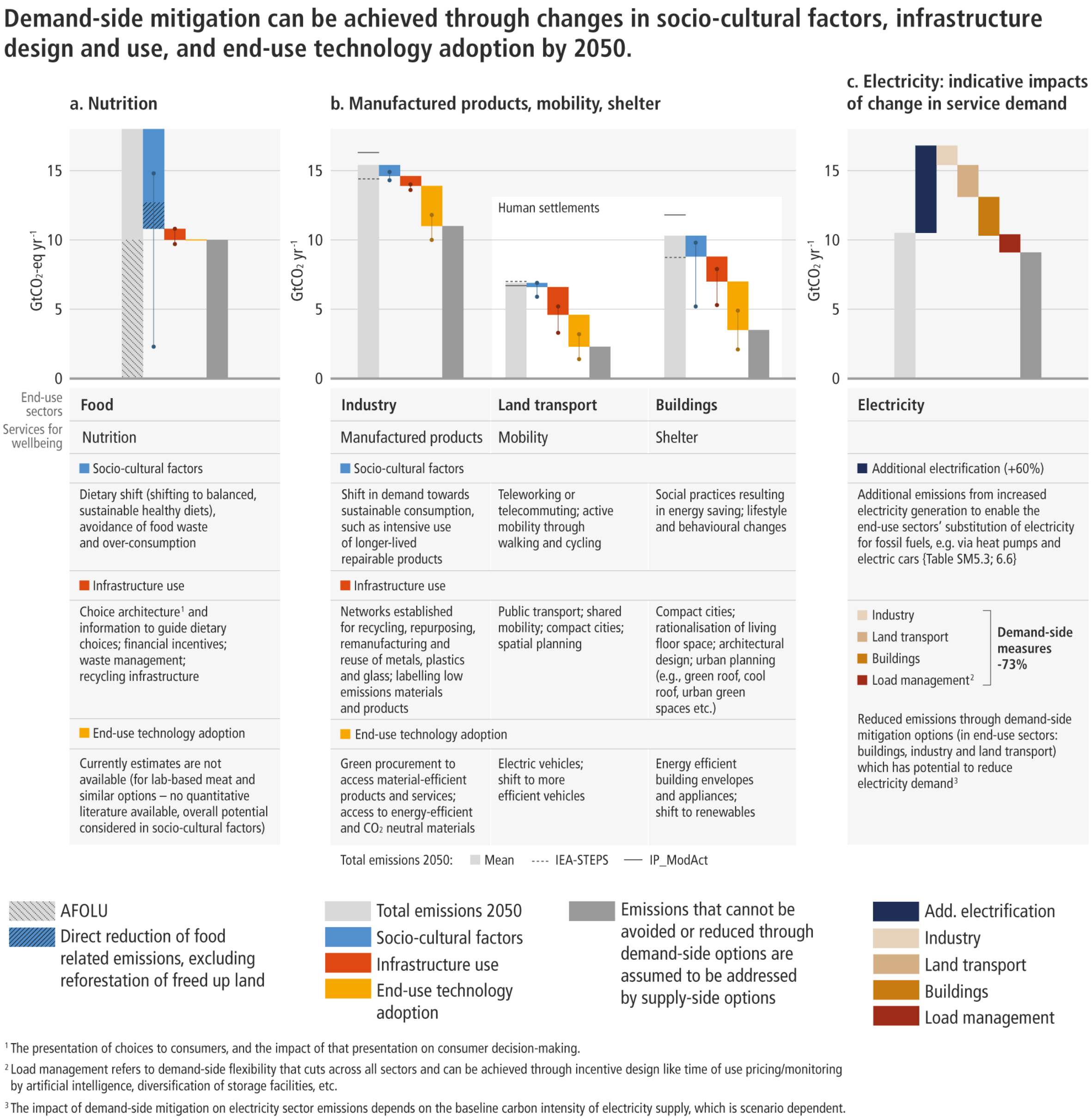

Figure SPM.6 Indicative potential of demand-side mitigation options by 2050

Figure SPM.6 covers the indicative potential of demand-side options for the year 2050. Figure SPM.7 covers cost and potentials for the year 2030. Demand-side mitigation response options are categorised into three broad domains: 'socio-cultural factors', associated with individual choices, behaviour; and lifestyle changes, social norms and culture; 'infrastructure use', related to the design and use of supporting hard and soft infrastructure that enables changes in individual choices and behaviour; and 'end-use technology adoption', refers to the uptake of technologies by end-users. Demand side mitigation is a central element of the IMP-LD and IMP-SP scenarios (Figure SPM.5).

Panel (a) (Nutrition) demand-side potentials in 2050 assessment is based on bottom-up studies and estimated following the 2050 baseline for the food sector presented in peer-reviewed literature (more information in Supplementary Material 5.II, and 7.4.5). Panel (b) (Manufactured products, mobility, shelter) assessment of potentials for total emissions in 2050 are estimated based on approximately 500 bottom up studies representing all global regions (detailed list is in Table SM5.2). Baseline is provided by the sectoral mean GHG emissions in 2050 of the two scenarios consistent with policies announced by national governments until 2020. The heights of the coloured columns represent the potentials represented by the median value. These are based on a range of values available in the case studies from literature shown in Chapter 5 Supplementary Material II. The range is

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shown by the dots connected by dotted lines representing the highest and the lowest potentials reported in the literature.

Panel (a) shows the demand side potential of socio-cultural factors and infrastructure use. The median value of direct emissions (mostly non-CO_2) reduction through socio-cultural factors is 1.9 $GtCO_2$-eq without considering land-use change through reforestation of freed up land. If changes in land use pattern enabled by this change in food demand are considered, the indicative potential could reach 7 $GtCO_2$-eq. Panel (b) illustrates mitigation potential in industry, land transport and buildings end-use sectors through demand-side options. Key options are presented in the summary table below the figure and the details are in Table SM5.2.

Panel (c) visualizes how sectoral demand-side mitigation options (presented in Panel (b)) change demand on the electricity distribution system. Electricity accounts for an increasing proportion of final energy demand in 2050 (additional electricity bar) in line with multiple bottom-up studies (detailed list is in Table SM5.3), and Chapters 6 (6.6). These studies are used to compute the impact of end-use electrification which increases overall electricity demand. Some of the projected increase in electricity demand can be avoided through demand-side mitigation options in the domains of socio-cultural factors and infrastructure use in end-use electricity use in buildings, industry, and land transport found in literature based on bottom-up assessments. Dark grey columns show the emissions that cannot be avoided through demand-side mitigation options.
{5.3, Figure 5.7, Supplementary Material 5.II}

C.11 The deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 or GHG emissions are to be achieved. The scale and timing of deployment will depend on the trajectories of gross emission reductions in different sectors. Upscaling the deployment of CDR depends on developing effective approaches to address feasibility and sustainability constraints especially at large scales. (*high confidence*) {3.4, 7.4, 12.3, Cross-Chapter Box 8 in Chapter 12}

