Scientific Facts on

IPCC Climate Change technical report 2022: Impacts, Adaptation and Vulnerability

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Summary & Details:
GreenFacts

Level 2 - Details on IPCC Climate Change technical report 2022: Impacts, Adaptation and Vulnerability

This is a faithful summary of the leading report

produced in 2022 by the Intergovernmental Panel on Climate Change (IPCC):
"Climate Change 2022: Impacts, Adaptation and Vulnerability"

The full Digest is available at: https://www.greenfacts.org/en/climate-change-ar6-impacts/

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1. 1. What are the issues more specifically covered in these Highlights?

These GreenFacts Highlights are the transcription without any comments or opinions of excerpts from the *Technical Summary of the Sixth Assessment Report* (AR6) published by the *International governemantal Panel on Climate Change* (IPCC)[1] of the *United Nations Environmental Programme* (UNEP) andapproved by the IPCC member governments line by line. This Technical Summary complements and expands the key findings of the Working Group II (WGII) contribution to the AR6 presented in the *Summary for Policymakers*[2] and covers literature accepted for publication by September 2021. It provides technical understanding and is developed from the key findings of chapters and cross-chapter papers as presented in their Executive Summaries and integrates across them.

More specifically, the Working Group II contribution to the ARS6 assessed the impacts of climate change, looking at ecosystems, biodiversity, and human communities at global and regional levels. It also reviews vulnerabilities and the capacities and limits of the natural world and human societies to adapt to climate change. The report also provides extensive regional information to enable Climate Resilient Development (CRD) and a detailed assessment of climate change impacts, risks and adaptation in cities, where more than half the world's population lives.

Note and answers to frequently asked questions (FAQs) of the report are avalable on the IPCC website[3]. Also, regional and crosscutting fact sheets give a snapshot of the key findings, distilled from the relevant Chapters and Cross-Chapter Papers, the Technical Summary and the Global to Regional Atlas. A Global to Regional Atlas provides visual summaries and case studies on climate change impacts and risks, vulnerabilities and adaptation, building on the report key findings[4].

- 3. **the three key components** associated to climate risks;
- 4. the **main climate changes impacts** observed since the former IPCC report;
- 5. the now **expected evolutions of global temperatures**;
- 6. the specific impacts of climate changes on **biodiversity**;
- 7. the damages caused **to terrestrial and freshwater marine ecosystems**;
- 8. the impacts on the various **water systems**;
- 9. the impacts on **agricultural activities and food security**;
- 10. the impacts of climate changes on **human health**;
- 11. the impact of climate change on **costal regions**;
- 12. **the vulnerability of more specifically affected people** and how it will evolve;
- 13. How, facing climate change, will human vulnerability evolve
- 14. How will this affect more specifically **human migrations**;
- 15. the main impacts of climate change on **economic activities**;
- 16. **How for the world possible to act** facing climate change;
- 17. **the main possible adaptations** to climate change;
- 18. an **Ecosystem-based Adaptation**;
- 19. the **main limits and key barriers to the implementation of adaptation options**;
- 20. overcoming the **barriers of maladaptations** to climate change;
- 21. **How more systemic practices** play a role in the responses to climate change;
- 22. a specific focus to be given to **governance practices**;

[1] www.ipcc.ch/report/ar6/wg2/ [see https://www.ipcc.ch/report/ar6/wg2/]
Final full report https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf [see https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf]

[2] www.ipcc.ch/report/sixth-assessment-report-working-group-ii/ [see https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/]

[3] www.ipcc.ch/report/ar6/wg2/about/frequently-asked-questions [see https://www.ipcc.ch/report/ar6/wg2/about/frequently-asked-questions]

[4] www.ipcc.ch/report/ar6/wg2/ [see https://www.ipcc.ch/report/ar6/wg2/]

2. 2. In brief

Warming pathways which imply a temporary temperature increase over "well below 2°C above pre-industrial" for multi-decadal time spans imply severe risks and irreversible impacts in many natural and human systems (e.g. glacier melt, loss of coral reefs, loss of human lives due to heat) even if the temperature goals are reached later (*high confidence*[5]). There is only limited opportunity to widen the remaining solution space and take advantage of many potentially effective, yet unimplemented options for reducing society and ecosystem vulnerability (*high confidence*). With progressive climate change, enabling conditions will diminish, and opportunities for successfully transitioning systems for both mitigation and adaptation will become more limited (*high confidence*). Societal choices in the near-term will determine future pathways. But prevailing development pathways are not advancing *climate resilient development* (***very high confidence***).

Even if the Paris temperature goal of 1.5°C is still reached by 2100, this "overshoot" entails severe risks and irreversible impacts to many natural and human systems. Overshoot substantially increases risk of carbon stored in the biosphere being released into the atmosphere due to increases in processes such as wildfires, tree mortality, insect pest outbreaks, peatland drying and permafrost thaw (*high confidence*). These phenomena exacerbate self-reinforcing feedbacks between emissions from high-carbon ecosystems (that currently store ~3000–4000 Gigatons of carbon) and increasing global temperatures.

Complex interactions of climate change, land use change, carbon dioxide fluxes and vegetation changes, combined with insect outbreaks and other disturbances, will regulate the future carbon balance of the biosphere, processes which are incompletely represented in current earth system models. The exact timing and magnitude of climate-biosphere feedbacks and potential tipping points of carbon loss are characterized by large uncertainty, but studies of feedbacks indicate increased ecosystem carbon losses can cause large future temperature increases (*medium confidence*). For example, the loss of species lowers the resilience of the ecosystem as a whole, including its capacity to persist through climate change and recover from extreme events (*high confidence*). Species extinctions levels that are >1,000 times natural background rates as a result of anthropogenic pressures and climate change will increasingly exacerbate this (*high confidence*).

With proactive, timely, and effective adaptation, many risks for human health and wellbeing could be reduced and some potentially avoided (***very high confidence***). National planning on health and climate change is advancing, but comprehensiveness of strategies and plans need to be strengthened to reduce future risks and implementing action on key health and climate change priorities remains challenging (*high confidence*). Various tools, measures and processes are available that can enable, accelerate and sustain adaptation implementation (*high confidence*), in particular when anticipating climate change impacts, empower inclusive decision making and action when they are supported by adaptation finance and leadership across all sectors and groups in society (*high confidence*). The COVID-19 pandemic demonstrated the value of coordinated planning across sectors, safety nets, and other capacities in societies to cope with a range of shocks and stresses and to alleviate systems-wide risks to health (*high confidence*).Also local leadership especially amongst women and youth can advance equity within and between generations (*medium confidence*).

