CLIMATE ANALYTICS

Overview briefing on the IPCC Special Report on Global Warming of 1.5°C

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Executive summary

The impacts of about 1°C of warming are felt globally today.

This IPCC *Special report on the impacts of global warming of 1.5°C* assesses projected impacts at a global average warming of 1.5°C and higher levels of warming. We are already seeing the consequences of 1°C of global warming through more extreme weather, rising sea levels and diminishing Arctic sea ice, among other changes. It also assesses the evidence of emerging climate impacts at 1°C and illustrates how warming of 0.5°C over the historical warming period has already led to substantial increases in ⇒climate extremes.

Limiting warming to 1.5°C avoids the worst impacts of climate

The report highlights a number of climate change impacts that could be avoided by limiting global warming to 1.5°C compared to 2°C: by 2100, global sea level rise would be 10cm lower; the likelihood of an Arctic ocean free of sea ice in summer would be once per century, compared to at least one per decade; coral reefs would decline by 70-90%, whereas virtually all would be lost under 2°C. The number of people both exposed to climate-related risks and susceptible to poverty would be substantially lower under 1.5°C.

Limiting warming to 1.5°C is possible

The report is clear that limiting warming is still possible even when accounting for uncertainties and feedbacks in the climate system such as the ⇒carbon cycle and ⇒aerosol forcing. With stringent emission reductions in the very near-term, it is still possible to limit warming to below 1.5°C. Under current warming trends, 1.5°C would be reached between 2030 and 2050.

Emission reductions until 2030 are decisive to achieve 1.5°C

The report is clear that if the current round of ⇒NDCs until 2030 are maintained, the 1.5°C limit will be out of reach. Near-term emission reductions are crucial to limit warming to 1.5°C. In order to set the world on track for 1.5°C, the total greenhouse gas emissions in 2030 need to be about 50% lower than what is implied by current policies.

Net-zero CO_2 emissions by mid-century and fossil fuel phase out

In order to halt the global temperature increase, global CO_2 emissions need to reach ⇒net zero around 2050. Global greenhouse gases subsequently later. Fossil fuel (coal, oil, gas) phase out is inseparable from limiting warming to 1.5°C.

Stringent climate action comes with multiple benefits for sustainable development

Urgent, ambitious, unprecedented mitigation and adaptation action is needed across all countries, communities, and sectors, to limit global warming to 1.5°C while achieving sustainable development and poverty eradication. Limiting warming to 1.5°C will avoid critical climate change impacts on sustainable development, eradication of poverty and reducing inequalities compared to 2°C. Stringent mitigation consistent with 1.5°C pathways are associated with more synergies than possible trade- offs across the Sustainable Development Goals (SDGs). Pathways that take a holistic approach to sustainability and are characterized by low energy demand, low material consumption, and low GHG-intensive food consumption have the most pronounced synergies and limit any possible trade-offs.

Projected impacts and risks	1.5°C	2°C
Temperature extremes	Increases of up to 3°C in the mid-latitude warm season and up to 4.5°C in the high-latitude cold season	Increases of up to 4°C in the mid-latitude warm season and up to 6°C in the high-latitude cold season
Frequency of sea-ice-free Arctic summer	At least one after 100 years of stabilized warming	At least one after 10 years of stabilized warming
Global changes in urban population exposure to severe drought	350.2 ± 158.8 million	410.7 ± 213.5 million
World population exposed to new or aggravated water scarcity compared to 2000	Additional 4%	Additional 8%
Increase in the population affected by fluvial flood compared to 1976-2005	100% increase	170% increase
Species range loss	6% insects, 4% vertebrates, 8% plants	18% insects, 16% vertebrates, 8% plants
Permafrost thawing	1.5 to 2.5 million km² less for 1.5°C than for 2°C	
Rise in sea-level by 2100 (relative to 1986-2005)	0.26 to 0.77m	0.04–0.16 m higher
Coral reefs loss	70-90%	>99%
Decrease in global annual catch for marine fisheries	1.5 million tonnes	> 3 million tonnes
Coastal area exposed when temperature first reached (assuming no defenses)	562–575 thousand km²	590–613 thousand km²
Coastal population exposed when temperature first reached (assuming no defences)	128–143 million	141–151 million
People at risk accounting for defences modelled in 1995	2-28 million	15-53 million
Potential of hydropower production in Greece, Spain and Portugal	5% or less decrease	10% decrease
Capacity of thermoelectric power plants using river for cooling for most European countries	5% decrease	10% decrease
Number of people both exposed to climate-related risks and susceptible to poverty	Reduced by 62 to 457 million for 1.5°C compared to 2°C	

Origin and meaning of the 1.5°C-warming limit

The Paris Agreement is an international treaty within the United Nations Framework Convention on Climate Change (UNFCCC) that was adopted by 196 parties at the 21st Conference of the Parties (COP21) in Paris in 2015. The Agreement aims to keep global average temperature increase to well below 2°C above pre-industrial and to pursue efforts to limit the increase to 1.5°C (Article 2.1 of the Paris Agreement).
This long-term goal of 1.5°C accommodates two interpretations: (1) Establishing 1.5°C as an upper limit that should not be exceeded, or (2) possibly allowing for a temporary exceedance (overshoot) of the 1.5°C warming level, while warming should always remain 'well below 2°C'.
The Paris Agreement clearly defines the 1.5°C limit as human-made warming only, excluding natural, year-to-year variations. As the world keeps warming and we get closer to the 1.5°C limit, the probability of individual years exceeding that limit is expected to increase due to natural variability. However, individual years that exceed 1.5°C do not mean that the Paris Agreement 1.5°C limit has been breached. Human-made long-term temperature change is assessed by averaging global mean temperature over periods of at least 20 years to avoid the influence of natural variations.

The purpose of the 1.5°C temperature goal is to 'reduce the risks and impacts of climate change' and not to achieve a mere objective in terms of a temperature number. In 2018, the Intergovernmental Panel on Climate Change Change (IPCC) published a special report, which outlined climate impacts at 1.5°C of warming, underscoring the urgency for governments to act. The report showed that achieving this goal is feasible and outlines global emission pathways that are needed to get there. This briefing aims to summarise the main points of this IPCC Special Report on 1.5°C.

The arrows (⇒) in the text in front of words indicate that a definition of the term is given in the Glossary at the end of the report.

1. Current adverse impacts of climate change

1.1 Current situation: approximately 1°C of global warming

- Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels;
- Anthropogenic global warming is currently increasing at 0.2°C per decade;

Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels. This estimation of anthropogenic global warming matches the level of observed warming to within ±20%. There is *high confidence* that in 2006-2015, observed ⇒global mean surface temperature (GMST) was 0.87°C higher than the average over the 1850-1900 period, and that anthropogenic global warming is currently increasing at 0.2°C per decade due to past and ongoing emissions.

Moreover, many land regions and seasons are experiencing greater warming than the global annual average. For example, the Arctic is experiencing warming that is two to three times higher. Warming over land is generally higher than over the ocean (high confidence). Due to these regional differences, there is *medium confidence* that 20-40% of the global human population live in regions that, by the decade 2006-2015, had already experienced warming of more than 1.5°C above pre-industrial in at least one season.

1.2 Persistence and long-term changes of anthropogenic emissions

- Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia;
- These past emissions alone are unlikely to cause global warming of 1.5°C.

Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia. Therefore, these past emissions will continue to cause long-term changes in the climate system, such as sea level rise, and associated impacts.

However, these past emissions alone are *unlikely* to raise global-mean temperature to 1.5°C above pre-industrial levels on multi-decadal time scales. As shown in Figure 1, reaching and sustaining ⇒net zero global anthropogenic CO2 emissions and declining net non-CO2 ⇒radiative forcing would halt anthropogenic global warming on multi-decadal time scales (*high confidence*). Nevertheless, on a century time scale, sustained ⇒net negative global anthropogenic CO2 emissions and/or further reductions in non-CO2 ⇒radiative forcing may still be required to prevent further warming due to Earth system feedbacks and to reverse ⇒ocean acidification (*medium confidence*), and to minimize sea level rise (*high confidence*).