C.11.1 CDR refers to anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products. CDR methods vary in terms of their maturity, removal process, timescale of carbon storage, storage medium, mitigation potential, cost, co-benefits, impacts and risks, and governance requirements (*high confidence*). Specifically, maturity ranges from lower maturity (e.g., ocean alkalinisation) to higher maturity (e.g., reforestation); removal and storage potential ranges from lower potential (<1 Gt CO_2 yr^{-1}, e.g., blue carbon management) to higher potential (>3 Gt CO_2 yr^{-1}, e.g., agroforestry); costs range from lower cost (e.g., 45-100 USD/tCO_2 for soil carbon sequestration) to higher cost (e.g., 100-300 USD/tCO_2 for DACCS) (*medium confidence*). Estimated storage timescales vary from decades to centuries for methods that store carbon in vegetation and through soil carbon management, to ten thousand years or more for methods that store carbon in geological formations (*high confidence*). The processes by which CO_2 is removed from the atmosphere are categorised as biological, geochemical or chemical. Afforestation, reforestation, improved forest management, agroforestry and soil carbon sequestration are currently the only widely practiced CDR methods (*high confidence*). {7.4, 7.6, 12.3, Table 12.6, Table TS.7, Cross-Chapter Box 8 in Chapter 12, WG I 5.6}

C.11.2 The impacts, risks and co-benefits of CDR deployment for ecosystems, biodiversity and people will be highly variable depending on the method, site-specific context, implementation and scale (*high confidence*). Reforestation, improved forest management, soil carbon sequestration, peatland restoration and blue carbon management are examples of methods that can enhance biodiversity and ecosystem functions, employment and local livelihoods, depending on context (*high confidence*). In contrast, afforestation or production of biomass crops for BECCS or biochar, when poorly implemented, can have adverse socio-economic and environmental impacts, including on biodiversity, food and water security, local livelihoods and on the rights of Indigenous Peoples, especially if implemented at large scales and where land tenure is insecure (*high confidence*). Ocean fertilisation, if implemented, could lead to nutrient redistribution, restructuring of ecosystems, enhanced oxygen consumption and acidification in deeper waters (*medium confidence*). {7.4, 7.6, 12.3, 12.5}

C.11.3 The removal and storage of CO_2 through vegetation and soil management can be reversed by human or natural disturbances; it is also prone to climate change impacts. In comparison, CO_2 stored in geological and ocean reservoirs (via BECCS, DACCS, ocean alkalinisation) and as carbon in biochar is less prone to reversal. (*high confidence*) {6.4, 7.4, 12.3}

C11.4 In addition to deep, rapid, and sustained emission reductions CDR can fulfil three different complementary roles globally or at country level: lowering net CO_2 or net GHG emissions in the near-term; counterbalancing 'hard-to-abate' residual emissions (e.g., emissions from agriculture, aviation, shipping, industrial processes) in order to help reach net zero CO_2 or net zero GHG emissions in the mid-term; achieving net negative CO_2 or GHG emissions in the long-term if deployed at levels exceeding annual residual emissions (*high confidence*) {3.3, 7.4, 11.3, 12.3, Cross-Chapter Box 8 in Chapter 12}

C.11.5 Rapid emission reductions in all sectors interact with future scale of deployment of CDR methods, and their associated risks, impacts and co-benefits. Upscaling the deployment of CDR methods depends on developing effective approaches to address sustainability and feasibility constraints, potential impacts, co-benefits and risks. Enablers of CDR include accelerated research, development and demonstration, improved tools for risk assessment and management, targeted incentives and development of agreed methods for measurement, reporting and verification of carbon flows. (*high confidence*) {3.4, 7.6, 12.3}

C.12 Mitigation options costing USD100 tCO_2-eq^{-1} or less could reduce global GHG emissions by at least half the 2019 level by 2030 (*high confidence*). Global GDP continues to grow in modelled pathways [FOOTNOTE 65] but, without accounting for the economic benefits of mitigation action from avoided damages from climate change nor from reduced adaptation costs, it is a few percent lower in 2050 compared to pathways without mitigation beyond current policies. The global economic benefit of limiting warming to 2°C is reported to exceed the cost of mitigation in most of the assessed literature. (*medium confidence*) (Figure SPM.7) {3.6, 3.8, Cross-Working Group Box 1 in Chapter 3, 12.2, Box TS.7}

FOOTNOTE 65: In modelled pathways that limit warming to 2°C (>67%) or lower.

C.12.1 Based on a detailed sectoral assessment of mitigation options, it is estimated that mitigation options costing USD100 tCO_2-eq^{-1} or less could reduce global GHG emissions by at least half of the 2019 level by 2030 (options costing less than USD20 tCO_2-eq^{-1} are estimated to make up more than half of this potential) [FOOTNOTE 66]. For a smaller part of the potential, deployment leads to net cost savings. Large contributions with costs less than USD20 tCO_2-eq^{-1} come from solar and wind energy, energy efficiency improvements, reduced conversion of natural ecosystems, and CH_4 emissions reductions (coal mining, oil and gas, waste). The mitigation potentials and mitigation costs of individual technologies in a specific context or region may differ greatly from the provided estimates. The assessment of the underlying literature suggests that the relative contribution of the various options could change beyond 2030. (*medium confidence*) (Figure SPM.7) {12.2}

FOOTNOTE 66. The methodology underlying the assessment is described in the caption to Figure SPM.7.

C.12.2 The aggregate effects of climate change mitigation on global GDP are small compared to global projected GDP growth in assessed modelled global scenarios that quantify the macroeconomic implications of climate change mitigation, but that do not account for damages from climate change nor adaptation costs (*high confidence*). For example, compared to pathways that assume the continuation of policies implemented by the end of 2020, assessed global GDP reached in 2050 is reduced by 1.3–2.7% in modelled pathways assuming coordinated global action starting between now and 2025 at the latest to limit warming to 2°C (>67%). The corresponding average reduction in annual global GDP growth over 2020-2050 is 0.04–0.09 percentage points. In assessed modelled pathways, regardless of the level of mitigation action, global GDP is projected to at least double (increase by at least 100%) over 2020-2050. For modelled global pathways in other temperature categories, the reductions in global GDP in 2050 compared to pathways that assume the continuation of policies implemented by the end of 2020 are as follows: 2.6 - 4.2% (C1), 1.6 - 2.8% (C2), 0.8 - 2.1% (C4), 0.5 - 1.2% (C5). The corresponding reductions in average annual global GDP growth over 2020-2050, in percentage points, are as follows: 0.09 - 0.14 (C1), 0.05 - 0.09 (C2), 0.03 - 0.07 (C4), 0.02 - 0.04 (C5) [FOOTNOTE 67]. There are large variations in the modelled effects of mitigation on GDP across regions, depending notably on economic structure, regional emissions reductions, policy design and level of international cooperation [FOOTNOTE 68] (*high confidence*). Country level studies also show large variations in the effect of mitigation on GDP depending notably on the level of mitigation and on the way it is achieved (*high confidence*). Macroeconomic implications of mitigation co-benefits and trade-offs are not quantified comprehensively across the above scenarios and depend strongly on mitigation strategies (*high confidence*). {3.6, 4.2, Box TS.7, Annex III I.2, I.9, I.10 and II.3}

FOOTNOTE 67: These estimates are based on 311 pathways that report effects of mitigation on GDP and that could be classified in temperature categories, but that do not account for damages from climate change nor adaptation costs and that mostly do not reflect the economic impacts of mitigation co-benefits and trade-offs. The ranges given are interquartile ranges. The macroeconomic implications quantified vary largely depending on technology assumptions, climate/emissions target formulation, model structure and assumptions, and the extent to which pre-existing inefficiencies are considered. Models that produced the pathways classified in temperature categories do not represent the full diversity of existing modelling paradigms, and there are in the literature models that find higher mitigation costs, or conversely lower mitigation costs and even gains. {1.7, 3.2, 3.6, Annex III I.2 I.9 I.10 and II.3}