Large-scale, transformational adaptation also necessitates enabling improved approaches to governance and coordination across sectors and jurisdictions to avoid overwhelming current adaptive capacities and to avoid future maladaptive actions (*high confidence*). Prospects for transformation towards climate resilient development increase when key governance actors work together in inclusive and constructive ways to create a set of appropriate enabling conditions (*high confidence*). Multilateral governance practices and efforts for climate resilient development will be most effective when supported by formal (e.g., the law) and informal (e.g., local customs and rituals) institutional arrangements providing for ongoing coordination between and alignment of local to international arrangements across sectors and policy domains (*high confidence*).

[5] See in appendix the scheme describing the process appliedby IPCC exeports to define a confidence level

[6] See the key difference between hazard, risk and safety in a short animation video: www.youtube.com/watch?v=PZmNZi8bon8 [see https://www.youtube.com/watch?v=PZmNZi8bon8]

3. 3. What is the subject of this report?

This report has a strong focus on the interactions and interdependence among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging impacts and risks from climate change, ecosystem degradation and, at the same time, offer opportunities for the future. Adaptation is set against concurrently unfolding non-climatic global trends e.g., biodiversity loss, overall unsustainable consumption of natural resources, land and ecosystem degradation, rapid urbanisation, human demographic shifts, social and economic inequalities and a pandemia.

Based on scientific understanding, the key findings are formulated as statements of facts or associated with an assessed level of confidence using the IPCC calibrated language. The concept of risk is central to all three AR6 Working Groups[6]. A risk framing and the concepts of adaptation, vulnerability, exposure, resilience, equity and justice, and transformation provide alternative, overlapping, complementary, and widely used entry points to the literature assessed in this WGII report.

The *Reasons for Concern* (RFCs) represent global risk levels for aggregated concerns about "*dangerous anthropogenic interference with the climate system*", they represent a great diversity of risks, and in reality, there is not one single dangerous climate threshold across sectors and regions:

- RCF1. Describing risks associated with unique and threatened systems;
- RCF2. Extreme weather events;
- RCF2. Extreme weather events;
- RCF4. Global aggregate impacts;
- RCF5. Large-scale singular events.

For all five major RFCs about climate change, more evidence than in the previous report supports increase to high level and very high levels at lower global warming levels (*high confidence*), and transition ranges are assigned with greater confidence.

Limiting global warming to 1.5ºC would ensure risk levels remain moderate for RFC3, RFC4 and RFC5 (*medium confidence*) but risk for RFC2 would have transitioned to a high risk at 1.5ºC and RFC1 would be well into the transition to very high risk (*high confidence*).

4. 4. What are the three key components associated to climate risks?

Vulnerability, adaptation and resilience are the three essentials components characterising the climate risks.

Urban infrastructure failures cascade risk and loss across and beyond the city
[see Annex 7, p. 35]

- a) **Vulnerability** which is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt of exposed human and natural systems is a component of risk. Vulnerability is widely understood to differ within communities and across societies, regions and countries, also changing through time. Approaches to analysing and assessing vulnerability have evolved since previous IPCC assessments.
- b) **Adaptation** is defined, in human systems, as the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities. Adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this. It plays a key role in reducing exposure and vulnerability to climate change in natural systems. Adaptation in ecological systems includes autonomous adjustments through ecological and evolutionary processes, bouncing back and returning to a previous state after a disturbance. In human systems, adaptation can be anticipatory or reactive, as well as incremental and / or transformational. The latter changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts. The limit of adaptations is the point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions. Adaptation is subject to hard and soft limits. A hard adaptation limit is when no adaptive actions are possible to avoid intolerable risks while in a soft adaptation limit options may exist but are currently not available to avoid intolerable risks through adaptive action. AR6 highlights adaptation solutions which are effective, feasible, and conform to principles of justice.
- c) **Resilience** is not just the ability to maintain essential function, identity and structure, but also the capacity for transformation. It is defined as the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure as well as biodiversity in case of ecosystems while also maintaining the capacity. for adaptation, learning and transformation. Resilience is a positive attribute when it maintains such a capacity for adaptation, learning, and/or transformation.

5. 5. What are the main climate changes impacts observed since the former 5th IPCC report (AR5)?

Widespread, pervasive impacts to ecosystems, people, settlements, and infrastructure have resulted from observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land and in the ocean, heavy precipitation events, drought and fire weather (*high confidence*). Increasingly since AR5, these observed impacts have been attributed to human-induced climate change particularly through increased frequency and severity of extreme events. These include increased heat related human mortality (*medium confidence*), warm-water coral bleaching and mortality (*high confidence*), and increased drought related tree mortality (*high confidence*).

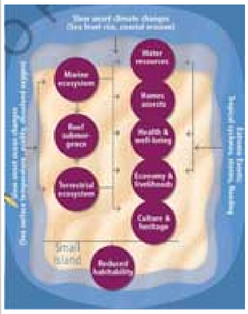
Observed increases in areas burned by wildfires have been attributed to human-induced climate change in some regions *(medium to high confidence)*. Adverse impacts from tropical cyclones, with related losses and damages, have increased due to sea level rise and the increase in heavy precipitation (*medium confidence*). Impacts in natural and human systems from slow-onset processes such as ocean acidification, sea level rise or regional decreases in precipitation have also been attributed to human induced climate change (*high confidence*). Glacier mass loss, permafrost thaw and decline in snow cover are projected to continue beyond 21st century (*high confidence*). Many low elevation and small glaciers around the world will lose most of their total mass at 1.5 ° C warming (*high confidence*). Glaciers are likely to disappear by nearly 50% in High Mountain Asia and about 70% in Central and Western Asia by the end of the 21st century under the medium warming scenario.

Some key risks contributing to the *Reasons for Concern* (RFCs) are projected to lead to widespread, pervasive, and potentially irreversible impacts at global warming levels of 1.5–2°C if exposure and vulnerability are high and adaptation is low (*medium confidence*). Population groups in most vulnerable and exposed regions to compound and cascading risks have the most urgent need for improved adaptive capacity (*high confidence*).