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

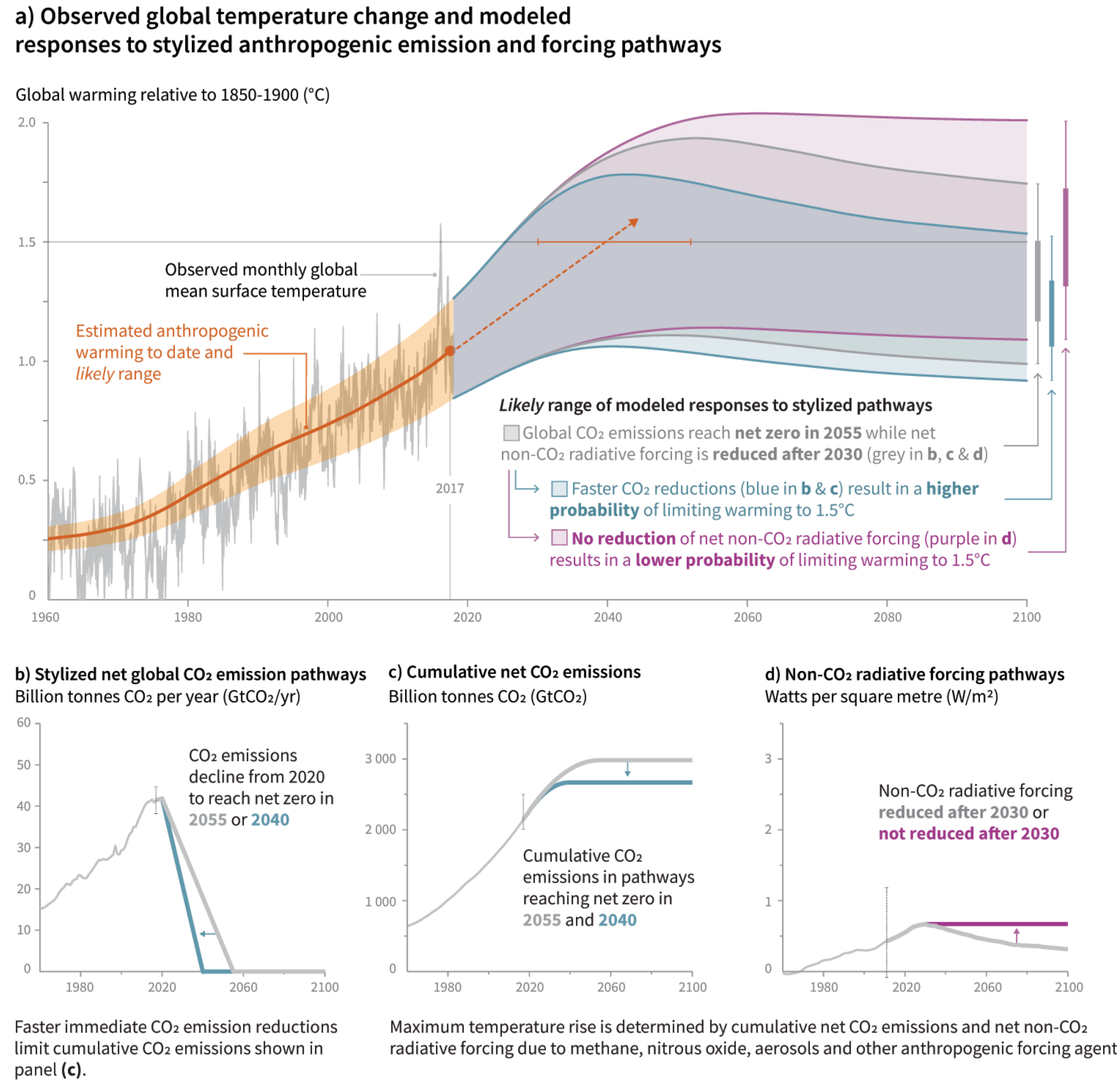


Figure 1 : (fig SPM.1) ***Panel a: Observed monthly global mean surface temperature*** *(GMST, grey line up to 2017)* ***change and estimated anthropogenic global warming*** *(solid orange line up to 2017, with orange shading indicating assessed likely range). Orange dashed arrow and horizontal orange 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 CO2 emissions (grey line in panels b and c) decline in a straight line from 2020 to reach net zero in 2055 and net non-CO2 radiative forcing (grey line in panel d) increases to 2030 and then declines. The blue plume in panel a) shows the response to faster CO2 emissions reductions (blue line in panel b), reaching net zero in 2040, reducing cumulative CO2 emissions (panel c). The purple plume shows the response to net CO2 emissions declining to zero in 2055, with net non-CO2 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 CO2 emissions in 2017 (data from the Global Carbon Project) and of net non-CO2 radiative forcing in 2011 from AR5, respectively. Vertical axes in panels c and d are scaled to represent approximately equal effects on GMST.*

1.3 Natural and human systems at risk

- Natural and human systems are already at risk at current levels of warming: climate change threatens terrestrial and ocean ecosystems and biodiversity, food security, human health and the economy; - Even if anthropogenic greenhouse gas emissions stopped today, the effort for human systems to adapt to the most crucial effects of climate-driven species redistribution will be far-reaching and extensive.

There are already observable impacts on natural and human systems from global warming (*high confidence*). Thus, many land and ocean ecosystems and some of the services they provide have been assessed with *high confidence* to have already changed due to global warming. Even if anthropogenic greenhouse gas emissions stopped today, the effort for human systems to adapt to the most crucial effects of climate-driven species redistribution will be far-reaching and extensive.

Ocean ecosystems

Climate change already poses a major threat to an increasing number of ocean ecosystems (especially warm water or tropical coral reefs) and consequently to many coastal communities that depend on marine resources for food, livelihoods and a safe place to live.

Anthropogenic carbon dioxide has decreased ocean pH by 0.2 pH units since 1870-1899. Increased ocean temperatures (+0.9°C on average) have intensified storms in several regions, expanded the ocean volume and increased sea levels globally. It has also reduced the extent of polar summer sea ice and decreased the overall solubility of the ocean for oxygen. For example, the number of 'dead zones' (areas where oxygenated waters have been replaced by hypoxic conditions) has been growing strongly since the 1990s.

These impacts on ecosystems have important consequences for human communities. Sea level rise interacts with other factors, such as strengthening storms, which together are driving larger storm surges, infrastructure damage, erosion and habitat loss; for example, inundation of parts of low-lying islands, land degradation due to saltwater intrusion have been observed in Kiribati and Tuvalu. Moreover, loss of coral reefs and mangroves poses a great risk for coastal protection and resources for coastal communities.

Food security & human health

Climate change influences food and nutritional security through its effects on food availability, quality, access and distribution. For example, reduced crop production and yields have already been observed, with the most negative impacts on wheat and maize. There is *medium confidence* that ocean deoxygenation interacts with ⇒ocean acidification to present substantial separate and combined challenges for fisheries and aquaculture.

Moreover, climate change can alter the availability of water and threaten water security, knowing that the population under water scarcity increased from 14% of the global population in the 1900s to 58% in the 2000s. It adversely affects human health by increasing exposure and vulnerability to climate-related stresses and decreasing the capacity of health systems to manage changes in the magnitude and pattern of climate-sensitive health outcomes. Changing weather patterns are associated with shifts in the geographic range, seasonality and transmission intensity of selected climate-sensitive infections, and increasing morbidity and mortality are associated with extreme weather and climate events.

Key economic sectors and services

The energy supply is at risk: increasing temperatures decrease the thermal efficiency of fossil, nuclear, biomass and solar power generation technologies, as well as buildings and other infrastructure. Tourism is also affected by climate change: for example, the direct relationship between increasing global temperatures, intensifying storms, elevated thermal stress, and the loss of tropical coral reefs has raised concerns about the risks of climate change for local economies and industries based on tropical coral reefs. Furthermore, road, air, rail, shipping and pipeline transportation can be impacted directly or indirectly by weather and climate, including increases in precipitation and temperature, extreme weather events (flooding and storms), sea level rise, and incidence of freeze–thaw cycles.

Biodiversity

Climate change has made a great contribution to latitudinal and elevational shifts of biomes in boreal, temperate and tropical regions. For example, there is *high confidence* that marine organisms are already responding to ocean changes by shifting their biogeographical ranges to higher latitudes at rates that range from approximately 0 to 40 km yr^{-1}, affecting the structure and functioning of the ocean, along with its biodiversity and food-web. Moreover, it has been found that 47% of local extinctions reported across the globe during the 20^{th} century could be attributed to climate change.

1.4 Differential impacts of 0.5°C warming in the observed record

Trends in intensity and frequency of extreme events, but also in the distribution of plant and animal species and in crop yields have been observed with a past global warming of approximately 0.5°C.

The 0.5°C rise in global temperatures that we have experienced in the past 50 years has contributed to shifts in the distribution of plant and animal species, decreases in crop yields and more frequent wildfires. There is also *medium confidence* that 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. For example, there is *high confidence* that increases in temperature extremes and heavy precipitation indices are detectable in observations for the 1991–2010 period compared with those for 1960–1979, with a global warming of approximately 0.5°C occurring between these two periods. Regarding changes in precipitation associated with global warming of 0.5°C, the observed record suggests that increases in precipitation extremes can be identified for annual maximum 1-day precipitation and consecutive 5-day precipitation for ⇒GMST changes of this magnitude.

2. Projected climate change, potential impacts and associated risks

2.1 Projected impacts on extreme events, sea level rise, biodiversity and ecosystems and human societies

- Increase in frequency and/or intensity of ⇒extreme events is projected;
- Sea level rise will continue to rise beyond 2100;
- Projected increase in impacts on biodiversity and ecosystems, such as species loss and extinctions;
- Human societies are impacted particularly through water scarcity, food security, and health.

Climate models project robust differences in regional climate characteristics between present-day and global warming of 1.5°C, and between 1.5°C and 2°C. General impacts are presented in this section, differences between 1.5°C and 2°C of warming are detailed in the next section.

Extreme temperature and ⇒extreme events

Future climate change is projected to cause warming of extreme temperatures in many regions (*high confidence*); temperature extremes on land are projected to warm more than ⇒GMST and the number of hot days is projected to increase in most land regions, with highest increases in the tropics. Frequency, intensity, and/or amount of heavy precipitation are projected to increase in several regions (*high confidence)*, and an increase in intensity or frequency of droughts in some regions (*medium confidence)*.

Sea level rise

There is *high confidence* that sea level will continue to rise well beyond 2100, with the magnitude and rate of this rise dependent on future emission pathways. Human and ecological systems, including health, heritage, freshwater availability, biodiversity, agriculture, fisheries and other services, are projected to be affected by this sea level rise.

Biodiversity and ecosystems

Impacts on biodiversity and ecosystems, such as species loss and extinctions, are projected to increase with further warming. For example, at 1.5°C of warming, ecosystems are experiencing increasing amounts of damage and many marine species are expected to shift to higher latitudes. Warming is expected to drive the loss of coastal resources and reduce the productivity of fisheries and aquaculture, especially at low latitudes, via impacts on the physiology, survivorship, habitat, reproduction, disease incidence, and risk of invasive species. The level of ⇒ocean acidification due to increasing CO2 concentrations associated with further warming is projected to amplify the adverse effects of warming, impacting the growth, development, calcification, survival, and thus abundance of a broad range of species from algae to fish (*high confidence*). High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss. Woody shrubs are already encroaching into the tundra (*high confidence*) and this will proceed with further warming.

Furthermore, the land ⇒carbon sink will be affected by global warming. Soil respiration is expected to increase with increasing temperature, thus reducing soil carbon storage. This is expected to increase for warming of 1.5°C, although some of the associated changes will be countered by enhanced gross primary production due to elevated CO2 concentrations (i.e., the ‘fertilization effect’) and higher temperatures.

Water scarcity and food security

Climate change will regionally exacerbate or offset the effects of population pressure on water scarcity. On many small islands for example (e.g., those constituting ⇒SIDS), freshwater stress is expected to occur as a result of projected aridity change. Moreover, increasing global temperature poses large risks to food security globally and regionally, especially in low-latitude areas (*medium confidence)*. Impacts on livestock are expected to increase. In temperate climates, warming is expected to lengthen the forage growing season but decrease forage quality, with important variations due to rainfall changes. A decline in livestock of 7–10% is expected at about 2°C of warming, with associated economic losses between $9.7 and $12.6 billion. Nevertheless, there is *high confidence* that production can also benefit from warming in higher latitudes, with more fertile soils, favouring crops, and grassland production, in contrast to the situation at low latitudes, and similar benefits could arise for high-latitude fisheries.

Human health

There is *high to very high confidence* that climate change will lead to greater risks of injuries, disease and death, owing to more intense heatwaves and fires, increased risks of undernutrition, and consequences of reduced labour productivity in vulnerable populations. In urban areas, future warming and urban expansion could lead to more extreme heat stress. At 1.5°C of warming, twice as many megacities (such as Lagos, Nigeria and Shanghai, China) could become heat stressed, exposing more than 350 million more people to deadly heat by 2050 under midrange population growth.

2.2 Avoided impacts from limiting warming to 1.5°C

- Generally, limiting warming to 1.5°C compared to 2°C highly limits risks for ecosystems and human societies;
- Sea level rise in 2100 will be 0.1m lower with 1.5°C, with up to 10 million fewer people exposed to related risks;
- Assuming a constant population, under 1.5°C of warming, an additional 4% of the world population in 2000 would be exposed to new or aggravated water scarcity, and 8% at 2°C of warming.

Extreme events

In mid-latitudes, extreme hot days are projected with *high confidence* to warm by up to about 3°C at global warming of 1.5°C and about 4°C at 2°C of global warming. Extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C of warming and about 6°C at 2°C of warming. Risks from droughts (in particular in the Mediterranean region and southern Africa) and precipitation deficits in some regions and risks from heavy precipitation events in several northern hemisphere high-latitude and/or high-elevation regions are projected with *medium confidence* to be higher at 2°C compared to 1.5°C of global warming. 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, 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)*.