FOOTNOTE 68: In modelled cost-effective pathways with a globally uniform carbon price, without international financial transfers or complementary policies, carbon intensive and energy exporting countries are projected to bear relatively higher mitigation costs because of a deeper transformation of their economies and changes in international energy markets. {3.6}

C.12.3 Estimates of aggregate economic benefits from avoiding damages from climate change, and from reduced adaptation costs, increase with the stringency of mitigation (*high confidence*). Models that incorporate the economic damages from climate change find that the global cost of limiting warming to 2°C over the 21st century is lower than the global economic benefits of reducing warming, unless: i) climate damages are towards the low end of the range; or, ii) future damages are discounted at high rates (*medium confidence*) [FOOTNOTE 69]. Modelled pathways with a peak in global emissions between now and 2025 at the latest, compared to modelled pathways with a later peak in global emissions, entail more rapid near-term transitions and higher up-front investments, but bring long-term gains for the economy, as well as earlier benefits of avoided climate change impacts (*high confidence*). The precise magnitude of these gains and benefits is difficult to quantify. {1.7, 3.6, Cross-Working Group Box 1 in Chapter 3 Box TS.7, WGII SPM B.4}

FOOTNOTE 69: The evidence is too limited to make a similar robust conclusion for limiting warming to 1.5°C.

Many options available now in all sectors are estimated to offer substantial potential to reduce net emissions by 2030. Relative potentials and costs will vary across countries and in the longer term compared to 2030.

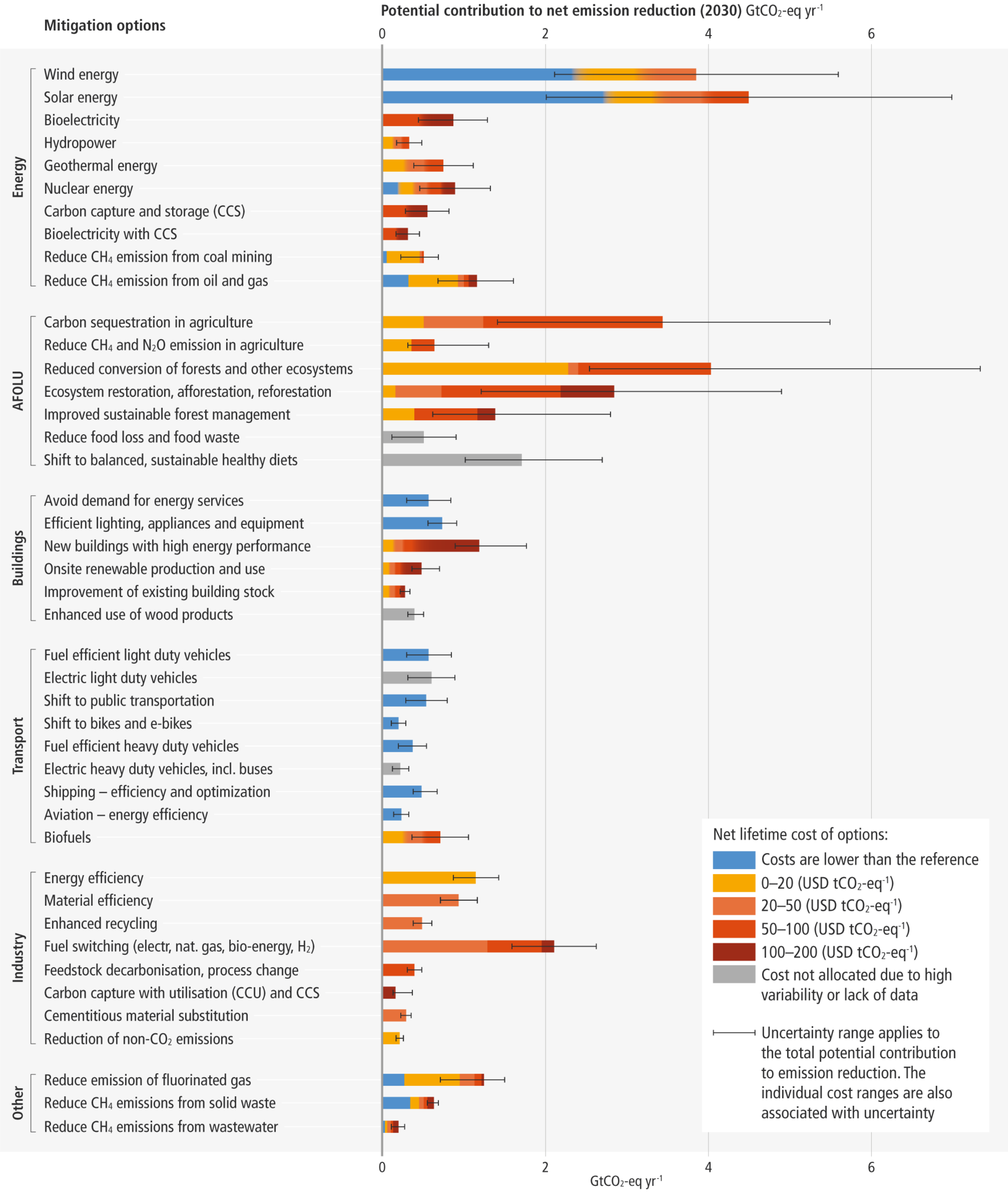

Figure SPM.7: Overview of mitigation options and their estimated ranges of costs and potentials in 2030.

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Costs shown are net lifetime costs of avoided greenhouse gas emissions. Costs are calculated relative to a reference technology. The assessments per sector were carried out using a common methodology, including definition of potentials, target year, reference scenarios, and cost definitions. The mitigation potential (shown in the horizontal axis) is the quantity of net greenhouse gas emission reductions that can be achieved by a given mitigation option relative to a specified emission baseline. Net greenhouse gas emission reductions are the sum of reduced emissions and/or enhanced sinks. The baseline used consists of current policy (~ 2019) reference scenarios from the AR6 scenarios database (25/75 percentile values). The assessment relies on approximately 175 underlying sources, that together give a fair representation of emission reduction potentials across all regions. The mitigation potentials are assessed independently for each option and are not necessarily additive. {12.2.1, 12.2.2}

The length of the solid bars represents the mitigation potential of an option. The error bars display the full ranges of the estimates for the total mitigation potentials. Sources of uncertainty for the cost estimates include assumptions on the rate of technological advancement, regional differences, and economies of scale, among others. Those uncertainties are not displayed in the figure.

Potentials are broken down into cost categories, indicated by different colours (see legend). Only discounted lifetime monetary costs are considered. Where a gradual colour transition is shown, the breakdown of the potential into cost categories is not well known or depends heavily on factors such as geographical location, resource availability, and regional circumstances, and the colours indicate the range of estimates. Costs were taken directly from the underlying studies (mostly in the period 2015-2020) or recent datasets. No correction for inflation was applied, given the wide cost ranges used. The cost of the reference technologies were also taken from the underlying studies and recent datasets. Cost reductions through technological learning are taken into account (FOOTNOTE 70).

When interpreting this figure, the following should be taken into account:

- The mitigation potential is uncertain, as it will depend on the reference technology (and emissions) being displaced, the rate of new technology adoption, and several other factors.
- Cost and mitigation potential estimates were extrapolated from available sectoral studies. Actual costs and potentials would vary by place, context and time.
- Beyond 2030, the relative importance of the assessed mitigation options is expected to change, in particular while pursuing long-term mitigation goals, recognising also that the emphasis for particular options will vary across regions (for specific mitigation options see sections C4.1, C5.2, C7.3, C8.3 and C9.1).
- Different options have different feasibilities beyond the cost aspects, which are not reflected in the figure (cf. section E.1).
- The potentials in the cost range 100 to 200 USD $tCO_2\text{-eq}^{-1}$ may be underestimated for some options.
- Costs for accommodating the integration of variable renewable energy sources in electricity systems are expected to be modest until 2030, and are not included because of complexities in attributing such costs to individual technology options.
- Cost range categories are ordered from low to high. This order does not imply any sequence of implementation.
- Externalities are not taken into account.