Risks to ecosystem integrity, functioning and resilience are projected to escalate with every tenth of a degree increase in global warming (***very high confidence***). Changes induced by climate change in the physiology, biomass, structure and extent of ecosystems will also determine their future carbon storage capacity (*high confidence*). Temperature rise of 4ºC by 2100 is projected to increase global burned area 50-70% and fire frequency by ~30%, potentially releasing 11-200 Gigatons of carbon from the Arctic alone (*medium confidence*). Changes in plankton community structure and productivity are projected to reduce carbon sequestration at depth (*low to medium confidence*).

Map of observed human vulnerability based on national averages [see Annex 4, p. 32]

Over large areas of northern South America, the Mediterranean, western China and high latitudes in North America and Eurasia, frequency of extreme agricultural droughts are projected to be 150 to 200% more likely at 2°C, and over 200% more likely at 4°C (*medium confidence*). An additional 350 and 410 million people living in urban areas will be exposed to water scarcity from severe droughts at 1.5°C and 2°C, respectively. Above 2°C, frequency and duration of meteorological drought is projected to be double over North Africa, the western Sahel and Southern Africa (*medium confidence*). More droughts and extreme fire weather are projected in southern and eastern Australia (*high confidence*) and over most of New Zealand (*medium confidence*).



Compound risks in coastal and island systems reduce habitability in coastal and island systems reduce hability
[see Annex 3, p. 31]

By contrast, projected increase in heavy rainfall events at all levels of warming in many regions in Africa will cause increasing exposure to pluvial and riverine flooding (*high confidence*), with expected human displacement increasing 200% for 1.6°C and 600% for 2.6°C. Particularly exposed and vulnerable coastal communities, especially those relying on coastal ecosystems for protection or livelihoods, may face adaptation limits well before the end of this century, even at low warming levels (*high confidence*). A 1.5°C increase would result in an increase of 100–200% in the population affected by floods in Colombia, Brazil and Argentina, 300% in Ecuador and 400% in Peru (*medium confidence*). Compounded and cascading climate risks, such as tropical cyclone storm surge damage to coastal infrastructure and supply chain networks, are expected to increase (*medium confidence*).

6. 6. What are the now expected evolutions of global temperatures?

Global warming of 1.5°C relative to 1850–1900 would be exceeded during the 21st century under the intermediate, high and very high greenhouse gas emissions scenarios considered in this report. Under the five illustrative scenarios, in the near term (2021–2040), the 1.5°C global warming level:

- Is very likely to be exceeded under the very high greenhouse gas emissions scenario ;
- Likely to be exceeded under the intermediate and high greenhouse gas emissions scenarios ;
- More likely than not to be exceeded under the low greenhouse gas emissions scenario ;
- and more likely than not to be reached under the very low greenhouse gas emissions scenario.

Furthermore, for the very low greenhouse gas emissions scenario, it is more likely than not that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.

Solar Radiation Modification (SRM) approaches attempt to offset warming and ameliorate some climate risks but introduce a range of new risks to people and ecosystems, which are not well understood (*high confidence*). There is high agreement in the literature that for addressing climate change risks SRM is, at best, a supplement to achieving sustained net zero or net negative carbon dioxide (CO_2) emission levels globally. SRM effects on climate hazards are highly dependent on deployment scenarios and substantial residual climate change or overcompensating change would occur at regional scales and seasonal timescales (*high confidence*). Due in part to limited research, there is low confidence in projected benefits or risks to crop yields, economies, human health, or ecosystems. By contrast, large negative impacts are projected from rapid warming for a sudden and sustained termination of SRM in a high-CO_2 scenario. SRM would not stop CO_2 from increasing in the atmosphere or reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*).

In conclusion, co-evolution of SRM governance and research provides a chance for responsibly developing SRM technologies with broader public participation and political legitimacy, guarding against potential risks and harms relevant across a full range of scenarios.

7. 7. What are the specific impacts of climate changes on biodiversity?

Biodiversity loss, and degradation, damages to and transformation of ecosystems are already key risks for every region due to past global warming and will continue to escalate with every increment of global warming (***very high confidence***). Near-term warming and increased frequency, severity and duration of extreme events will place many terrestrial, freshwater, coastal and marine ecosystems at high or very high risks of biodiversity loss (*medium to* ***very high confidence****, depending on ecosystem*)[7]. In terrestrial ecosystems, 3 to 14% of species assessed will likely face very high risk of extinction at global warming levels of 1.5°C, increasing up to to 39% at 4°C and to 48% at 5°C.

Near-term warming will continue to cause plants and animals to alter their timing of seasonal events (*high confidence*) and to move their geographic ranges (*high confidence*). Even for less-vulnerable species and systems, projected climate-change risks surpass hard limits to natural adaptation, increasing species at high risk of population declines (*medium confidence*), loss of critical habitats *(medium to high confidence)* and compromising ecosystem structure, functioning and resilience (*medium confidence*). Global warming will progressively weaken soil health and ecosystem services such as pollination, increase pressure from pests and diseases, and reduce marine animal biomass, undermining food productivity in many regions on land and in the ocean (*medium confidence*). Climate change will indeed reduce the effectiveness of pollination as species are lost from certain areas, or the coordination of pollinator activity and flower receptiveness is disrupted in some regions (*high confidence*).

These near-term risks for biodiversity loss are moderate to high in forest ecosystems (*medium confidence*), kelp and seagrass ecosystems *(high to* ***very high confidence****)* and high to very high in Arctic sea-ice and terrestrial ecosystems (*high confidence*) and warmwater coral reefs (***very high confidence***).

Continued and accelerating sea level rise will encroach on coastal settlements and infrastructure (*high confidence*) and commit low-lying coastal ecosystems to submergence and loss (*medium confidence*). If trends in urbanisation in exposed areas continue, this will exacerbate the impacts, with more challenges where energy, water and other services are constrained (*medium confidence*). The number of people at risk from climate change and associated loss of biodiversity will progressively increase (*medium confidence*).

Effective ecosystem conservation on approximately 30% to 50% of Earth’s land, freshwater and ocean areas, including all remaining areas with a high degree of naturalness and ecosystem integrity, will help protect biodiversity, build ecosystem resilience and ensure essential ecosystem services (*high confidence*).

[7] Important to note that biodiversity is essential to the resilience of natural ecosystems in functions like pollination, climate regulation, flood protection, soil fertility, etc. It is also

crucial to ensure the productivity of resources and the services that nature supplies to humanity for the production of food, fuels, fibres (a.o. wood and paper) and medicines.

8. 8. What are the damages caused more specifically to terrestrial and freshwater?