Sea level rise and implication for human communities

Global mean sea level (relative to 1986–2005) is projected to rise between 0.26 m and 0.77 m by 2100 for 1.5°C of global warming (*medium confidence*), 0.1 m (0.04–0.16 m) less than for a global warming of 2°C. There is *medium confidence* that 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 (e.g., saltwater intrusion, flooding and damage to infrastructure), based on population in the year 2010 and assuming no adaptation. The slower rate of sea level rise with global warming of 1.5°C is assessed with *medium confidence* to reduce these risks, enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems and infrastructure reinforcement.

Biodiversity, ecosystems and their implications for human services

Limiting global warming to 1.5°C compared to 2°C is projected to lower impacts on terrestrial, freshwater and coastal ecosystems (such as forest fires or the spread of invasive species) and to retain more of their services to humans (*high confidence*). For global warming of 1.5°C, 6% of insects, 8% of plants and 4% of vertebrates (of 105,000 species studied) are projected with *medium confidence* to lose over half of their habitat, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C. Moreover, there is medium confidence that the area of ecosystems at risk of undergoing transformation to another type of ecosystem is projected to be approximately 50% lower at 1.5°C compared to 2°C. The permafrost area that is projected to thaw is 1.5 – 2.5 million km2 lower for 1.5°C than 2°C, but the resulting CO2 and CH4 release from thawed permafrost takes many centuries.

There is *high confidence* that limiting global warming to 1.5°C compared to 2°C reduces the increase in ocean temperatures as well as the associated rise in ⇒ocean acidity and decline in ocean oxygen levels. This would reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans. Coral reefs, for example, are projected with *high confidence* to further decline by 70–90% at 1.5°C, larger losses are projected with *very high confidence* (>99%) at 2°C. Additionally, at 2°C, risks for seagrass and mangroves are high. As coastal protection is a service provided by natural barriers such as mangroves, seagrass meadows, coral reefs, and other coastal ecosystems, it poses great risks for the protection of human communities and infrastructure against the impacts associated with rising sea levels, larger waves and intensifying storms. With 1.5°C of global warming, one sea ice-free Arctic summer is projected per century, and this likelihood increases to at least one per decade with 2°C global warming. There is *medium confidence* that global annual catch for marine fisheries will decrease by about 1.5 million tonnes for 1.5°C, compared to a loss of more than 3 million tonnes for 2°C.

Water scarcity and food security

Constraining warming to 1.5°C instead of 2°C might mitigate the risks for water availability, although socio-economic drivers could affect water availability more than the risks posed by variation in warming levels. There is *medium confidence* that the risks are not homogeneous among regions. Assuming a constant population, an additional 8% of the world population in 2000 would be exposed to new or aggravated water scarcity at 2°C of global warming, for 4% under 1.5°C of warming. Mediterranean water stress is projected to increase from 9% at 1.5°C to 17% at 2°C compared to values in the 1986–2005 period.

Warming of 2°C will result in a greater reduction in global crop yields and global nutrition than warming of 1.5°C with *high confidence*, owing to the combined effects of changes in temperature, precipitation and extreme weather events, as well as increasing CO2 concentrations. Constraining warming to 1.5°C rather than 2°C would avoid significant risks of declining tropical crop yield in West Africa, Southeast Asia, and Central and South America.

Human health

There is *very high confidence* that the magnitude of projected heat-related morbidity and mortality is greater at 2°C than at 1.5°C of global warming, although the extent to which morbidity and mortality are projected to increase vary by region. For example, stabilizing at 1.5°C of warming instead of 2°C could decrease mortality related to extreme temperatures in key European cities, assuming no adaptation and constant vulnerability.

Key economic sectors and services

Considering potential changes in natural snow only, winter overnight stays at 1.5°C are projected to decline by 1–2% in Austria, Italy and Slovakia, with an additional 1.9 million overnight stays lost under 2°C of warming. A 2°C warmer world could reduce European tourism by 5% (€15 billion yr^{-1}), with losses of up to 11% (€6 billion yr–1) for southern Europe and a potential gain of €0.5 billion yr^{-1} in the UK. Moreover, a global analysis of sea level rise risk to 720 UNESCO Cultural World Heritage sites projected that about 47 sites might be affected under 1°C of warming, with this number increasing to 110 and 136 sites under 2°C and 3°C, respectively.

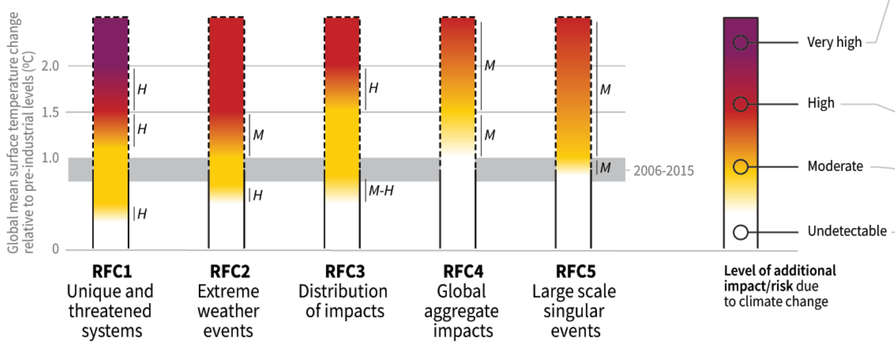
Furthermore, when comparing the impacts on hydropower production at 1.5°C and 2°C, it is found that mean gross potential increases in northern, eastern and western Europe, and decreases in southern Europe. In Greece, Spain and Portugal, warming of 2°C is projected to decrease hydropower potential below 10%, while limiting global warming to 1.5°C would keep the reduction to 5% or less. Due to a combination of higher water temperatures and reduced summer river flows, the capacity of thermoelectric power plants that use river water for cooling is expected to reduce in all European countries, with the magnitude of decreases being 5% for 1.5°C and 10% for 2°C of global warming for most European countries.

Figure *2* illustrates the impacts and risks of different levels of warming for people, economies and ecosystems across sectors and regions:

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

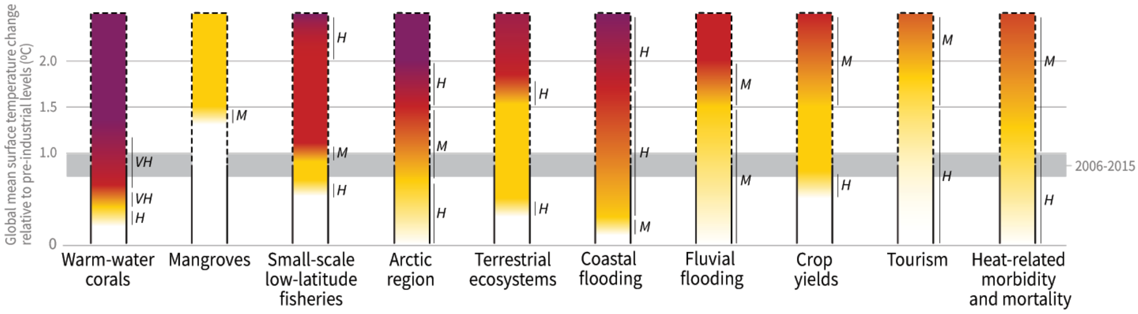
Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

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 2: (fig SPM.2) ***Five integrative reasons for concern*** *(RFCs)* ***provide a framework for summarizing key impacts and risks across sectors and regions****. 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. 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.* ***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.*

2.2.1 Irreversible impacts, ⇒tipping points, loss and damage

- The Greenland ice sheet and the West Antarctic ice sheet are at risk of irreversible loss, leading to multi-meter sea level rise; - At 2°C of warming, almost all coral reefs (>99%) will be lost; - Some coastal populations are forced to retreat and abandon their homes due to sea level rise and associated impacts.

Irreversible impacts and ⇒tipping points

The Greenland ice sheet is at risk of irreversible loss, due to various feedbacks between the ice sheet and the wider climate system. The threshold is around 2°C of warming. The threshold of global temperature increase that may initiate irreversible loss of the West Antarctic ice sheet and marine ice sheet instability is estimated to lie between 1.5°C and 2°C. These could result in multi-meter sea level rise over hundreds to thousands of years.

The frequency of extreme ⇒El Nino events increases linearly with global mean temperature; the number of such events might double (one event every ten years) under 1.5°C of global warming. This pattern is projected to persist for a century after stabilization at 1.5°C, thereby challenging the limits to adaptation, and thus indicates a high risk even at the 1.5°C threshold.

Widespread thawing of permafrost potentially makes a large carbon store vulnerable to decomposition, which could lead to further increases in atmospheric carbon dioxide and methane and hence to further global warming. This feedback loop between warming and the release of greenhouse gas from thawing tundra represents a potential ⇒tipping point. However, there is *medium confidence* that the carbon released to the atmosphere from thawing permafrost is projected to be restricted to 0.09–0.19 GtC yr^{-1} at 2°C of global warming and to 0.08–0.16 GtC yr^{-1} at 1.5°C which does not indicate a ⇒tipping point for these temperatures. Nevertheless, a ⇒tipping point due to higher temperatures may lead to a smaller ice fraction in soils in the tundra and lead to more rapidly warming soils and a positive feedback mechanism that results in permafrost collapse. This is projected to be reached at 3°C of warming.

Biodiversity and biomass

Moreover, there is *high confidence* that the risk of irreversible loss of rainforest biomass, many marine and coastal ecosystems increase with global warming, especially at 2°C or more. Coral reefs are among the most impacted; already 50% of shallow-water corals across hundreds of kilometers of the world's largest continuous coral reef system, the Great Barrier Reef, has been lost due to heatwaves.

Warm water (tropical) coral reefs are projected to reach a very high risk of impact at 1.2°C, and there is *high confidence* that coral-dominated ecosystems will be non-existent at this temperature or higher. At this point, coral abundance will be near zero at many locations and storms will contribute to 'flattening' the three-dimensional structure of reefs without recovery, as already observed for some coral reefs. Coral reefs are projected to decline by 70–90% at 1.5°C (*high confidence)*, with more than 99% loss at 2°C (*very high confidence)*. Moreover, the impacts of warming, coupled with ⇒ocean acidification, are expected to undermine the ability of tropical coral reefs to provide habitat for thousands of species, which together provide a range of ecosystem services (e.g., food, livelihoods, coastal protection, cultural services) that are important for millions of people (*high confidence)*.

Loss of land and homes

Some vulnerable regions are forced to pursue drastic adaptive responses, including migration, thus losing their land and homes. For example, flooding may result in migration or relocation, as in Vunidogoloa, Fiji, or the Solomon Islands. Projections indicate that at 1.5°C there will be increased incidents of internal migration and displacement.

At 2°C of warming, there is a potential for significant population displacement concentrated in the tropics. Tropical populations may have to move distances greater than 1000 km if global mean temperature rises by 2°C from 2011–2030 to the end of the century. A disproportionately rapid evacuation from the tropics could lead to a concentration of population in tropical margins and the subtropics, where population densities could increase by 300% or more.