{12.2, Table 12.3, 6.4, Table 7.3, Supplementary Material Table 9.2, Supplementary Material Table 9.3, 10.6, 11.4, Fig 11.13, Supplementary Material 12.A.2.3}

FOOTNOTE 70: For nuclear energy, modelled costs for long-term storage of radio-active waste are included.

D. Linkages between mitigation, adaptation, and sustainable development

D.1 Accelerated and equitable climate action in mitigating, and adapting to, climate change impacts is critical to sustainable development. Climate change actions can also result in some trade-offs. The trade-offs of individual options could be managed through policy design. The Sustainable Development Goals (SDGs) adopted under the UN 2030 Agenda for Sustainable Development can be used as a basis for evaluating climate action in the context of sustainable development. (*high confidence*) (Figure SPM.8) {1.6, 3.7, 17.3, Figure TS.29}

D.1.1 Human-induced climate change is a consequence of more than a century of net GHG emissions from unsustainable energy use, land-use and land use change, lifestyle and patterns of consumption and production. Without urgent, effective and equitable mitigation actions, climate change increasingly threatens the health and livelihoods of people around the globe, ecosystem health and biodiversity. There are both synergies and trade-offs between climate action and the pursuit of other SDGs. Accelerated and equitable climate action in mitigating, and adapting to, climate change impacts is critical to sustainable development. (*high confidence*) {1.6, Cross-Chapter Box 5 in Chapter 4, 7.2, 7.3, 17.3, WGI, WGII}

D.1.2 Synergies and trade-offs depend on the development context including inequalities, with consideration of climate justice. They also depend on means of implementation, intra- and inter-sectoral interactions, cooperation between countries and regions, the sequencing, timing and stringency of mitigation actions, governance, and policy design. Maximising synergies and avoiding trade-offs pose particular challenges for developing countries, vulnerable populations, and Indigenous Peoples with limited institutional, technological and financial capacity, and with constrained social, human, and economic capital. Trade-offs can be evaluated and minimized by giving emphasis to capacity building, finance, governance, technology transfer, investments, and development and social equity considerations with meaningful participation of Indigenous Peoples and vulnerable populations. (*high confidence*) {1.6, 1.7, 3.7, 5.2, 5.6, 7.4, 7.6, 17.4}

D.1.3 There are potential synergies between sustainable development and energy efficiency and renewable energy, urban planning with more green spaces, reduced air pollution, and demand side mitigation including shifts to balanced, sustainable healthy diets (*high confidence*). Electrification combined with low GHG energy, and shifts to public transport can enhance health, employment, and can elicit energy security and deliver equity (*high confidence*). In industry, electrification and circular material flows contribute to reduced environmental pressures and increased economic activity and employment. However, some industrial options could impose high costs (*medium confidence*). (Figure SPM.8) {5.2, 8.2, 11.3, 11.5, 17.3, Figure TS.29}

D.1.4 Land-based options such as reforestation and forest conservation, avoided deforestation and restoration and conservation of natural ecosystems and biodiversity, improved sustainable forest management, agroforestry, soil carbon management and options that reduce CH_4 and N_2O emissions in agriculture from livestock and soil, can have multiple synergies with the SDGs. These include enhancing sustainable agricultural productivity and resilience, food security, providing additional biomass for human use, and addressing land degradation. Maximising synergies and managing trade-offs depend on specific practices, scale of implementation, governance, capacity building, integration with existing land-use, and the involvement of local communities and Indigenous Peoples and through benefit sharing supported by frameworks such as Land Degradation Neutrality within the UNCCD. (*high confidence*) {3.7, 7.4, 12.5, 17.3}

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D.1.5 Trade-offs in terms of employment, water use, land use competition and biodiversity, as well as access to, and the affordability of, energy, food, and water can be avoided by well-implemented land-based mitigation options, especially those that do not threaten existing sustainable land uses and land rights, though more frameworks for integrated policy implementation are required. The sustainability of bioenergy and other biobased products is influenced by feedstock, land management practice, climatic region, the context of existing land management, and the timing, scale and speed of deployment. (*medium confidence*) {3.5, 3.7, 7.4, 12.4, 12.5, 17.1}

D.1.6 CDR methods such as soil carbon sequestration and biochar [FOOTNOTE 71] can improve soil quality and food production capacity. Ecosystem restoration and reforestation sequester carbon in plants and soil, and can enhance biodiversity and provide additional biomass, but can displace food production and livelihoods, which calls for integrated approaches to land use planning, to meet multiple objectives including food security. However, due to limited application of some of the options today, there are some uncertainties about potential benefits (*high confidence*) {3.7, 7.4, 7.6, 12.5, 17.3, Table TS.7}

FOOTNOTE 71: Potential risks, knowledge gaps due to the relative immaturity of use of biochar as soil amendment and unknown impacts of widespread application, and co-benefits of biochar are reviewed in 7.4.3.2.