Widespread deterioration of ecosystem structure and function, resilience and natural adaptive capacity, as well as shifts in seasonal timing have occurred due to climate change (*high confidence*), with adverse socioeconomic consequences (*high confidence*). Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems (*high confidence*). The extent and magnitude of these impacts are larger than estimated in previous assessments (*high confidence*). Impacts are evident on ecosystem structure, species geographic ranges and timing of seasonal life cycles.

Projected climate change, combined with non-climatic drivers, will cause loss and degradation of much of the world's forests (*high confidence*), coral reefs and low-lying coastal wetlands (***very high confidence***). Approximately half of the species assessed globally have shifted polewards or, on land, also to higher elevations (***very high confidence***). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (*high confidence*), as well as mass mortality events on land and in the ocean (***very high confidence***) and loss of kelp forests (*high confidence*).

Extinction risk increases disproportionally from global warming of 1.5 to 3°C and is especially high for endemic species and species rendered less resilient by human-induced non-climate stressors ***(very high confidence)***. Some losses are already irreversible, such as the first species extinctions driven by climate change *(medium confidence)*. Other impacts are approaching irreversibility such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain *(medium confidence)* and Arctic ecosystems driven by permafrost thaw *(high confidence)*.

9. 9. What are the impacts of climate change on the various water systems?

Risks in physical water availability and water-related hazards will continue to increase by the mid to long-term in all assessed regions, with greater risk at higher global warming levels (*high confidence*). Central to equity issues about water is that it remains a public good (*high confidence*).

By 2050, environmentally critical streamflow is projected to be affected in 42% to 79% of the world's watersheds, causing negative impacts on freshwater ecosystems (*medium confidence*). Increased wildfire, combined with soil erosion due to deforestation, could degrade water supplies (*medium confidence*). Projected climate-driven water cycle changes, including increase in evapotranspiration, altered spatial patterns and amount of precipitation, and associated changes in groundwater recharge, runoff and streamflow, will impact terrestrial, freshwater, estuarine and coastal ecosystems and the transport of materials through the biogeochemical cycles, impacting humans and societal well-being (*medium confidence*).

At approximately 2°C global warming, snowmelt water availability for irrigation is projected to decline in some snowmelt dependent river basins by up to 20%, and global glacier mass loss of 18 ± 13% is projected to diminish water availability for agriculture, hydropower, and human settlements in the mid- to long-term, with these changes projected to double with 4°C global warming (*medium confidence*).

In small islands, groundwater availability is threatened by climate change (*high confidence*). Changes to streamflow magnitude, timing and associated extremes are projected to adversely impact freshwater ecosystems in many watersheds by the mid- to long-term across all assessed scenarios (*medium confidence*). Projected increases in direct flood damages are higher by 1.4 to 2 times at 2°C and 2.5 to 3.9 times at 3°C compared to 1.5°C global warming without adaptation (*medium confidence*).

At global warming of 4°C, approximately 10% of the global land area is projected to face increases in both extreme high and low river flows in the same location, with implications for planning for all water use sectors (*medium confidence*). Challenges for water management will be exacerbated in the near, mid and long term, depending on the magnitude, rate and regional details of future climate change and will be particularly challenging for regions with constrained resources for water management (*high confidence*).

10. 10. What are the impacts of climate change on agricultural activities and food security?

Increasing weather and climate extreme events have already exposed millions of people to acute food insecurity and reduced water security, with the largest impacts observed in many locations and/or communities in Africa, Asia, Central and South America, Small Islands and the Arctic (*high confidence*). Jointly, sudden losses of food production and access to food compounded by decreased diet diversity have increased malnutrition in many communities (*high confidence*), especially for Indigenous Peoples, small-scale food producers and low-income households (*high confidence*), with children, elderly people and pregnant women particularly impacted (*high confidence*). Roughly half of the world's population currently experience severe water scarcity for at least some part of the year due to climatic and non-climatic drivers (*medium confidence*).

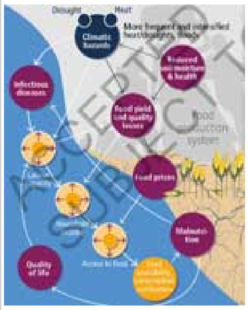
Increases in frequency, intensity and severity of droughts, floods and heatwaves, and continued sea level rise will also increase risks to food security (*high confidence*) in vulnerable regions from moderate to high between 1.5°C and 2°C global warming level, with no or low levels of adaptation (*medium confidence*) hindering efforts to meet the United Unions's 17 Sustainable Development Goals (*high confidence*). At 3ºC or higher global warming levels, adverse impacts on all food sectors will become prevalent, further stressing food availability (*high confidence*), agricultural labour productivity, and food access (*medium confidence*). Regional disparity in risks to food security will grow at these higher warming levels, increasing poverty traps, particularly in regions characterized by a high level of human vulnerability (*high confidence*).

Ocean warming and ocean acidification have already adversely affected food production from shellfish aquaculture and fisheries in some oceanic regions (*high confidence*). For example, cascading effects on food webs have been reported in the Baltic, due to detrimental oxygen levels (*high confidence*). Global marine aquaculture will decline under increasing temperature and acidification conditions by 2100, with potential short-term gains for finfish aquaculture in some temperate regions. Aquatic food safety will also decrease through increased detrimental impacts from harmful algal blooms (*high confidence*) and human exposure to elevated6 bioaccumulation of persistent organic pollutants and methylmercury (*low to medium confidence*).

Climate change will thus increasingly add pressure on food production systems, undermining food security (*high confidence*). With every increment of warming, exposure to climate hazards will grow substantially (*high confidence*), and adverse impacts on all food sectors will become prevalent, further stressing food security (*high confidence*).

While agricultural development contributes to food security, unsustainable agricultural expansion, driven in part by unbalanced diets, increases ecosystem and human vulnerability and leads to competition for land and/or water resources (*high confidence*). Acute food insecurity can occur at any time with a severity that threatens lives, livelihoods or both, regardless of the causes, context or duration, as a result of shocks risking determinants of food security and nutrition, and used to assess the need for humanitarian action[8.]

Irrigation is widely used and effective for yield stability, but with several negative outcomes, including water demand (*high confidence*), groundwater depletion (*high confidence*); alteration of local to regional climates (*high confidence*); increasing soil salinity (*medium confidence*) widening inequalities and loss of rural smallholder livelihoods with weak governance (*medium confidence*).Irrigation expansion will face increasing limits due to water availability beyond 1.5°C (*medium confidence*), with a potential doubling of regional risks to irrigation water availability between 2°C and 4°C (*medium confidence*).