2.2.2 Risks for vulnerable and disadvantaged populations

- Climate change is expected to be a poverty multiplier that makes poor people poorer;
- It could force more than 3 million to 16 million people into extreme poverty;
- Limiting warming to 1.5°C instead of 2°C could reduce the number of people exposed to climate risks and vulnerable to poverty by 62 to 457 million.

At 1.5°C of global warming (2030), climate change is expected to be a poverty multiplier that makes poor people poorer and increases the poverty head count. Poor people might be heavily affected by climate change even when impacts on the rest of population are limited. Climate change alone could force more than 3 million to 16 million people into extreme poverty, mostly through impacts on agriculture and food prices. The most severe impacts are projected for urban areas and some rural regions in sub-Saharan Africa and Southeast Asia. For example, drought significantly increases the likelihood of sustained conflict for particularly vulnerable nations or groups, owing to the dependence of their livelihood on agriculture. This is particularly relevant for groups in the least developed countries, in sub-Saharan Africa and in the Middle East. Forced displacement also mostly impacts small islands, that are particularly vulnerable to sea level rise and coastal flooding.

However, there is *medium evidence* and *high agreement* that limiting global warming to 1.5°C rather than 2°C above preindustrial levels would make it markedly easier to achieve many aspects of sustainable development, with greater potential to eradicate poverty and reduce inequalities. Impacts avoided with the lower temperature limit could, with *medium evidence* and *medium agreement*, reduce the number of people exposed to climate risks and vulnerable to poverty by 62 to 457 million, and lessen the risks of poor people to experience food and water insecurity, adverse health impacts, and economic losses, particularly in regions that already face development challenges.

2.2.3 Adaptation opportunities and limits

- A wide range of adaptation options are available to reduce the risks to natural and managed ecosystems, the risks of sea-level rise, the risks to health, livelihoods, food, water, and economic growth;
- At 2°C of warming, adaptation needs and challenges will be higher than under 1.5°C.

Adaptation options and limits

A wide range of adaptation options are available to reduce the risks for 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 defense 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).

For example, strategies for reducing the impact of climate change on framework organisms include reducing stresses not directly related to climate change (e.g., coastal pollution, overfishing and destructive coastal development) in order to increase their ecological resilience in the face of accelerating climate change impacts, as well as protecting locations where organisms may be more robust or less exposed to climate change. For corals, there is also interest in ex situ conservation approaches involving the restoration of corals via aquaculture or the use of 'assisted evolution' to help corals adapt to changing sea temperatures.

Changing agricultural practices, such as improving irrigation efficiency or including mixed crop-livestock production systems, can be a cost-effective adaptation strategy in many global agriculture systems with *robust evidence* and *medium agreement*.

There is *medium confidence* that high levels of adaptation are expected to be required to prevent impacts on food security and livelihoods in coastal populations. Integrating coastal infrastructure with changing ecosystems such as mangroves, seagrasses and salt marsh, may offer adaptation strategies as they shift shoreward with rising sea levels (*high confidence*). However, as these ecosystems are degraded by climate change, their protection capacity decreases with warming. Furthermore, human retreat and migration are increasingly being considered as an adaptation response, which highlights the limits of adaptation and, in particular, coastal adaptation.

1.5°C vs 2°C

There is *high confidence* that most adaptation needs will be lower for global warming of 1.5°C compared to 2°C; adaptation is expected to be more challenging for ecosystems, food and health systems at 2°C of global warming than for 1.5°C. For example, climate change mitigation will reduce the rate of sea level rise this century, decreasing the need for extensive and, in places, immediate adaptation.

3. Limiting warming to 1.5°C

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

3.1.1 Different possible courses of action

Pathways that are consistent with the 1.5°C limit are "as likely as not" to stay below 1.5°C throughout the 21st century and have a higher than 50% chance to limit warming to below 1.5°C in 2100. The 1.5°C limit can be achieved under a range of different socio-economic assumptions

Four illustrative model pathways consistent with limiting warming to 1.5°C above pre-industrial levels are displayed in Figure 3. These pathways describe integrated, quantitative evolutions of all emissions over the 21st century associated with global energy, land use and, the world economy. CO2 emissions reductions that limit global warming to 1.5°C in these different pathways 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 (CDR). There is *high confidence* that for all pathways, limiting warming to 1.5°C implies very ambitious, internationally cooperative policy environments that transform both supply and demand.
1.5°C-consistent pathways are summarized in the '1.5°C low or no overshoot' category. They are "as likely as not" (probability >33%) to limit peak warming to 1.5°C and have a probability of more than 50% to limit warming to 1.5°C in 2100. At the same time, these pathways are "very likely" (>90% chance) to hold warming to below 2°C, which is consistent with holding warming to "well below 2°C". These pathways can thus be seen as being Paris Agreement compatible.

Pathways in the so-called 'high overshoot' category cannot be considered 1.5°C compatible, as they are in fact "likely" (with a probability >66%) to exceed 1.5°C and it is only through deployment of extreme ⇒carbon dioxide removal beyond sustainability limits that temperatures are brought back down below 1.5°C by 2100 in these scenarios. As they do not meet the ⇒CDR sustainability limits identified in the SR1.5, these pathways are excluded from the Summary for Policy Makers apart from pathway P4 (Figure 3), which remains for illustrative purposes.

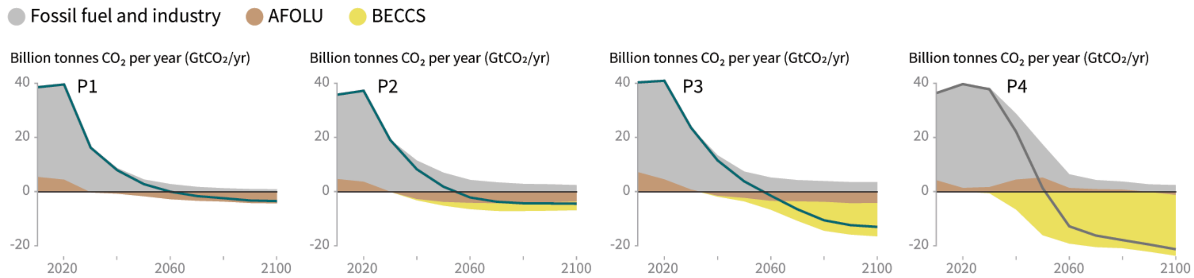
Table 1: Overview of pathway class specifications in the SR1.5 (see Chapter 2 Supplementary Material Table 11)

Pathway Group	Class Name	Short Name Combined Classes	MAGICC Exceedance Probability Filter	Number of Scenarios
1.5°C	Below 1.5°C	-	P(1.5°C) ≤ 0.34	0
	Below 1.5°C	Below-1.5°C	0.34 < P(1.5°C) ≤ 0.5	9
	1.5°C Return with low overshoot (OS)	1.5°C-low-OS	0.5 < P(1.5°C) ≤ 0.67 AND P(1.5°C in 2100) ≤ 0.34	34
			0.5 < P(1.5°C) ≤ 0.67 AND 0.34 < P(1.5°C in 2100) ≤ 0.5	10
	1.5°C Return with high OS	1.5°C-high-OS	0.67 < P(1.5°C) AND P(1.5°C in 2100) ≤ 0.34	19
			0.67 < P(1.5°C) AND 0.34 < P(1.5°C in 2100) ≤ 0.5	18
2°C	Lower 2°C	Lower-2°C	P(2°C) ≤ 0.34 (excluding above)	74
	Higher 2°C	Higher-2°C	0.34 < P(2°C) ≤ 0.5 (excluding above)	58
Above 2°C	Above 2°C	-	0.5 < P(2°C)	189

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-10(*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

Figure 3 : (fig SPM.3b) ***Characteristics of four illustrative model pathways in relation to global warming of 1.5°C****. 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 CO2 emissions into the contributions in terms of CO2 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. Note that P4 is a so-called 'high-overshoot' 1.5°C pathway that deploys carbon dioxide removal beyond identified sustainability limits.

3.1.2 Near-term mitigation needs and 2030 benchmarks for 1.5°C

- Greenhouse gas emissions consistent with pathways that aim for no or limited overshoot of 1.5°C decline by about 45% from 2010 levels by 2030;
- These pathways require ⇒net zero CO_2 emissions around 2050;
- Under current Nationally Determined Contributions, global warming is expected to surpass 1.5°C.

Limiting warming to 1.5°C depends on greenhouse gas emissions over the next decades, where lower GHG emissions in 2030 lead to a higher chance of keeping peak warming to 1.5°C (*high confidence)*. Available pathways that aim for no or limited (less than 0.1°C) overshoot of 1.5°C keep greenhouse gas emissions in 2030 to 25-30 GtCO2e yr^{-1} in 2030, which corresponds to a decline by about 45% from 2010 levels by 2030 (25% for a 2°C scenario). These pathways reach ⇒net zero CO2 around 2050 (2070 for a 2°C scenario). There is *high confidence* that non-CO2 emissions (methane, nitrous oxide, black carbon) show deep reductions in pathways that limit global warming to 1.5°C that are similar to those in pathways limiting warming to 2°C.

This contrasts with median estimates for current unconditional ⇒NDCs (Nationally Determined Contributions) of 52-58 GtCO2e yr^{-1} in 2030. Even with ⇒net zero CO2 emissions in less than 15 years after 2030, temperatures would only be expected to remain below the 1.5°C threshold if the actual geophysical response ends up being towards the low end of the currently estimated uncertainty range.

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)*. Hence, transition challenges as well as identified trade-offs can be reduced if global emissions peak before 2030 and marked emissions reductions compared to today are already achieved by 2030.

3.1.3 Net-zero targets

Limiting warming to 1.5°C implies reaching ⇒net zero CO2 emissions globally around 2050.

Limiting warming to 1.5°C implies reaching ⇒net zero CO2 emissions globally around 2050 alongside deep reductions in emissions of non-CO2 forcers, particularly methane (*high confidence)*. Such mitigation pathways are characterized by energy demand reductions, decarbonization of electricity and other fuels, electrification of energy end use, deep reductions in agricultural emissions, and some form of ⇒carbon dioxide removal with carbon storage on land or sequestration in geological reservoirs. Achieving the net-zero CO2 emission target rapidly is necessary to achieve 1.5°C, as 2°C warming scenarios foresee net-zero CO2 to be reached not much later, in 2070.

3.1.4 Need for rapid and far-reaching transitions in energy, land, urban, infrastructure and industrial systems across pathways to limit warming to 1.5°C with no or limited overshoot

- Rapid and far-reaching changes in land use and urban planning practices, deeper emission reductions in transport and buildings, lower energy use, reductions in the industry CO2 emissions are required to limit global warming to 1.5°C;
- Depending on pathways reaching 1.5°C, by 2050, the share of electricity supplied by renewables increases to 59–97%;
- CO2 emissions from industry in pathways limiting global warming to 1.5°C with no or limited overshoot are projected to be about 65-90% lower in 2050 relative to 2010.