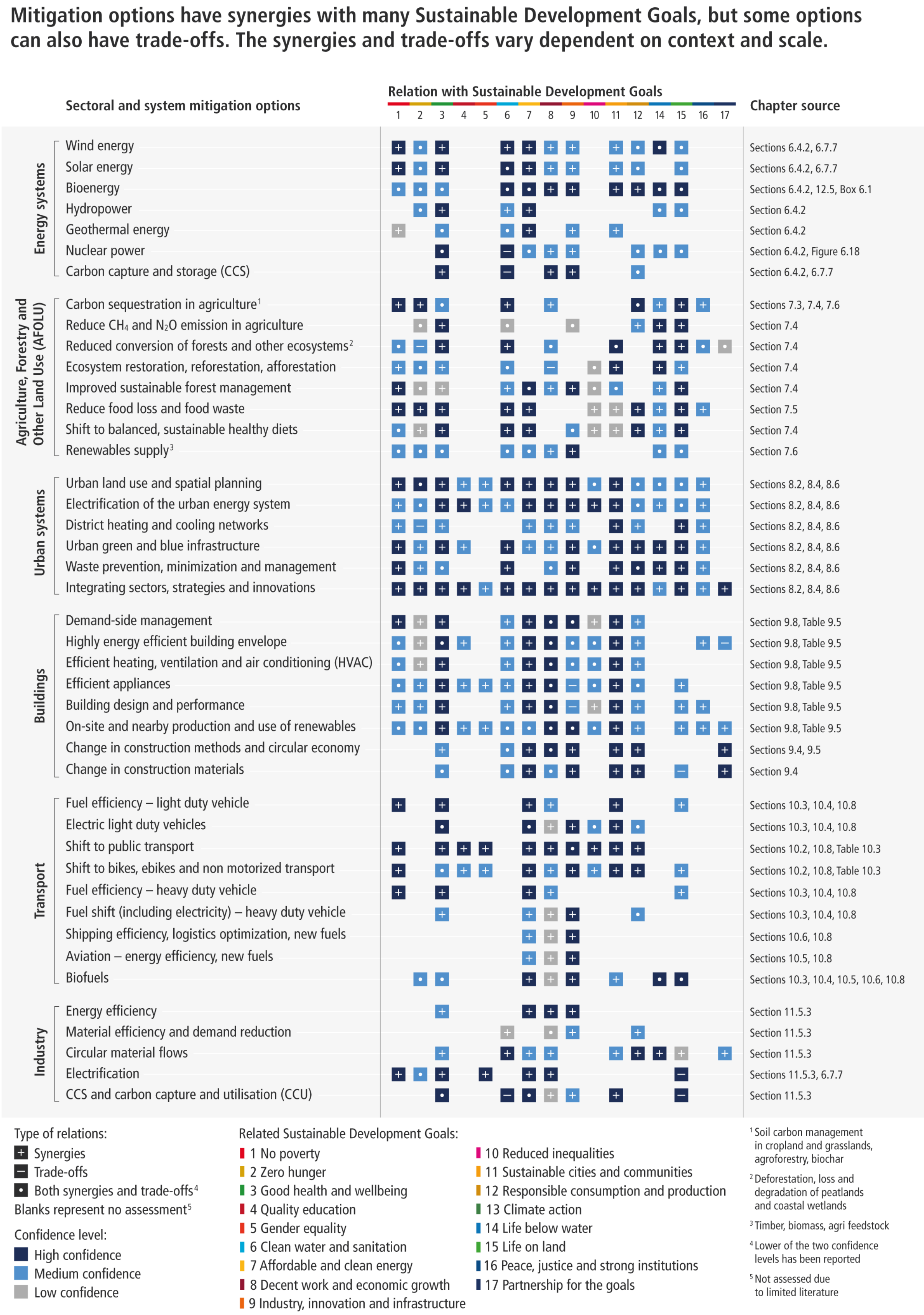

Figure SPM.8 Synergies and trade-offs between sectoral and system mitigation options and the SDGs

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The sectoral chapters (Chapters 6–11) include qualitative assessments of synergies and trade-offs between sectoral mitigation options and the SDGs. Figure SPM.8 presents a summary of the chapter-level assessment for selected mitigation options (see Supplementary Material Table 17.1 for the underlying assessment). The last column provides a line of sight to the sectoral chapters, which provide details on context specificity and dependence of interactions on the scale of implementation. Blank cells indicate that interactions have not been assessed due to limited literature. They do not indicate the absence of interactions between mitigation options and the SDGs. Confidence levels depend on the quality of evidence and level of agreement in the underlying literature assessed by the sectoral chapters. Where both synergies and trade-offs exist, the lower of the confidence levels for these interactions is used.

Some mitigation options may have applications in more than one sector or system. The interactions between mitigation options and the SDGs might differ depending on the sector or system, and also on the context and the scale of implementation. Scale of implementation particularly matters when there is competition for scarce resources.

{6.3, 6.4, 6.7, 7.3, 7.4, 7.5, 7.6, 8.2, 8.4, 8.6, Figure 8.4, Table SM8.1, Table SM8.2, 9.4, 9.5, 9.8, Table 9.5, 10.3, 10.4, 10.5, 10.6, 10.8, Table 10.3, 11.5, 12.5, 17.3, Figure 17.1, Table SM17.1, Annex II Part IV Section 12}

D.2 There is a strong link between sustainable development, vulnerability and climate risks. Limited economic, social and institutional resources often result in high vulnerability and low adaptive capacity, especially in developing countries *(medium confidence)*. Several response options deliver both mitigation and adaptation outcomes, especially in human settlements , land management, and in relation to ecosystems. However, land and aquatic ecosystems can be adversely affected by some mitigation actions, depending on their implementation (*medium confidence*). Coordinated cross-sectoral policies and planning can maximise synergies and avoid or reduce trade-offs between mitigation and adaptation (*high confidence*). {3.7, 4.4, 13.8, 17.3, WG II}

D.2.1 Sustainable urban planning and infrastructure design including green roofs and facades, networks of parks and open spaces, management of urban forests and wetlands, urban agriculture, and water-sensitive design can deliver both mitigation and adaptation benefits in settlements (*medium confidence*). These options can also reduce flood risks, pressure on urban sewer systems, urban heat island effects, and can deliver health benefits from reduced air pollution (*high confidence*). There could also be trade-offs. For example, increasing urban density to reduce travel demand, could imply high vulnerability to heat waves and flooding (*high confidence*). (Figure SPM.8) {3.7, 8.2, 8.4, 12.5, 13.8, 17.3}

D.2.2 Land-related mitigation options with potential co-benefits for adaptation include agroforestry, cover crops, intercropping, and perennial plants, thus restoring natural vegetation and rehabilitating degraded land. These can enhance resilience by maintaining land productivity and protecting and diversifying livelihoods. Restoration of mangroves and coastal wetlands sequester carbon, while also reducing coastal erosion and protecting against storm surges, thus, reduce the risks from sea level rise and extreme weather. (*high confidence*) {4.4, 7.4, 7.6, 12.5, 13.8}

D.2.3 Some mitigation options can increase competition for scarce resources including land, water and biomass. Consequently, these can also reduce adaptive capacity, especially if deployed at larger scale and with high expansion rates thus exacerbating existing risks in particular where land and water resources are very limited. Examples include the large-scale or poorly planned deployment of bioenergy, biochar, and afforestation of naturally unforested land. (*high confidence*) {12.5, 17.3}

D.2.4 Coordinated policies, equitable partnerships and integration of adaptation and mitigation within and across sectors can maximise synergies and minimise trade-offs and thereby enhance the support for climate action (*medium confidence*). Even if extensive global mitigation efforts are implemented, there will be a large need for financial, technical, and human resources for adaptation. Absence or limited resources in social and institutional systems can lead to poorly coordinated responses, thus reducing the potential for maximising mitigation and adaptation benefits, and increasing risk (*high confidence*). {12.6, 13.8, 17.1, 17.3}

D.3 Enhanced mitigation and broader action to shift development pathways towards sustainability will have distributional consequences within and between countries. Attention to equity and broad and meaningful participation of all relevant actors in decision-making at all scales can build social trust, and deepen and widen support for transformative changes. (*high confidence*) {3.6, 4.2, 4.5, 5.2, 13.2, 17.3, 17.4}

D.3.1 Countries at all stages of economic development seek to improve the well-being of people, and their development priorities reflect different starting points and contexts. Different contexts include social, economic, environmental, cultural, or political conditions, resource endowment, capabilities, international environment, and history. The enabling conditions for shifting development pathways towards increased sustainability will therefore also differ, giving rise to different needs. (*high confidence*) (Figure SPM.2) {1.6, 1.7, 2.4, 2.6, Cross-Chapter Box 5 in Chapter 4, 4.3.2, 17.4}

D.3.2 Ambitious mitigation pathways imply large and sometimes disruptive changes in economic structure, with significant distributional consequences, within and between countries. Equity remains a central element in the UN climate regime, notwithstanding shifts in differentiation between states over time and challenges in assessing fair shares. Distributional consequences within and between countries include shifting of income and employment during the transition from high to low emissions activities. While some jobs may be lost, low-emissions development can also open more opportunities to enhance skills and create more jobs that last, with differences across countries and sectors. Integrated policy packages can improve the ability to integrate considerations of equity, gender equality and justice. (*high confidence*). {1.4, 1.6, 3.6, 4.2, 5.2, Box 11.1, 14.3, 15.2, 15.5, 15.6}