Cascading impacts of climate hazards on food and nutrition
[see Annex 1, p. 29]

Meeting the increasing needs of the human population, for food and fibre production requires thus transformation in management regimes to recognize dependencies on local healthy ecosystems, with greater sustainability, including through increased use of agroecological farming approaches, and adaptation to the changing climate (*high confidence*). Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally (*medium confidence*), related negative impacts were mainly in mid- and low latitude regions but positive impacts occurred in some high latitude regions (*high confidence*).

To reduce vulnerability of fisheries, adaptation options exist through better management, governance and socioeconomic dimensions (*medium confidence*) to eliminate overexploitation and pollution (*high confidence*). Indigenous knowledge and local knowledge can facilitate adaptation in small-scale fisheries, especially when combined with scientific knowledge and utilized in management regimes (*medium confidence*).

Among others, genetic improvements through modern biotechnology have also the potential to increase climate resilience in food production systems (*high confidence*) but with biophysical ceilings, and technical, agroecosystem, socio-economic and political variables strongly influence and limit uptake of climate-resilient crops, particularly for smallholders (*medium confidence*).

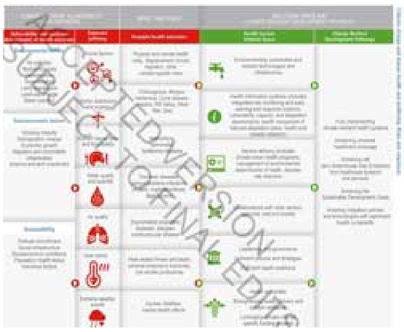
[8] IPC Global Partners, 2019.

11. 11. What are the impacts of climate changes on human health?

In all regions, extreme heat events have already resulted in human mortality and morbidity ***(very high confidence)***. The occurrence of climate-related food-borne and water-borne diseases has also increased ***(very high confidence)***.

Opportunities for pathogens to spread from wildlife to human populations have increased as climate change has already driven range shifts of wildlife, exploitation of wildlife, and loss of wildlife habitat quality. The incidence of vector-borne diseases has already increased from range expansion and/or increased reproduction of disease vectors. This has resulted in increased emergence of zoonotic disease epidemics and pandemics (*medium confidence*). Animal and human diseases, including zoonoses, are emerging in new areas (*high confidence*). Zoonoses that have been historically rare or never documented in Arctic and subarctic regions of Europe, Asia, and North America are emerging as a result of climate-induced environmental change (e.g., anthrax) and spreading poleward and increasing in incidence (e.g., tularemia) (***very high confidence***).

Water and food-borne disease risks have also increased regionally from climate-sensitive aquatic pathogens, including Vibrio spp. (*high confidence*), and from toxic substances from harmful freshwater cyanobacteria (*medium confidence*). Although diarrheal diseases have decreased globally, higher temperatures, increased rain and flooding have increased the occurrence of diarrheal diseases, including cholera (***very high confidence***) and other gastrointestinal infections (*high confidence*).


Climate change and human health and wellbeing: Risks and responses
[see Annex 2, p. 30]

As the likelihood of dangerous risks to human health continue to increase, there is greater need for transformational changes to health and other systems (***very high confidence***). Climate change will further increase the number of deaths and the global burden of non communicable and infectious diseases (*high confidence*). Over 9 million climate-related deaths per year are projected by the end of the century, under a high emissions scenario and accounting for population growth, economic development, and adaptation. Health risks will be differentiated by gender, age, income, social status and region (*high confidence*). Projections under mid-range emissions scenarios show an additional 250,000 deaths per year by 2050 (compared to 1961-1990) due to malaria, heat, childhood undernutrition, and diarrhea (*high confidence*). Overall, more than half of this excess mortality is projected for Africa.

Cardiovascular disease mortality could increase by 18%, 47%, and 69% in the 2020s, 2050s, and 2080s or by 16%, 73% and 134% compared to the 1980s, depending on the scenario considered (*high confidence*). Future risks of respiratory disease associated with aeroallergens and ozone exposure 41 are expected to increase (*high confidence*). In assessed regions, some mental health challenges, including anxiety and stress, are associated with increasing temperatures (*high confidence*), trauma from weather and climate extreme events (***very high confidence***), and loss of livelihoods and culture (*high confidence*). These are expected to increase under further global warming in all assessed regions, particularly for children, adolescents, particularly girls, elderly people with existing mental, physical, underlying health conditions and medical challenges (*high confidence*).

Several chronic, non-communicable respiratory diseases are climate-sensitive based on their exposure pathways (e.g., heat, cold, dust, small particulates, ozone, fire smoke, and allergens) (*high confidence*), although climate change is not the dominant driver in all cases.

Increased exposure to wildfire smoke, atmospheric dust, and aeroallergens have been associated with climate-sensitive cardiovascular and respiratory distress (*high confidence*). Health services have been disrupted by extreme events such as floods (*high confidence*).

In urban settings, observed climate change has also caused impacts on human health, livelihoods and key infrastructure (*high confidence*).

Despite acknowledgement of the importance of health adaptation as a key component, action has been slow since AR5 (*high confidence*). Globally, health systems are poorly resourced in general, and their capacity to respond to climate change is weak, with mental health support being particularly inadequate (***very high confidence***). Financial constraints are the most referenced barrier to health adaptation and therefore scaling up financial investments remains a key international priority (***very high confidence***).

Meanwhile, the burden of diseases could be reduced and resilience increased through:

- Health systems generating awareness of climate change impacts on health (*medium confidence*);
- Strengthening access to water and sanitation (*high confidence*);
- Integrating vector control management approaches (*very high confidence*);
- Expansion of existing early-warning monitoring systems (*high confidence*);
- Increasing vaccine development and coverage (*medium confidence*);
- Increasing vaccine development and coverage (*medium confidence*);
- Building financial safety nets (*medium confidence*).

12. 12. What will be more specifically the impact of climate change on costal regions?

Sea-level rise, combined with altered rainfall patterns, will increase coastal inundation and water-use allocation issues between water-dependent sectors, such as agriculture, direct human consumption, sanitation, and hydropower (*medium confidence*). For example, in Europe coastal flood damage is projected to increase at least 10-fold by the end of the 21st century, and even more or earlier with current adaptation and mitigation (*high confidence*).