Energy systems

Across those pathways that limit warming to 1.5°C with no or limited overshoot, there is *high confidence* that energy service demand is generally met with lower energy use, including through enhanced energy efficiency and fast electrification of energy end use. The share of primary energy from renewables increases while the share of fossil fuels, and particularly coal usage, decreases. A large fraction of this leftover coal use is combined with carbon capture and storage (for detailed figures, see Figure 3 above). There is *high confidence* that political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies have substantially improved over the past few years. These improvements signal a potential system transition in electricity generation.

Land

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 with *medium confidence*, 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 forest area by 2050 relative to 2010.

Urban and infrastructure system

There is *medium confidence* that the urban and infrastructure system transition consistent with pathways 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 to below 2°C. In these pathways, there is *medium confidence* that the electricity share of energy demand in buildings would be about 55-75% in 2050 (compared to 50-70% in 2050 for 2°C of global warming), and that 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).

Industry

CO2 emissions from industry in pathways limiting global warming to 1.5°C with no or limited overshoot are projected to be about 65-90% lower in 2050 relative to 2010 (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. However, although these options are technically proven at various scales, their large-scale deployment may be limited by economic, financial and human capacity as well as institutional constraints in specific contexts, and specific characteristics of large-scale industrial installations.

3.1.5 Implications for fossil fuel phase out

- Fossil fuel (coal, oil, gas) phase out is inseparable from a warming limited to 1.5°C;
- The use of coal would be reduced to close to 0% of electricity in 2050 in all 1.5°C pathways.

Limiting warming to 1.5°C requires a virtual abandonment of coal and a drastic reduction in all other fossil fuels. While in pathways with no or limited overshoot, renewables are projected to supply 70–85% of electricity in 2050, there is *high confidence* the use of coal would be reduced to close to 0% of electricity in 2050 in all pathways. Compared to 2010 values, the primary energy from coal must be reduced by 61-78% in 2030 for no or limited overshoot pathways, and by 59% for the higher overshoot pathway. However, the weaker reduction in high overshoot pathways reduction must then be compensated by a 97% reduction in 2050. Not only coal, but also oil and gas are reduced in 1.5°C pathways: a 32% to 87% reduction compared to 2010 values for oil in 2050 and a decrease in gas of 74% in three out of the four pathways. A rapid fossil fuel phase out, particularly of coal, is inseparable from a warming limit of 1.5°C.

3.1.6 Near-term emission reductions and ⇒carbon dioxide removal needs

- All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of ⇒carbon dioxide removal (CDR), but the scale depends strongly on other pathway assumptions
- The longer the delay in reducing CO2 emissions towards zero, the larger the likelihood of exceeding 1.5°C, and the heavier the implied reliance on ⇒net negative emissions after mid-century to return warming to 1.5°C;
- CDR deployed at large scale is unproven, and reliance on such technology is a major risk

All pathways that achieve the goal of the Paris Agreement of reaching ⇒net-zero greenhouse gas emissions (Article 4) will require some form of ⇒negative CO_2 emissions to compensate for remaining emissions of non-CO_2 gases such as methane, mainly from the agricultural sector.
Existing and potential CDR measures include afforestation and reforestation, land restoration and soil carbon sequestration, bioenergy carbon capture and storage (BECCS), and, less studied, direct air carbon capture and storage (DACCS), enhanced weathering and ocean alkalinization. CDR would be used to compensate for residual emissions (see Figure 4 light small black dotted area) (*high confidence*) and, in most cases, achieve ⇒net negative emissions to return global warming to 1.5°C following a temporary temperature overshoot.

In pathways without an overshoot, ⇒CDR deployment would be limited to compensate for remaining emissions, such as e.g. from non-CO_2 greenhouse gases in the agriculture sector.

For low-overshoot pathways (maximum peak at 1.6°C) the exact pathway definitions matter (compare Table 1). Most low-overshoot pathways require a probability of more than 66% to limit warming to below 1.5°C in 2100 (34 pathways). This means that median temperatures in those pathways would need to be reduced from ~1.6°C at the time of net-zero CO_2 mid-century to around 1.2-1.3°C by 2100 (such as in the case of the S2 pathway in Figure 4). This reduction by about 0.3-0.4°C would require CDR of around 600-800 Gt CO_2 (compare Figure 4, S2). The need for such a CDR deployment, however, strongly depends on the probability assumptions made. If a 50% chance of limiting warming to 1.5°C by 2100 was being put as the benchmark, the need for net CO_2 removal beyond achieving net-zero could be much reduced, to the order of 100-200 Gt CO_2 (compare pathway S1 and LED, Figure 4).

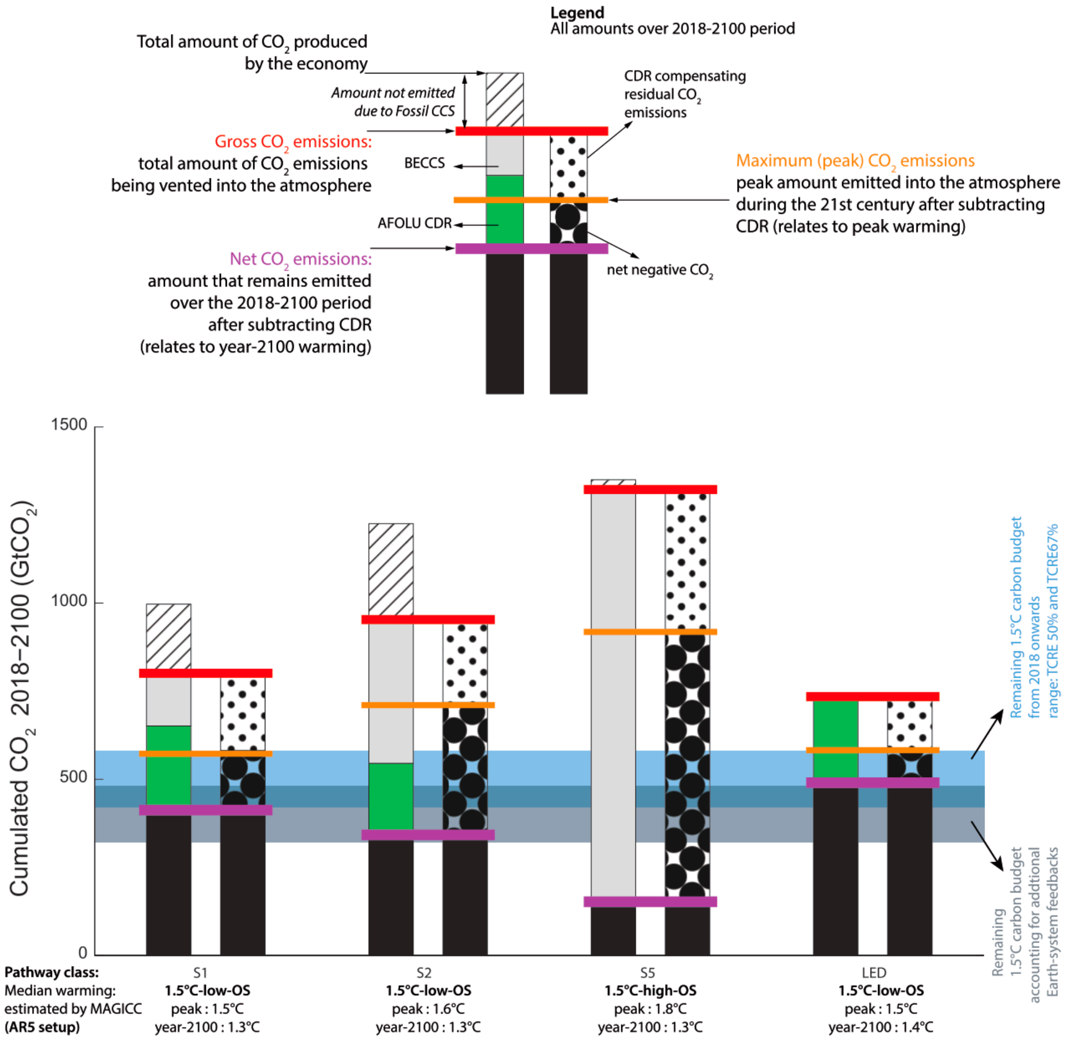


Figure 4: Accounting of cumulative CO2 emissions for the four 1.5°C-consistent pathway archetypes (Source: Chapter 2 Figure 10). It provides information on the total CO_2 emissions (red) as well as net CO_2 emissions in 2100, highlighting very different assumptions about the need to compensate remaining greenhouse gas emission (dotted bar segments), as well as net-negative CO_2 emissions (large dotted bar segments). The amount of net-negative CO_2 emissions required does depend on the peak warming as well as on the 2100 warming outcome that is targeted by the pathways.

While a high chance of limiting peak warming to 1.5°C is desirable, the benefits of rapidly declining temperatures thereafter and until 2100 through large-scale CDR deployment are not well established.

Choosing a 67% below 1.5°C probability in 2100 after a temporary potential overshoot such as in many 1.5°C pathways (including pathway S2, or even high overshoot pathways such as S5) is a value judgement that is not directly linked to limiting peak-warming, or holding warming to below 1.5°C.

The IPCC SR1.5 has identified sustainable deployment ranges for BECCS of up to 5 GtCO2 yr^{-1} and afforestation potential of up to 3.6 GtCO2 yr^{-1} by mid-century. There is *medium confidence* that some pathways avoid BECCS deployment completely through demand-side changes and greater reliance on AFOLU-related CDR measures. 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*).

Nevertheless, one cannot rely on ⇒CDR techniques to reach the 1.5°C target. Urgent emission reductions are needed to achieve this goal. Indeed, the faster reduction of net CO2 emissions in 1.5°C compared to 2°C pathways is predominantly achieved by measures that result in less CO2 being produced and emitted, and only to a smaller degree through additional CDR. For example, there is *high confidence* that significant near-term emission reductions and measures to lower energy and land demand can limit CDR deployment to a few hundred GtCO2 without reliance on bioenergy with carbon capture and storage. Moreover, limitations on the speed, scale and societal acceptability of CDR deployment (trade-offs with other sustainability objectives occur predominantly through increased land, energy, water and investment demand, see section 3.2.1) limit the manageable extent of temperature overshoot. Furthermore, limits to our understanding of how the ⇒carbon cycle responds to ⇒net negative emissions increase the uncertainty about the effectiveness of CDR to decline temperatures after a peak.

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

3.2.1 Synergies and trade-offs with achieving the sustainable development goals

- Mitigation options consistent with 1.5°C pathways are associated with multiple synergies and tradeoffs across the sustainable development goals (SDGs);
- The total number of possible synergies exceeds the number of trade-off;
- 1.5°C pathways that include low energy demand, 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.

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 with *high confidence* 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.

Mitigation options consistent with 1.5°C pathways are associated with multiple synergies and tradeoffs across the SDGs. These are summarized in Figure 5. For instance, sustainable water management and investment in green infrastructure to deliver sustainable water and environmental services and to support urban agriculture are assessed (with *high evidence, medium agreement* for the former and *medium evidence, high agreement* for the latter) to be less cost-effective than other adaptation options but can help build climate resilience. There is *high confidence* that the total number of possible synergies exceeds the number of trade-offs, but also that their net effect will depend on the pace and magnitude of changes, the composition of the mitigation portfolio and the management of the transition.