D.3.3 Inequalities in the distribution of emissions and in the impacts of mitigation policies within countries affect social cohesion and the acceptability of mitigation and other environmental policies. Equity and just transitions can enable deeper ambitions for accelerated mitigation. Applying just transition principles and implementing them through collective and participatory decision-making processes is an effective way of integrating equity principles into policies at all scales, in different ways depending on national circumstances. (*medium confidence*) This is already taking place in many countries and regions, as national just transition commissions or task forces, and related national policies, have been established in several countries. A multitude of actors, networks, and movements are engaged. (*high confidence*) {1.6, 1.7, 2.4, 2.6, 4.5, 13.2, 13.9, 14.3, 14.5}

D.3.4 Broadening equitable access to domestic and international finance, technologies that facilitate mitigation, and capacity, while explicitly addressing needs can further integrate equity and justice into national and international policies and act as a catalyst for accelerating mitigation and shifting development pathways (*medium confidence*). The consideration of ethics and equity can help address the uneven distribution of adverse impacts associated with 1.5°C and higher levels of global warming, in all societies (*high confidence*). Consideration of climate justice can help to facilitate shifting development pathways towards sustainability, including through equitable sharing of benefits and burdens of mitigation, increasing resilience to the impacts of climate change, especially for vulnerable countries and communities, and equitably supporting those in need (*high confidence*). {1.4, 1.6, 1.7, 3.6, 4.2, 4.5, Box 5.10, 13.4, 13.8, 13.9, 14.3, 14.5, 15.2, 15.5, 15.6, 16.5, 17.3, 17.4, SR1.5 SPM, WGII CH18}

E. Strengthening the response

E.1 There are mitigation options which are feasible [FOOTNOTE 72] to deploy at scale in the near term. Feasibility differs across sectors and regions, and according to capacities and the speed and scale of implementation. Barriers to feasibility would need to be reduced or removed, and enabling conditions [FOOTNOTE 73] strengthened to deploy mitigation options at scale. These barriers and enablers include geophysical, environmental-ecological, technological, and economic factors, and especially institutional and socio-cultural factors. Strengthened near-term action beyond the NDCs (announced prior to UNFCCC COP26) can reduce and/or avoid long-term feasibility challenges of global modelled pathways that limit warming to 1.5 °C (>50%) with no or limited overshoot. ***(high confidence)*** **{3.8, 6.4, 8.5, 9.9, 10.8, 12.3, Figure TS.31, Annex II Part IV Section 11}**

FOOTNOTE 72: In this report, the term 'feasibility' refers to the potential for a mitigation or adaptation option to be implemented. Factors influencing feasibility are context-dependent and may change over time. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined and increase when enabling conditions are strengthened.

FOOTNOTE 73: In this report, the term 'enabling conditions' refers to conditions that enhance the feasibility of adaptation and mitigation options. Enabling conditions include finance, technological innovation, strengthening policy instruments, institutional capacity, multi-level governance and changes in human behaviour and lifestyles.

E.1.1 Several mitigation options, notably solar energy, wind energy, electrification of urban systems, urban green infrastructure, energy efficiency, demand side management, improved forest- and crop/grassland management, and reduced food waste and loss, are technically viable, are becoming increasingly cost effective, and are generally supported by the public. This enables deployment in many regions. (*high confidence*) While many mitigation options have environmental co-benefits, including improved air quality and reducing toxic waste, many also have adverse environmental impacts, such as reduced biodiversity, when applied at very large scale, for example very large scale bioenergy or large scale use of battery storage, that would have to be managed (*medium confidence*). Almost all mitigation options face institutional barriers that need to be addressed to enable their application at scale (*medium confidence*). {6.4, Figure 6.19, 7.4, 8.5, Figure 8.19, 9.9, Figure 9.20, 10.8, Figure 10.23, 12.3, Figure 12.4, Figure TS.31}

E.1.2 The feasibility of mitigation options varies according to context and time. For example, the institutional capacity to support deployment varies across countries; the feasibility of options that involve large-scale land use changes varies across regions; spatial planning has a higher potential at early stages of urban development; the potential of geothermal is site specific; and capacities, cultural and local conditions can either inhibit or enable demand-side responses. The deployment of solar and wind energy has been assessed to become increasingly feasible over time. The feasibility of some options can increase when combined or integrated, such as using land for both agriculture and

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centralised solar production. (*high confidence*) {6.4, 6.6, 7.4, 8.5, 9.9, 10.8, 12.3, Appendix 10.3, Table SM6, Table SM8.2, Table SM9.1, Table SM12.B}

E.1.3 Feasibility depends on the scale and speed of implementation. Most options face barriers when they are implemented rapidly at a large scale, but the scale at which barriers manifest themselves varies. Strengthened and coordinated near-term actions in cost-effective modelled global pathways that limit warming to 2°C (>67%) or lower, reduce the overall risks to the feasibility of the system transitions, compared to modelled pathways with relatively delayed or uncoordinated action.[FOOTNOTE 74] (*high confidence*) {3.8, 6.4, 10.8, 12.3}

FOOTNOTE 74: The future feasibility challenges described in the modelled pathways may differ from the real-world feasibility experiences of the past.

E.2 In all countries, mitigation efforts embedded within the wider development context can increase the pace, depth and breadth of emissions reductions (*medium confidence*). Policies that shift development pathways towards sustainability can broaden the portfolio of available mitigation responses, and enable the pursuit of synergies with development objectives (*medium confidence*). Actions can be taken now to shift development pathways and accelerate mitigation and transitions across systems (*high confidence*). {4.3, 4.4, Cross-Chapter Box 5 in Chapter 4, 5.2, 5.4, 13.9, 14.5, 15.6, 16.3, 16.4, 16.5}

E.2.1 Current development pathways may create behavioural, spatial, economic and social barriers to accelerated mitigation at all scales (*high confidence*). Choices made by policymakers, citizens, the private sector and other stakeholders influence societies' development pathways (*high confidence*). Actions that steer, for example, energy and land systems transitions, economy-wide structural change, and behaviour change, can shift development pathways towards sustainability [FOOTNOTE 75] (*medium confidence*). {4.3, Cross-Chapter Box 5 in Chapter 4, 5.4, 13.9}

FOOTNOTE 75: Sustainability may be interpreted differently in various contexts as societies pursue a variety of sustainable development objectives.

E.2.2 Combining mitigation with policies to shift development pathways, such as broader sectoral policies, policies that induce lifestyle or behaviour changes, financial regulation, or macroeconomic policies can overcome barriers and open up a broader range of mitigation options (*high confidence*). It can also facilitate the combination of mitigation and other development goals (*high confidence*). For example, measures promoting walkable urban areas combined with electrification and renewable energy can create health co-benefits from cleaner air and benefits from enhanced mobility (*high confidence*). Coordinated housing policies that broaden relocation options can make mitigation measures in transport more effective (*medium confidence*). {3.2, 4.3, 4.4, Cross-Chapter Box 5 in Chapter 4, 5.3, 8.2, 8.4}

E.2.3 Institutional and regulatory capacity, innovation, finance, improved governance and collaboration across scales, and multi-objective policies enable enhanced mitigation and shifts in development pathways. Such interventions can be mutually reinforcing and establish positive feedback mechanisms, resulting in accelerated mitigation. (*high confidence*) {4.4, 5.4, Figure 5.14, 5.6, 9.9, 13.9, 14.5, 15.6, 16.3, 16.4, 16.5, Cross-Chapter Box 12 in Chapter 16}