Under all emissions scenarios, coastal wetlands will likely face high risk from sea-level rise in the mid-term (*medium confidence*), with substantial losses before 2100. These risks will be compounded where coastal development prevents upshore migration of habitats or where terrestrial sediment inputs are limited and tidal ranges are small (*high confidence*). Near- to mid-term sea-level rise will also exacerbate coastal erosion and submersion, and the salinisation of coastal groundwater, expanding the loss of many different coastal habitats, ecosystems and ecosystem services (*medium confidence*).

Globally, population change in low-lying cities and settlements will lead to approximately a billion people projected to be at risk from coastal-specific climate hazards in the mid-term under all scenarios, including in Small Islands (*high confidence*). The population potentially exposed to a 100-year coastal flood is projected to increase by about 20% if global mean sea level rises by 0.15 m relative to 2020 levels; this exposed population doubles at a 0.75 m rise in mean sea level and triples at 1.4 m without population change and additional adaptation (*medium confidence*). By 2050, more than a billion people located in low-lying cities and settlements will be at risk from coast-specific climate hazards, influenced by coastal geomorphology, geographical location and adaptation action (*high confidence*).

Flood and drought-related acute food insecurity and malnutrition have already increased in Africa (*high confidence*) and Central and South America (*high confidence*). Climate change increases risks of violent conflict, primarily intrastate conflicts, by strengthening climate-sensitive drivers (*medium confidence*). While non-climatic factors are the dominant drivers of existing intrastate violent conflicts, in some assessed regions extreme weather and climate events have had a small, adverse impact on their length, severity or frequency, but the statistical association is weak (*medium confidence*). Through displacement and involuntary migration from extreme weather and climate events, climate change has generated and perpetuated vulnerability (*medium confidence*).

Regions and people with considerable development constraints have high vulnerability to climatic hazards (*high confidence*). Global hotspots of high human vulnerability are found particularly in West-, Central- and East Africa, South Asia, Central and South America, Small Island Developing States and the Arctic (*high confidence*). Vulnerability is higher in locations with poverty, governance challenges and limited access to basic services and resources, violent conflict and high levels of climate-sensitive livelihoods (e.g., smallholder farmers, pastoralists, fishing communities) (*high confidence*). Between 2010-2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability (*high confidence*). Vulnerability at different spatial levels is exacerbated by inequity and marginalization linked to gender, ethnicity, low income or combinations thereof (*high confidence*), especially for many Indigenous Peoples and local communities (*high confidence*).

13. 13. How is the vulnerability of people more specifically affected and will evolve?

Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change (*high confidence*). Under an inequality scenario (SSP4) by 2030, the number of people living in extreme poverty will increase by 122 million from currently around 700 million (*medium confidence*).

Climate change is particularly impacting Indigenous Peoples’ ways of life (***very high confidence***), cultural and linguistic diversity (*medium confidence*), food security (*high confidence*), and health and wellbeing (***very high confidence***). Asian and African urban areas are considered high risk locations from projected climate, extreme events, unplanned urbanisation, and rapid land use change (*high confidence*). The COVID-19 pandemic is also expected to increase the adverse consequences of climate change since the financial consequences have led to a shift in priorities and constrain vulnerability reduction (*medium confidence*).

Human and ecosystem vulnerability are interdependent (*high confidence*) and a high proportion of species is vulnerable to climate change (*high confidence*). Vulnerability to climate change is thus a multi-dimensional phenomenon, dynamic and shaped by intersecting historical and contemporary political, economic, and cultural processes of marginalisation (*high confidence*). Climate-induced changes are not experienced equally across gender, income, class, ethnicity, age, or physical ability (*high confidence*). Societies with high levels of inequity are less resilient to climate change (*high confidence*). It differs substantially among and within regions (***very high confidence***), driven also by unsustainable ocean and land use, inequity, marginalization, historical and ongoing patterns of inequity such as colonialism, and governance (*high confidence*)[9] .

Since the previous report AR5, there is increasing evidence that degradation and destruction of ecosystems by humans increases the vulnerability of people (*high confidence*). Unsustainable land-use and land cover change, unsustainable use of natural resources, deforestation, loss of biodiversity, pollution, and their interactions, adversely affect the capacities of ecosystems, societies, communities and individuals to adapt to climate change (*high confidence*). Loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems, to meet basic needs (*high confidence*). Non-climatic human-induced factors exacerbate current ecosystem vulnerability to climate change (***very high confidence***). Globally, and even within protected areas, unsustainable use of natural resources, habitat fragmentation, and ecosystem damage by pollutants increase ecosystem vulnerability to climate change (*high confidence*). For example, in the Mediterranean and parts of Europe, potential reductions of up to 40% are projected under 3°C warming, while declines below 10% and 5% are projected under 2°C and 1.5°C warming levels, respectively[10].

Current unsustainable development patterns are increasing exposure of ecosystems and people to climate hazards (*high confidence*). Key infrastructure and services such as energy supply and transmission, communications, food and water supply, and transport systems in and between urban and peri-urban areas are disrupted by sea-level rise, heat waves, droughts, changes in run-off, floods, wildfires and permafrost thaw (*high confidence*).

[9] See in this context the question 21: Could more systemic views and management practices play a role in the management of responses and adaptations to climate change challenges?

[10] The droughts impact on water levels in rivers would indirectlyaffect the capacty of refrigeration of energy production systems such as nuclear power units.

14. 14. How will this human vulnerability affect more specifically human migrations?

Over 130 key risks have been found across regions and sectors. The intertwined issues of biodiversity loss and climatic change together with human demographic changes, particularly rapid growth in low-income countries, an aging population in high-income countries and rapid urbanisation are seen as core in understanding risk distribution at all scales. Future human vulnerability will continue to concentrate where the capacities of local, municipal and national governments, communities and the private sector are least able to provide infrastructures and basic services (*high confidence*). Under the global trend of urbanization, human vulnerability will also concentrate in informal settlements and rapidly growing smaller settlements (*high confidence*). Most at risk are women and children who make up the majority populations of these settlements (*high confidence*). Globally, urban key infrastructure systems are increasingly sites of risk creation that potentially drive compounding and cascading risks (*high confidence*). Unplanned rapid urbanization is a major driver of risk, particularly where increasing climate-driven risks affect key infrastructures.

Maladaptation is also a challenge and the AR6, refers to actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence.