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.

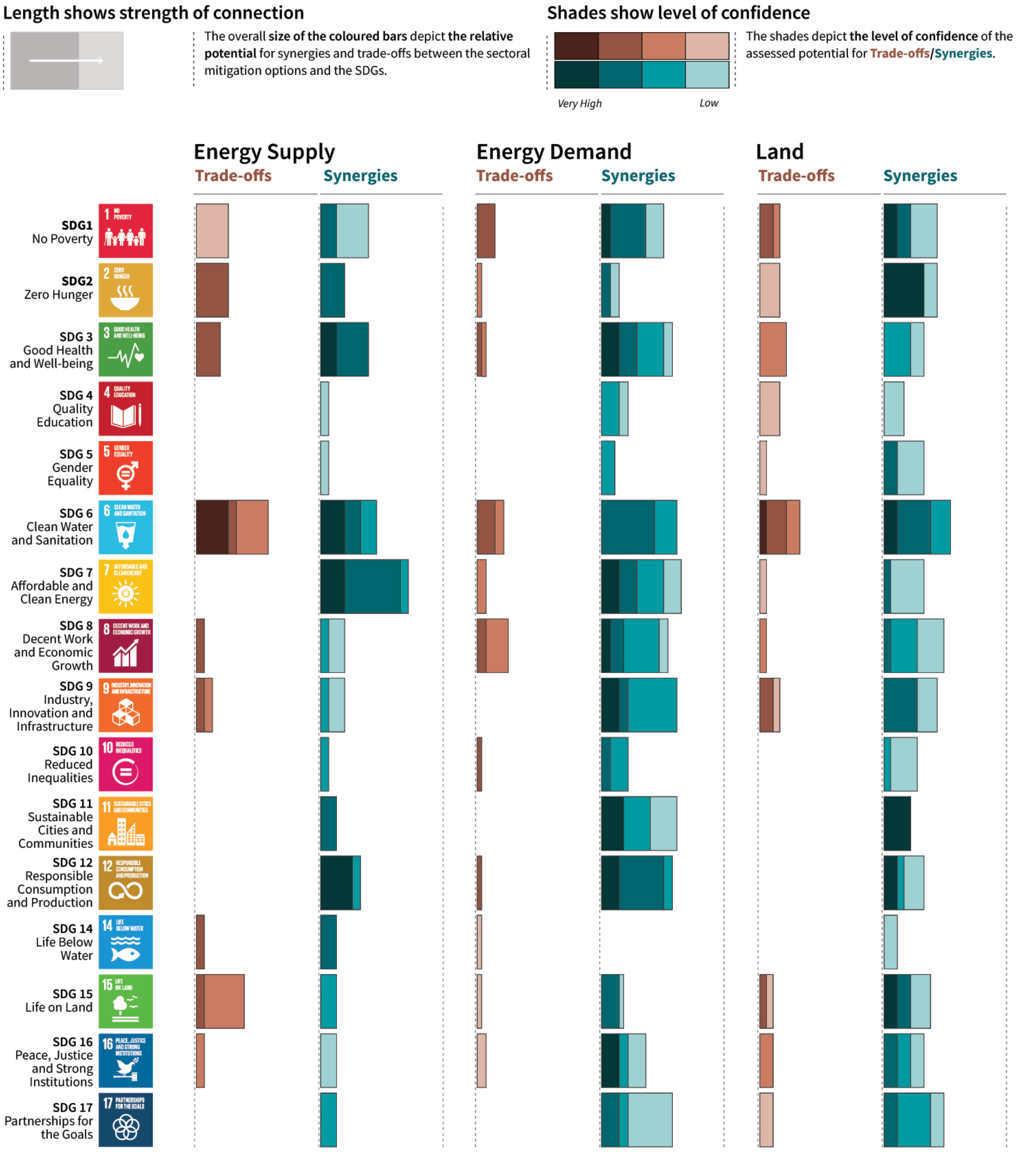


Figure 5 : (fig SPM.4) ***Potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs).*** *The SDGs serve as an analytical framework for the assessment of the different sustainable development dimensions, which extend 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. 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 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. 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.*

There is *high confidence* that 1.5°C pathways that include low energy demand (e.g., P1 in Figure 3), 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. Such pathways would reduce the dependence on CDR. More specifically, there is *high confidence* that transitions in land-use, and particularly CDR measures such as afforestation and bioenergy, if deployed at large scale, pose profound challenges for sustainable land management to satisfy land demand for human settlements, food, livestock feed, fiber, bioenergy, carbon storage, biodiversity and other ecosystem services. On the other hand, 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.

Moreover, there is *high confidence* that 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. However, policies that promote diversification of the economy and the energy sector can address the associated challenges. And, although fossil CO2 dominates long-term warming, the reduction of warming from ⇒short-lived climate forcers, such as methane and black carbon, can, in the short term, contribute significantly to limiting warming to 1.5°C above pre-industrial levels and have, with *high confidence*, substantial co-benefits, such as improved health due to reduced air pollution.

Furthermore, carefully selected adaptation options specific to national contexts will provide benefits to sustainable development and poverty reduction with global warming of 1.5°C with *high confidence*. For example, adaptation options that also mitigate emissions can provide synergies and cost savings in most sectors and system transitions, such as a reduction in emissions and disaster risk from improved land management, or low-carbon buildings designed for efficient cooling.

3.2.2 Necessity to increase adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behaviour changes

- Almost all countries and communities need to significantly raise their level of ambition, in terms of adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behavioural changes; Limiting warming to 1.5°C requires a marked shift in investment patterns, with substantial investments in climate solutions being accompanied by substantial divestments from fossil fuels - International cooperation is needed, particularly for poor countries that need resources to implement mitigation and adaptation measures.

To achieve the 1.5°C limit, almost all countries need to significantly raise their level of ambition. There is *high confidence* that public, financial, institutional and innovation capabilities currently fall short of implementing far-reaching measures at scale in all countries. 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.

Adaptation and mitigation investments

The rapid and far-reaching response required to keep warming below 1.5°C and enhance the capacity to adapt to climate risks entails, with *robust evidence* and *high agreement*, a large increase of investments in low-emission infrastructure and buildings, along with a redirection of financial flows towards low-emission investments. For example, there is *medium confidence* that limiting warming to 1.5°C requires a marked shift in energy investment patterns, with additional annual average energy related investments for the period 2016 to 2050 estimated to be around 830 billion USD2010, compared to pathways without new climate policies beyond those in place today. This compares to energy investment needs of around 2400 billion USD2010 over the same period without any climate policy. Average annual investment in low-carbon energy technologies and energy efficiency are upscaled by roughly a factor of six by 2050 compared to 2015, overtaking fossil investments globally by around 2025 with *medium confidence*.

Policy instruments

Enabling investment in infrastructure for mitigation and adaptation requires the mobilization and better integration of a range of policy instruments that include the reduction of socially inefficient fossil fuel subsidy regimes and innovative price and non-price national and international policy instruments. These would need to be complemented by de-risking financial instruments and the emergence of long-term low-emission assets. It could involve the mobilization of private funds by institutional investors, asset managers and development of investment banks, as well as the provision of public funds. These instruments would aim to reduce the demand for carbon-intensive services and shift market preferences away from fossil fuel-based technology. 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.

There is *robust evidence* and *medium agreement* that ⇒carbon pricing alone, in the absence of sufficient transfers to compensate their unintended distributional cross-sector, cross-nation effects, cannot reach the incentive levels needed to trigger system transitions. But, embedded in consistent policy packages, they can help mobilize incremental resources and provide flexible mechanisms that help reduce the social and economic costs of the triggering phase of the transition, with *robust evidence* and *medium agreement.*

Moreover, there is *high confidence* that 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.

International cooperation

International cooperation can provide an enabling environment for limiting warming to 1.5°C to be achieved in all countries and for all people, in the context of sustainable development; moreover, there is *high confidence* that it is a critical enabler for developing countries and vulnerable regions. Indeed, in developing countries and for poor and vulnerable people, implementing the response would require financial, technological and other forms of support to build capacity, for which additional local, national and international resources would need to be mobilized (*high confidence*). These redistributive policies across sectors and populations can resolve trade-offs for a range of SDGs, particularly hunger, poverty and energy access. Investment needs for such complementary policies are assessed to represent only a small fraction of the overall mitigation investments in 1.5°C pathways (*high confidence*).

Technological innovation

The system 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.

For example, there is *high confidence* that improving productivity of existing agricultural systems generally reduces the emissions intensity of food production and offers strong synergies with rural development, poverty reduction and food security objectives, but options to reduce absolute emissions are limited unless paired with demand-side measures. Technological innovation including biotechnology, with adequate safeguards, could contribute to resolving current feasibility constraints and expand the future mitigation potential of agriculture.

Financial innovations are also required to limit warming to 1.5°C. Increasing evidence suggests that a climate-sensitive realignment of savings and expenditure towards low-emission, climate-resilient infrastructure and services requires an evolution of global and national financial systems. In addition to climate-friendly allocation of public investments, a potential redirection of 5% to 10% of the annual capital revenues is necessary for limiting warming to 1.5°C. This could be facilitated by a change of incentives for private day-to-day expenditure and the redirection of savings from speculative and precautionary investments towards long term productive low-emission assets and services. This implies the mobilization of institutional investors and mainstreaming of climate finance within financial and banking system regulation. There is *medium evidence* and *high agreement* that access by developing countries to low-risk and low-interest finance through multilateral and national development banks would have to be facilitated. New forms of public– private partnerships may be needed with multilateral, sovereign and sub-sovereign guarantees to de-risk climate-friendly investments, support new business models for small-scale enterprises and help households with limited access to capital.

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, with *high confidence*, more effective when they combine public support for research and development with policy mixes that provide incentives for technology diffusion.

Behavioural changes

Demand-side measures are key elements of 1.5°C pathways. Lifestyle choices that lower energy demand and the land- and GHG-intensity of food consumption can further support achievement of 1.5°C pathways (*high confidence*). For example, decreasing food loss and waste and changing dietary behaviour could result in mitigation and adaptation by reducing both emissions and pressure on land, with significant co-benefits for food security, human health and sustainable development (*high confidence*). Moreover, by 2030 and 2050, all end-use sectors (including building, transport, and industry) show marked energy demand reductions in modelled 1.5°C pathways, comparable to or beyond those projected in 2°C pathways. The wide-scale behavioural changes consistent with adapting to and limiting global warming to 1.5°C can be accelerated by education, information, and community approaches, including those that are informed by indigenous and local knowledge.

4. Hot topics since the SR1.5 and beyond

Update on renewables compatible with 1.5°C pathways

A comparative analysis of electricity generation costs from renewable, fossil fuel and nuclear sources in G20 countries for the period 2015-2030, Ram et al., 2018[1]

This research studies the cost of different sources of energy, using the LCOE (levelized cost of energy, a measure of the average net present cost of electricity generation for a generating plant over its lifetime, calculated as the ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted sum of the actual energy amounts delivered) and considering external as well as GHG emission costs.