E.2.4 Enhanced action on all the above enabling conditions can be taken now (*high confidence*). In some situations, such as with innovation in technology at an early stage of development and some changes in behaviour towards low-emissions, because the enabling conditions may take time to be established, action in the near-term can yield accelerated mitigation in the mid-term (*medium *confidence*). In other situations, the enabling conditions can be put in place and yield results in a relatively short time frame, for example the provision of energy related information, advice and feedback to promote energy saving behaviour (*high confidence*). {4.4, 5.4, Figure 5.14, 5.6, 6.7, 9.9, 13.9, 14.5, 15.6, 16.3, 16.4, 16.5, Cross-Chapter Box 12 in Chapter 16}

E.3 Climate governance, acting through laws, strategies and institutions, based on national circumstances, supports mitigation by providing frameworks through which diverse actors interact, and a basis for policy development and implementation (*medium confidence*). Climate governance is most effective when it integrates across multiple policy domains, helps realise synergies and minimize trade-offs, and connects national and sub-national policy-making levels (*high confidence*). Effective and equitable climate governance builds on engagement with civil society actors, political actors, businesses, youth, labour, media, Indigenous Peoples and local communities (*medium confidence).* {5.4, 5.6, 8.5, 9.9, 13.2, 13.7, 13.9}

E.3.1 Climate governance enables mitigation by providing an overall direction, setting targets, mainstreaming climate action across policy domains, enhancing regulatory certainty, creating specialised organisations and creating the context to mobilise finance *(medium confidence)*. These functions can be promoted by climate-relevant laws, which are growing in number, or climate strategies, among others, based on national and sub-national context (*medium confidence*). Framework laws set an overarching legal basis, either operating through a target and implementation approach, or a sectoral mainstreaming approach, or both, depending on national circumstance *(medium confidence)*. Direct national and sub-national laws that explicitly target mitigation and indirect laws that impact emissions through mitigation related policy domains have both been shown to be relevant to mitigation outcomes (*medium confidence*). {13.2}

E.3.2 Effective national climate institutions address coordination across sectors, scales and actors, build consensus for action among diverse interests, and inform strategy setting *(medium confidence)*. These functions are often accomplished through independent national expert bodies, and high-level coordinating bodies that transcend departmental mandates. Complementary sub-national institutions tailor mitigation actions to local context and enable experimentation but can be limited by inequities and resource and capacity constraints (*high confidence*). Effective governance requires adequate institutional capacity at all levels (*high confidence*). {4.4, 8.5, 9.9, 11.3, 11.5, 11.6, 13.2, 13.5, 13.7, 13.9}

E.3.3 The extent to which civil society actors, political actors, businesses, youth, labour, media, Indigenous Peoples, and local communities are engaged influences political support for climate change mitigation and eventual policy outcomes. Structural factors of national circumstances and capabilities (e.g., economic and natural endowments, political systems and cultural factors and gender considerations) affect the breadth and depth of climate governance. Mitigation options that align with prevalent ideas, values and beliefs are more easily adopted and implemented. Climate-related litigation, for example by governments, private sector, civil society and individuals is growing, with a large number of cases in some developed countries, and with a much smaller number in some developing countries, and in some cases, has influenced the outcome and ambition of climate governance. (*medium confidence*) {5.2, 5.4, 5.5, 5.6, 9.9, 13.3, 13.4}

E.4 Many regulatory and economic instruments have already been deployed successfully. Instrument design can help address equity and other objectives. These instruments could support deep emissions reductions and stimulate innovation if scaled up and applied more widely (*high confidence*). Policy packages that enable innovation and build capacity are better able to support

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a shift towards equitable low-emission futures than are individual policies (*high confidence*). Economy-wide packages, consistent with national circumstances, can meet short-term economic goals while reducing emissions and shifting development pathways towards sustainability (*medium confidence*). {13.6, 13.7, 13.9, 16.3, 16.4, 16.6, Cross-Chapter Box 5 in Chapter 4}

E.4.1 A wide range of regulatory instruments at the sectoral level have proven effective in reducing emissions. These instruments, and broad-based approaches including relevant economic instruments[FOOTNOTE 76], are complementary. (*high confidence*) Regulatory instruments that are designed to be implemented with flexibility mechanisms can reduce costs (*medium confidence*). Scaling up and enhancing the use of regulatory instruments, consistent with national circumstances, could improve mitigation outcomes in sectoral applications, including but not limited to renewable energy, land-use and zoning, building codes, vehicle and energy efficiency, fuel standards, and low-emissions industrial processes and materials (*high confidence*). {6.7, 7.6, 8.4, 9.9, 10.4, 11.5, 11.6, 13.6}

FOOTNOTE 76: Economic instruments are structured to provide a financial incentive to reduce emissions and include, among others, market- and price-based instruments.

E.4.2 Economic instruments have been effective in reducing emissions, complemented by regulatory instruments mainly at the national and also sub-national and regional level (*high confidence*). Where implemented, carbon pricing instruments have incentivized low-cost emissions reduction measures, but have been less effective, on their own and at prevailing prices during the assessment period, to promote higher-cost measures necessary for further reductions (*medium confidence*). Equity and distributional impacts of such carbon pricing instruments can be addressed by using revenue from carbon taxes or emissions trading to support low-income households, among other approaches (*high confidence*). Practical experience has informed instrument design and helped to improve predictability, environmental effectiveness, economic efficiency, distributional goals and social acceptance (*high confidence*). Removing fossil fuel subsidies would reduce emissions, improve public revenue and macroeconomic performance, and yield other environmental and sustainable development benefits; subsidy removal may have adverse distributional impacts especially on the most economically vulnerable groups which, in some cases can be mitigated by measures such as re-distributing revenue saved, all of which depend on national circumstances (*high confidence*); fossil fuel subsidy removal is projected by various studies to reduce global CO_2 emissions by 1-4%, and GHG emissions by up to 10% by 2030, varying across regions (*medium confidence*). {6.3, 13.6}

E.4.3 Low-emission technological innovation is strengthened through the combination of dedicated technology-push policies and investments (e.g., for scientific training, R&D, demonstration), with tailored demand-pull policies (e.g., standards, feed-in tariffs, taxes), which create incentives and market opportunities. Developing countries' abilities to deploy low-emission technologies, seize socio-economic benefits and manage trade-offs would be enhanced with increased financial resources and capacity for innovation which are currently concentrated in developed countries, alongside technology transfer. *(high confidence)* {16.2, 16.3, 16.4, 16.5}

E.4.4 Effective policy packages would be comprehensive in coverage, harnessed to a clear vision for change, balanced across objectives, aligned with specific technology and system needs, consistent in terms of design and tailored to national circumstances. They are better able to realise synergies and avoid trade-offs across climate and development objectives. Examples include: emissions reductions from buildings through a mix of efficiency targets, building codes, appliance performance standards, information provision, carbon pricing, finance and technical assistance; and industrial GHG emissions reductions through innovation support, market creation and capacity building. (*high confidence*) {4.4, 6.7, 9.9, 11.6, 13.7, 13.9, 16.3, 16.4}

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E.4.5 Economy-wide packages that support mitigation and avoid negative environmental outcomes include: long-term public spending commitments, pricing reform; and investment in education and training, natural capital, R&D and infrastructure (*high confidence*). They can meet short-term economic goals while reducing emissions and shifting development pathways towards sustainability (*medium confidence*). Infrastructure investments can be designed to promote low-emissions futures that meet development needs (*medium confidence*). {Cross Chapter Box 7 in Chapter 4, 5.4, 5.6, 8.5, 13.6, 13.9, 16.3, 16.5, 16.6}