In rural areas vulnerability high emigration, reduced habitability and high will height reliance on climate-sensitive livelihoods by compounding processes (*high confidence*). Key infrastructure systems including sanitation, water, health, transport, communications and energy will be increasingly vulnerable if design standards do not account for changing climate conditions (*high confidence*). Vulnerability will also rapidly rise in low-lying Small

Island Developing States and atolls in the context of sea level rise and in some mountain regions, already characterised by high vulnerability due to high dependence on climate-sensitive livelihoods, rising population displacement, the accelerating loss of ecosystem services and limited adaptive capacities (*high confidence*).

Climate variability and extremes are associated with more prolonged conflict through food price spikes, food and water insecurity, loss of income and loss of livelihoods (*high confidence*), with more consistent evidence for low-intensity organized violence within countries than for major or international armed conflict (*medium confidence*). Climate impacts and projected risks have been insufficiently internalized into private and public sector planning and budgeting practices and adaptation finance (*medium confidence*).

Future exposure to climatic hazards is also increasing globally due to socio-economic development trends including migration, growing inequality and urbanization (*high confidence*). Projected estimates of global aggregate net economic damages generally increase non-linearly with global warming levels (*high confidence*). In the mid- to long-term, displacement will increase with intensification of heavy precipitation and associated flooding, tropical cyclones, drought and, increasingly, sea level rise (*high confidence*). At progressive levels of warming, involuntary migration from regions with high exposure and low adaptive capacity would occur (*medium confidence*). Compared to other socioeconomic factors the influence of climate on conflict is assessed as relatively weak (*high confidence*). Along long-term socio-economic pathways that reduce non-climatic drivers, risk of violent conflict would decline (*medium confidence*). At higher global warming levels, impacts of weather and climate extremes, particularly drought, by increasing vulnerability will increasingly affect violent intrastate conflict (*medium confidence*).

15. 15. What are the main impacts of climate change on economic activities?

Climate and weather extremes are increasingly driving displacement in all regions (*high confidence*), with small island states disproportionately affected (*high confidence*). There is increased evidence that climate hazards associated with extreme events and variability act as direct drivers of involuntary migration and displacement and as indirect drivers through deteriorating climate-sensitive livelihoods (*high confidence*). The most common climatic drivers for migration and displacement are drought, tropical storms and hurricanes, heavy rains and floods (*high confidence*). Future climate change may increase involuntary displacement, but severe impacts also undermine the capacity of households to use mobility as a coping strategy, causing high exposure to climate risks, with consequences for basic survival, health and wellbeing (*high confidence*). While relocation may in the near-term appear socially unacceptable, economically inefficient, or technically infeasible, it may become the only feasible option as protection costs become unaffordable and technical limits are reached (*medium confidence*).

Most climate-related displacement and migration occur within national boundaries, with international movements occurring primarily between countries with contiguous borders (*high confidence*). Since 2008, an annual average of over 20 million people have been internally displaced annually by weather-related extreme events, with storms and floods being the most common (*high confidence*). By 2100, compound and cascading risks will result in submergence of some low-lying islands states, damage to coastal heritage, livelihoods and infrastructure (***very high confidence***).

Improving the feasibility of planned relocation and resettlement is a high priority for managing climate risks (*high confidence*). Planned relocation will be increasingly required as climate change undermines livelihoods, safety and overall habitability, especially for coastal areas and small islands (*medium confidence*). This will have implications for traditional livelihood practices, social cohesion and knowledge systems that have inherent value as intangible culture as well as introduce new risks for communities by amplifying existing and generating new vulnerabilities (*high confidence*).

Reducing future risks of involuntary migration and displacement due to climate change is possible by improving outcomes of existing migration patterns, addressing vulnerabilities that pose barriers to in situ adaptation and livelihood strategies, and meeting existing migration agreements and development objectives (*medium confidence*).

16. 16. Is it still possible for the world to act facing climate change?

Across sectors and regions, market and non-market damages and adaptation costs will be lower at 1.5°C compared to 3°C or higher global warming levels (*high confidence*). Recent estimates of projected global economic damages of climate impacts are overall higher than previous estimates and generally increase with global average temperature (*high confidence*). However, the spread in the estimates of the magnitude of these damages is substantial and does not allow for robust range to be established (*high confidence*). Non-market, non-economic damages and adverse impacts on livelihoods will be concentrated in regions and populations that are already more vulnerable (*high confidence*). Socioeconomic drivers and more inclusive development will largely determine the extent of these damages (*high confidence*).

At higher levels of warming, climate impacts will pose risks to financial and insurance markets, especially if climate risks are incompletely internalized (*medium confidence*), with adverse implications for stability of markets *(low confidence)*. While the overall economic consequences are clearly negative, opportunities may arise for a few economic sectors and regions, such as from longer growing seasons or reduced sea ice, primarily in Northern latitudes *(medium to high confidence)*.

Under high warming (>4°C) and limited adaptation, the magnitude of decline in annual global GDP in 2100 relative to a non-global warming scenario exceeds economic losses during the Great Recession 2008-2009 and the COVID-19 pandemic 2020. Much smaller effects are estimated for less warming, lower vulnerability and more adaptation (*medium confidence*). Regional estimates of Gross Domestic Product (GDP) damages vary (*high confidence*). Severe risks are more likely in (typically hotter) developing countries because of nonlinearities in the relationship between economic damages and temperature (*medium confidence*). Higher growth scenarios along higher warming levels increase exposure to hazards and assets at risk, such as Sea Level Rise (SLR) for coastal regions which will have large implications for economic activities, including shipping and ports (*high confidence*).

Interconnectedness and globalization establish pathways for the transmission of climate related risks across sectors and borders, through trade, finance, food, and ecosystems (*high confidence*). Flows of commodities and goods, as well as people, finance and innovation, can be driven or disrupted by distant climate change impacts on rural populations, transport networks and commodity speculation (*high confidence*). Losses become systemic when affecting entire systems and can even jump from one system to another (e.g. drought impacting on rural food production contributing to urban food insecurity) (*medium confidence*). For example, Europe faces climate risks from outside the area due to global supply chain positioning and shared resources (*high confidence*). Inversely, climate risks in Europe also impact finance, food production and marine resources beyond Europe (*medium confidence*).

17. 17. What are the main possible adaptations to climate change?

Climate change impacts and risks are becoming increasingly complex and more difficult to manage. Multiple climate hazards will occur simultaneously, and multiple climatic and non-climatic risks will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Some responses to climate change result in new impacts and risks (*high confidence*)[11].