The results of the study show that renewables and their storage are far cheaper than fossil and nuclear sources by 2030 across G20 countries, not considering external costs (such as effects on human health or the environment). They found that renewables offer the lowest LCOE in 2030, if external costs are not considered, and, when considering external costs, the lowest LCOE is already reached in 2015. The authors argue that costs are often felt disproportionately by the most vulnerable people.

In 2030, solar photovoltaic utility power plants represent the lowest LCOE of all technologies across all G20 countries with the exception of Northern European countries that are part of the European Union, where onshore wind has the lowest LCOE. On a global level, rooftop photovoltaic systems become more competitive than conventional energy production (fossil fuels and nuclear) in 2030. Moreover, the authors find that carbon capture and storage (CCS) offers an opportunity to reduce costs associated with fossil fuel combustion but remains significantly higher in costs than renewable energy generation, even with the anticipated cost reductions due to CCS technology development.

The authors conclude “all countries should begin to invest in renewable energy sources well ahead of 2030 in order to take full advantage of this opportunity and minimise adverse impacts.”

Equitable Job creation during the global energy transition towards 100% renewable power system by 2050, Ram et al., 2020[2]

Ram et al., 2020 show how renewable energy technologies create more jobs than conventional energy technologies and hence generate greater socioeconomic benefits. Assuming the world derives 100% of its electricity from renewable sources in 2050, would mean an increase in direct global jobs associated with the electricity sector from 21 million in 2015 to nearly 35 million in 2050. Solar PV (22.2 million jobs by 2050), batteries (4.5 million jobs by 2050) and wind power (1.4 million jobs by 2050) are the major job creating technologies during this energy transition. The global results are presented in Figure 6:

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[1] Ram, M., Child, M., Aghahosseini, A., Bogdanov, D., Lohrmann, A., & Breyer, C. (2018). A comparative analysis of electricity generation costs from renewable, fossil fuel and nuclear sources in G20 countries for the period 2015-2030. *Journal of Cleaner Production*, *199*(October), 687–704. https://doi.org/10.1016/j.jclepro.2018.07.159

[2] Ram, M., Aghahosseini, A., & Breyer, C. (2020). Job creation during the global energy transition towards 100% renewable power system by 2050. *Technological Forecasting and Social Change*, *151*(July). https://doi.org/10.1016/j.techfore

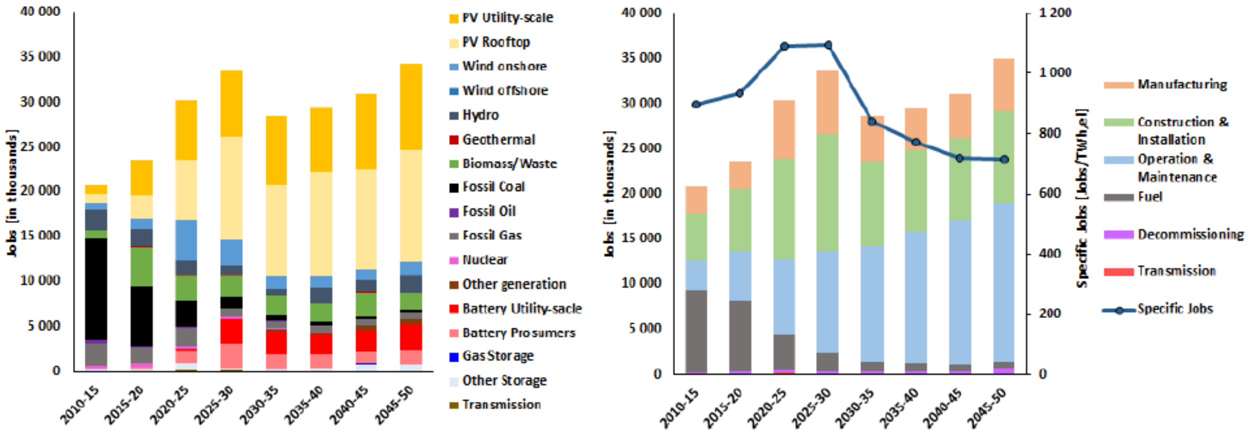

Figure 6: Jobs created by the various power generation and storage technologies (left) and jobs created based on different categories with the development of electricity demand specific jobs (right) during the energy transition from 2015 to 2050 globally.

The number of new jobs increases to around 34 million direct energy jobs by 2030. Beyond this point, they decline to around 30 million followed by a steady increase to nearly 35 million by 2050. This is mainly due to the replacement and reinvestment in large capacities, as they would reach end of their lifetimes with decommissioning contributing around 2% of total jobs by 2050. Operation and maintenance jobs have the most significant increase in the share of total jobs created from 15% in 2015 to 50% by 2050. This demonstrates how a transition towards a 100% renewable power system enables the creation of more stable jobs, which can contribute to a stable economic growth mainly in the developing regions of the world and provide a means of tackling youth unemployment.

There are large regional variations in the distribution of created job. Most renewable energy and storage technologies are still in their initial phases of development and are expected to grow in proportion to their current lower levels of installations. The pattern varies across different renewable power generation and storage technologies, and therefore across different regions. Due to limited activity in some countries compared to the rapid growth observable in others, regional differences arise, as shown in Figure 7:

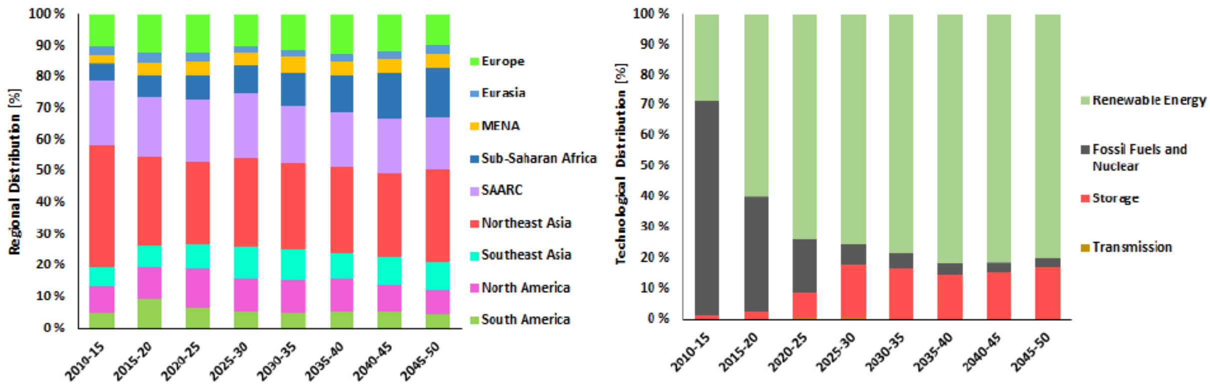

Figure 7: Regional distribution of jobs created (left) and technological distribution of jobs created (right) during the energy transition from 2015 to 2050 globally.

The "Hothouse Earth": trajectories of the Earth system in the Anthropocene, Steffen et al., 2018[1]

This study explores potential future trajectories of the Earth system. They analyse the existence of a planetary threshold that, when crossed, leads to a pathway of unstoppable climate change. More specifically they argue that a chain of self-reinforcing feedbacks could prevent the stabilisation of Earth's climate at intermediate temperature levels and cause continued warming on a 'Hothouse Earth' trajectory even when GHG emissions are reduced. These self-reinforcing feedbacks are often referred to as tipping elements. An example is permafrost thawing which releases the GHG methane into the atmosphere, leading to more warming which again causes more permafrost to thaw and likely triggering other tipping elements. Other examples are the large-scale dieback of the Amazon rainforest or the boreal forest, the loss of the Greenland ice sheet, the coral reefs and the Indian summer monsoon. The counterpart to the 'Hothouse Earth' trajectory is the 'Stabilized Earth', where feedback mechanisms are not triggered and temperatures remain at similar to current levels. The planetary threshold represents the critical level of global warming between these two trajectories. The authors speculate that this threshold could be as low as 2°C above pre-industrial level but acknowledge that there are currently large uncertainties surrounding the estimate.

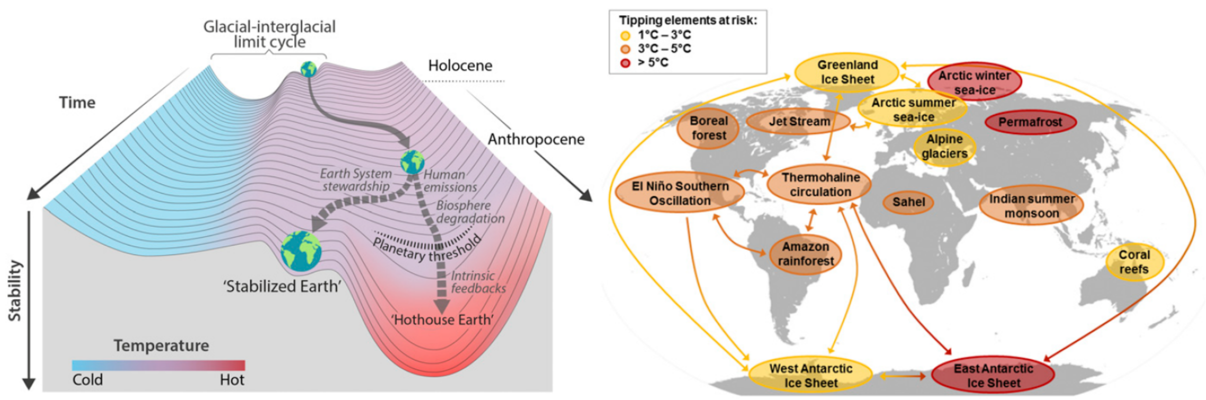

*Figure 8: **Left: Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene**. Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold at ∼2 °C, beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship guided by human-created feedbacks to a quasistable, human-maintained basin of attraction. "Stability" (vertical axis) is defined here as the inverse of the potential energy of the system. Systems in a highly stable state (deep valley) have low potential energy, and considerable energy is required to move them out of this stable state. Systems in an unstable state (top of a hill) have high potential energy, and they require only a little additional energy to push them off the hill and down toward a valley of lower potential energy.*
***Right: Global map of potential tipping cascades**. The individual tipping elements are color-coded according to estimated thresholds in global average surface temperature (tipping points). Arrows show the potential interactions among the tipping elements based on expert elicitation that could generate cascades. Note that, although the risk for tipping (loss of) the East Antarctic Ice Sheet is proposed at >5 °C, some marine-based sectors in East Antarctica may be vulnerable at lower temperatures.*

[1] Steffen, W., Rockström, J., Richardson, K., Lenton, T. M., Folke, C., Liverman, D., Summerhayes, C. P., Barnosky, A. D., Cornell, S. E., Crucifix, M., Donges, J. F., Fetzer, I., Lade, S. J., Scheffer, M., Winkelmann, R., & Schellnhuber, H. J. (2018). Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(33), 8252–8259. https://doi.org/10.1073/pnas.1810141115

The authors make the point that social and technological transitions over the next decade could significantly influence the trajectory of the Earth System. They suggest that, similarly to the self-reinforcing processes that lead to 'Hothouse Earth', global action to avoid 2°C would involve large changes to social systems where one process could lead to another and represent a reinforcing system as well.