E.4.6 National policies to support technology development and diffusion, and participation in international markets for emission reduction, can bring positive spill-over effects for other countries (*medium confidence*), although reduced demand for fossil fuels could result in costs to exporting countries (*high confidence*). There is no consistent evidence that current emission trading systems have led to significant emissions leakage, which can be attributed to design features aimed at minimising competitiveness effects among other reasons (*medium confidence*). {13.6, 13.7, 13.8, 16.2, 16.3, 16.4}

E.5 Tracked financial flows fall short of the levels needed to achieve mitigation goals across all sectors and regions. The challenge of closing gaps is largest in developing countries as a whole. Scaling up mitigation financial flows can be supported by clear policy choices and signals from governments and the international community. (*high confidence*) Accelerated international financial cooperation is a critical enabler of low-GHG and just transitions, and can address inequities in access to finance and the costs of, and vulnerability to, the impacts of climate change (*high confidence*). {15.2, 15.3, 15.4, 15.5, 15.6}

E.5.1 Average annual modelled investment requirements for 2020 to 2030 in scenarios that limit warming to 2°C or 1.5°C are a factor of three to six greater than current levels, and total mitigation investments (public, private, domestic and international) would need to increase across all sectors and regions (*medium confidence*). Mitigation investment gaps are wide for all sectors, and widest for the AFOLU sector in relative terms and for developing countries [FOOTNOTE 77] (*high confidence*). Financing and investment requirements for adaptation, reduction of losses and damages, general infrastructure, regulatory environment and capacity building, and climate-responsive social protection further exacerbate the magnitude of the challenges for developing countries to attract financing (*high confidence*). {3.2, 14.4, 15.1, 15.2, 15.3, 15.4, 15.5}

FOOTNOTE 77: In modelled pathways, regional investments are projected to occur when and where they are most cost-effective to limit global warming. The model quantifications help to identify high-priority areas for cost-effective investments, but do not provide any indication on who would finance the regional investments.

E.5.2 There is sufficient global capital and liquidity to close global investment gaps, given the size of the global financial system, but there are barriers to redirect capital to climate action both within and outside the global financial sector, and in the macroeconomic headwinds facing developing regions. Barriers to the deployment of commercial finance from within the financial sector as well as macroeconomic considerations include: inadequate assessment of climate-related risks and investment opportunities, regional mismatch between available capital and investment needs, home bias factors, country indebtedness levels, economic vulnerability, and limited institutional capacities (*high confidence*). Challenges from outside the financial sector include: limited local capital markets; unattractive risk-return profiles, in particular due to missing or weak regulatory environments consistent with ambition levels; limited institutional capacity to ensure safeguards; standardization, aggregation, scalability and replicability of investment opportunities and financing models; and, a pipeline ready for commercial investments. *(high confidence)* {15.2, 15.3, 15.5, 15.6}

E.5.3 Accelerated financial support for developing countries from developed countries and other sources is a critical enabler to enhance mitigation action and address inequities in access to finance, including its costs, terms and conditions and economic vulnerability to climate change for developing countries (*high confidence*). Scaled-up public grants for mitigation and adaptation funding for vulnerable regions, especially in Sub-Saharan Africa, would be cost-effective and have high social returns in terms of access to basic energy (*high confidence*). Options for scaling up mitigation in developing regions include: increased levels of public finance and publicly mobilised private finance flows from developed to developing countries in the context of the USD100 billion-a-year goal; increase the use of public guarantees to reduce risks and leverage private flows at lower cost; local capital markets development; and building greater trust in international cooperation processes (*high confidence*). A coordinated effort to make the post-pandemic recovery sustainable and increased flows of financing over the next decade can accelerate climate action, including in developing regions and countries facing high debt costs, debt distress and macro-economic uncertainty (*high confidence*). {15.2, 15.3, 15.4, 15.5, 15.6, Box 15.6}

E.5.4 Clear signalling by governments and the international community, including a stronger alignment of public sector finance and policy, and higher levels of public sector climate finance, reduces uncertainty and transition risks for the private sector. Depending on national contexts, investors and financial intermediaries, central banks, and financial regulators can support climate action and can shift the systemic underpricing of climate climate-related risk by increasing awareness, transparency and consideration of climate-related risk, and investment opportunities. Financial flows can also be aligned with funding needs through: greater support for technology development; a continued role for multilateral and national climate funds and development banks; lowering financing costs for underserved groups through entities such as green banks existing in some countries, funds and risk-sharing mechanisms; economic instruments which consider economic and social equity and distributional impacts; gender-responsive and women-empowerment programs as well as enhanced access to finance for local communities and Indigenous Peoples and small landowners; and greater public-private cooperation. (*high confidence*) {15.2, 15.5, 15.6}

E.6 International cooperation is a critical enabler for achieving ambitious climate change mitigation goals. The UNFCCC, Kyoto Protocol, and Paris Agreement are supporting rising levels of national ambition and encouraging development and implementation of climate policies, although gaps remain. Partnerships, agreements, institutions and initiatives operating at the sub-global and sectoral levels and engaging multiple actors are emerging, with mixed levels of effectiveness. (*high confidence*) {8.5, 14.2, 14.3, 14.5, 14.6, 15.6, 16.5}

E.6.1 Internationally agreed processes and goals, such as those in the UNFCCC, Kyoto Protocol, and Paris Agreement, including transparency requirements for national reporting on emissions, actions and support, and tracking progress towards the achievement of nationally determined contributions, are enhancing international cooperation, national ambition and policy development. International financial, technology and capacity building support to developing countries will enable greater implementation and encourage ambitious nationally determined contributions over time. (*medium confidence*) {14.3}

E.6.2 International cooperation on technology development and transfer accompanied by capacity building, knowledge sharing, and technical and financial support can accelerate the global diffusion of mitigation technologies, practices and policies at national and sub-national levels, and align these with

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other development objectives (*high confidence*). Challenges in and opportunities to enhance innovation cooperation exist, including in the implementation of elements of the UNFCCC and the Paris Agreement as per the literature assessed, such as in relation to technology development and transfer, and finance (*high confidence*). International cooperation on innovation works best when tailored to specific institutional and capability contexts, when it benefits local value chains, when partners collaborate equitably and on voluntary and mutually agreed terms, when all relevant voices are heard, and when capacity building is an integral part of the effort (*medium confidence*). Support to strengthen technological innovation systems and innovation capabilities, including through financial support in developing countries would enhance engagement in and improve international cooperation on innovation (*high confidence*). {4.4, 14.2, 14.4, 16.3, 16.5, 16.6}

E.6.3 Transnational partnerships can stimulate policy development, low-emissions technology diffusion and emission reductions by linking sub-national and other actors, including cities, regions, non-governmental organisations and private sector entities, and by enhancing interactions between state and non-state actors. While this potential of transnational partnerships is evident, uncertainties remain over their costs, feasibility, and effectiveness. Transnational networks of city governments are leading to enhanced ambition and policy development and a growing exchange of experience and best practices (*medium confidence*). {8.5, 11.6, 14.5, 16.5, Cross-Chapter Box 12 in Chapter 16}

E.6.4 International environmental and sectoral agreements, institutions, and initiatives are helping, and in some cases may help, to stimulate low GHG emissions investment and reduce emissions. Agreements addressing ozone depletion and transboundary air pollution are contributing to mitigation, and in other areas, such as atmospheric emissions of mercury, may contribute to mitigation (*high confidence)*. Trade rules have the potential to stimulate international adoption of mitigation technologies and policies, but may also limit countries' ability to adopt trade-related climate policies (*medium confidence*). Current sectoral levels of ambition vary, with emission reduction aspirations in international aviation and shipping lower than in many other sectors (*medium confidence*). {14.5, 14.6}