It is important to highlight that the exact thresholds for any such tipping elements are highly uncertain, and the assertion of such tipping cascades being triggered at certain warming levels is the expert judgement of the authors, and not necessarily supported by the wider scientific community including the IPCC (see e.g. assessments of risks of ⇒tipping points in the SROCC). However, these risks call for a precautionary principle to limit warming to 1.5°C in order to avoid risks of crossing ⇒tipping points of the Earth System.

Technical note

Shared Socio-economic Pathways

Shared socio-economic pathways (SSPs) are used in the IPCC special report on the impacts of warming of 1.5°C to explore implications of future socio-economic development on climate change mitigation, adaptation, and land-use. Based on five narratives the SSPs describe alternative socio-economic futures: sustainable development (SSP1), middle-of-the-road development (SSP2), regional rivalry (SSP3), inequality (SSP4), and fossil-fueled development (SSP5).

- 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 as a continuation of past trends, and only a gradual reduction in inequality. 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) (see below) which represent 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., 1.5°C) are not possible in SSP3 in modelled pathways.

Representative Concentration Pathways

RCPs are scenarios that include time series of emissions and concentrations of greenhouse gases (GHGs), ⇒aerosols and chemically active gases, as well as land use / land cover. Each RCP is named after the ⇒radiative forcing they have at the end of the 2100. For example, RCP2.6 describes a pathway where ⇒radiative forcing peaks at 3W/m2 and then declines to around 2.6W/m2 in 2100.

Each RCP is only one of many possible scenarios that would lead to the specific ⇒radiative forcing characteristics.

RCP1.9 limits global warming to below 1.5 °C, the aspirational goal of the Paris Agreement. RCP2.6 represents a low emission, high mitigation future, with a two in three chance of limiting global warming to below 2°C by 2100 in model simulations. RCP4.5 and RCP6.0 have intermediate levels of greenhouse gas emissions and result in intermediate levels of warming. RCP8.5 is a high greenhouse gas emissions scenario in the absence of policies to combat climate change, leading to continued and sustained growth in atmospheric greenhouse gas concentrations.

Due to uncertainties in feedback processes in the earth system, the response of the climate system to anthropogenic CO_2 emissions is subject to considerable uncertainty. The IPCC Fifth' Assessment Report estimates the ⇒transient climate response to cumulative CO_2 emissions to be between 0.2-0.7°C per 1000 Gt CO_2. **Error! Reference source not found.** provides the ranges of estimates of total warming since the pre-industrial period under four different RCPs. The uncertainty of the ⇒transient climate response is included in the uncertainty ranges.

	Near-term: 2031–2050		End-of-century: 2081–2100	
Scenario	Mean (°C)	*Likely* range (°C)	Mean (°C)	*Likely* range (°C)
RCP2.6	1.6	1.1 to 2.0	1.6	0.9 to 2.4
RCP4.5	1.7	1.3 to 2.2	2.5	1.7 to 3.3
RCP6.0	1.6	1.2 to 2.0	2.9	2.0 to 3.8
RCP8.5	2.0	1.5 to 2.4	4.3	3.2 to 5.4

Table 2: Projected ⇒global mean surface temperature change relative to 1850–1900 for two time periods under four RCPs.

IPCC's calibrated language

The SRCCL uses IPCC calibrated language for the communication of confidence in the assessment process. This calibrated language uses qualitative expressions of confidence based on the robustness of evidence for a finding, and (where possible) uses quantitative expressions to describe the likelihood of a finding.

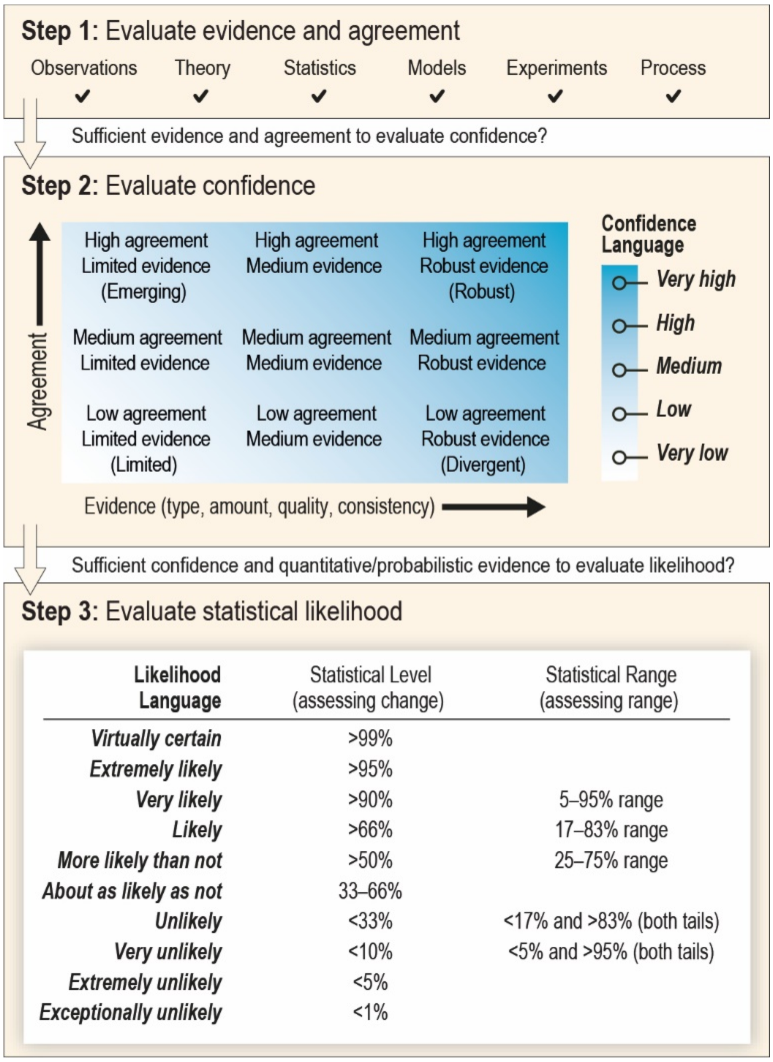

Figure 9: (fig TS.1) Schematic of the IPCC usage of calibrated language

Glossary

Aerosol A suspension of airborne solid or liquid particles, with a typical size between a few nanometres and 10 µm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. They influence climate in several ways: through interactions that scatter and/or absorb radiation and through interactions with cloud microphysics and other cloud properties, or upon deposition on snow- or ice-covered surfaces thereby altering their albedo and contributing to climate feedback.

Carbon cycle The term used to describe the flow of carbon (in various forms, e.g., as carbon dioxide (CO2), carbon in biomass, and carbon dissolved in the ocean as carbonate and bicarbonate) through the atmosphere, hydrosphere, terrestrial and marine biosphere and lithosphere.

Carbon Dioxide Removal (CDR) Anthropogenic removal of atmospheric carbon dioxide and sequestration in geological, terrestrial or ocean reservoirs, or in products. CDR includes activities that enhance the natural carbon sinks but excludes natural CO2 uptake that is not directly caused by human activities.

Carbon pricing Carbon pricing is a strategy that ties the external costs of greenhouse gas emissions (damage to crops, costs from extreme events etc.) to their sources through a price. The carbon price is therefore the price for released CO2 or CO2-equivalent emissions.

Carbon sink A reservoir (natural or anthropogenic, in soil, ocean, and plants) where CO2 is stored.

Climate extreme (extreme weather or climate event) An event that is rare at a particular place and time of year.

El Niño The term El Niño describes an oceanic event where the tropical Pacific Ocean east of the dateline warms. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to seven years, is known as the El Niño-Southern Oscillation (ENSO). During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea surface temperatures warm, further weakening the trade winds. This phenomenon has a great impact on the wind, sea surface temperature and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world, through global teleconnections.

Forcing (or Radiative Forcing) The difference between incoming and outgoing radiation is known as a planet's radiative forcing. Forcing is the change in this radiative flux, expressed in Wm^{-2}, at the tropopause or top of atmosphere due to a change in a driver of climate (for example the change in atmospheric CO2 concentration or solar radiation).

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. Changes in GMST are usually expressed as departures from a value over a specified reference period.

Nationally Determined Contribution (NDC) A term used under the United Nations Framework Convention on Climate Change (UNFCCC) whereby a country that has joined the Paris Agreement outlines its plans for reducing its emissions. Some countries' NDCs also address how they will adapt to climate change impacts, and what support they need from, or will provide to, other countries to adopt low-carbon pathways and to build climate resilience. Each Party shall prepare, communicate and maintain successive NDCs that it intends to achieve.

Negative emissions Removal of greenhouse gases (GHGs) from the atmosphere by deliberate human activities, i.e., in addition to the removal that would occur via natural ⇒carbon cycle processes. See also Carbon Dioxide Removal.

Net negative CO2 emissions A situation of net negative CO2 emissions is achieved when, as result of human activities, more carbon dioxide is removed from the atmosphere than is emitted into it. See also Negative emissions, Carbon Dioxide Removal and Net zero CO2 emissions.

Net zero CO2 emissions Net zero carbon dioxide (CO2) emissions are achieved when anthropogenic CO2 emissions are balanced globally by anthropogenic CO2 removals over a specified period.

Ocean acidification This refers to the reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by ocean uptake of carbon dioxide (CO2) from the atmosphere.

Short-lived climate forcers Short-lived climate forcers refer to a set of compounds that are primarily composed of those with short lifetimes in the atmosphere compared to well-mixed / long-lived greenhouse gases. These are methane, ozone, aerosols and their precursors, and some halogenated species that are not well-mixed greenhouse gases. Short-lived climate forcers do not accumulate in the atmosphere at decadal to centennial time scales, and so their effect on climate is predominantly in the first decade after their emission, although their changes can still include long-term effects such as sea level change.

Small Island developing states (SIDS) SIDS are a distinct group of developing countries facing specific social, economic and environmental vulnerabilities.

Tipping point Tipping points refer to critical thresholds in a system that, when exceeded, can lead to a significant change in the state of the system, often with an understanding that the change is irreversible.

Transient Climate Response (TCR) Is a measure of the change in global mean surface temperature in response to a change in the atmospheric CO2 concentration or other forcing. The change in global mean surface temperature, averaged over a 20-year period, centred at the time of atmospheric CO2 doubling, in a climate model simulation in which CO2 increases at 1%yr^{-1} from preindustrial. It is a measure of the strength of climate feedbacks and the timescale of ocean heat uptake.

Transient Climate Response to cumulative CO2 emissions (TCRE) The change in transient global average surface temperature per unit cumulative CO2 emissions, usually 1000 GtC. TCRE combines both information on the airborne fraction of cumulative CO_2 emissions and on the transient climate response.

CLIMATE
ANALYTICS