Human society impacts ecosystems but also can restore and conserve them. The recognition of climate risks and their causes can strengthen adaptation and mitigation actions and transitions that reduce risks. Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (***very high confidence***). Societal resilience is strengthened by improving management of environmental resources and ecosystem health, boosting adaptive capabilities of individuals and communities to anticipate future risks and minimize them, and removing drivers of vulnerability to bringing together gender justice, equity, Indigenous and local knowledge systems and adaptation planning (***very high confidence***).

There is high evidence *(medium agreement)* that diversifying livelihoods improves incomes and reduces socio-economic vulnerability, but feasibility changes depending on livelihood type, opportunities, and local context. Key barriers to livelihood diversification include socio-cultural and institutional barriers as well as inadequate resources and livelihood opportunities that hinder the full adaptive possibilities of existing livelihood diversification practices (*high confidence*).

Meeting the objectives of climate resilient development thereby supporting human, ecosystem and planetary health, as well as human well-being, requires society and ecosystems to move over (transition) to a more resilient state. Taking action is enabled by governance, finance, knowledge and capacity building, technology and catalysing conditions. Empowering marginalised communities in coproduction of policy at all scales of decision-making advances equitable adaptation efforts and reduce the risks of maladaptation (*high confidence*). Inter-sectional, gender-responsive and inclusive decision making can accelerate transformative adaptation over the long term to reduce vulnerability (*high confidence*). People with higher levels of contact with nature have been found to be significantly happier, healthier and more satisfied with their lives (*high confidence*).

Reorienting existing institutions to become more flexible (e.g., through capacity building and institutional reform) and inclusive is key to build adaptive governance systems that are equipped to take long-term decisions (*medium confidence*). Enhancing climate governance, institutional capacity and differentiated policies and regulation from the local to global-scale enables and accelerate climate resilient development.

Transformation and system transitions in energy, land, ocean, coastal and freshwater ecosystems, in urban, rural and infrastructure and in industry and society make possible the adaptation required. These system transitions for high levels of human health and wellbeing, economic and social resilience, ecosystem health and planetary health are also important for achieving the low global warming levels (WGIII) that would avoid many limits to adaptation.

[11] See again in this context the question 21: Could more systemic views and management practices play a role in the management of responses and adaptations to climate change challenges?

18. 18. What is an Ecosystem-based Adaptation?

Effective management of climate risks is dependent on systematically integrating adaptations across interacting climate risks and across sectors (***very high confidence***). Integrated adaptation frameworks and decision-support tools that anticipate multi-dimensional risks and accommodate community values, are more effective than those with a narrow focus on single risks (*medium confidence*). Approaches that integrate the adaptation needs of multiple sectors such as disaster management, account for different risk perceptions, and integrate multiple knowledge systems, are better suited to addressing key risks (*medium confidence*). Many forms of climate adaptation and integration of risks across sectors can be more effective, efficient and equitable when organized collectively with multiple objectives and when assisted by mainstreaming climate considerations across institutions and decision-making processes (*high confidence*).

Available adaptation options can reduce risks to ecosystems and the services they provide but they cannot prevent all changes and should not be regarded as a substitute for reductions in greenhouse gas emissions (*high confidence*). The ambition, scope and progress on adaptation have risen amongst Governments at the local, national, and international levels, along with businesses, communities, and civil society, but many funding, knowledge, and practice gaps remain for effective implementation, monitoring and evaluation (*high confidence*).

Ways to enhance climate literacy and foster behavioural change also include access to education and information, programmes using the performing and visual arts, storytelling, training workshops, participatory dimensional modelling, climate services, and community-based monitoring. Examples that can accelerate adaptation action include accountability and transparency mechanisms, monitoring and evaluation of adaptation progress, social movements, climate litigation, building the economic case for adaptation and increased adaptation finance *(medium evidence, high agreement)*.

Forward-looking adaptive planning and iterative risk management can avoid path dependencies, maladaptation and ensure timely action (*high confidence*) and adaptation is considered in the climate policies of at least 170 countries. Opportunities exist to integrate adaptation into institutionalised decision cycles (e.g., budget reforms, statutory monitoring and evaluation, election cycles) and during windows of opportunity: e.g. recovery after disastrous events, designing new or replacing existing critical infrastructure, or developing COVID recovery projects (*high confidence*).

Concepts of justice, consent and rights-based decision making, together with societal measures of well-being, are increasingly used to legitimate adaptation actions and evaluate the impacts on individuals and ecosystems, diverse communities and across generations (*medium confidence*). Applying these principles as part of monitoring and evaluating the outcomes of adaptation, particularly during system transitions, provides a basis for ensuring that the distribution of benefits and costs are identified (*medium confidence*).

In practice, responses have accelerated in both developed and developing regions since AR5, with some examples of regression (*high confidence*). However, adaptive capacity is highly uneven across and within regions (*high confidence*). There are gaps between current adaptation and the adaptation needed for avoiding the increase of climate impacts that can be observed across sectors and regions, specially under medium and high warming levels (*high confidence*). Greatest adaptation gaps exist in projects that manage complex risks, for example in the food energy-water-health nexus or the inter-relationships of air quality and climate risk (*high confidence*). However, most financial investment continues to be directed narrowly at large-scale hard engineering projects after climate events have caused harm (*medium confidence*).

Transformations for energy include the options of efficient water use and water management, infrastructure resilience, and reliable power systems, including the use of intermittent renewable energy sources, such as solar and wind energy, with the use of storage (***very high confidence***). Increasing adaptation is being observed in natural and human systems (***very high confidence***), yet the majority of climate risk management and adaptation currently being planned and implemented is incremental (*high confidence*) such as reactive changes to usual practices often after extreme weather events, whilst evidence of transformative adaptation in human systems is limited (*high confidence*). Droughts, pluvial, fluvial and coastal flooding are the most common hazards for which adaptation is being implemented and many of these have physical, affordability and social limits (*high confidence*). For example, reliance on hard protection against sea-level rise can lead to development intensification that compounds risk and locks in exposure of people and assets as socio-economic and governance barriers and technical limits are reached. Competition, trade-offs and conflict between mitigation and adaptation priorities will increase with climate change impacts (*high confidence*). Integrated, multisectoral, inclusive and systems-oriented solutions should reinforce long-term resilience (*high confidence*) along with supportive public policies (*medium confidence*).

Current adaptation in natural and managed ecosystems includes earlier planting and changes in crop varieties, soil improvement and water management for livestock and crops, aquaculture, restoration of coastal and hydrological processes, introduction of heat and drought adapted genotypes into high-risk populations, increasing size and connectivity of habitat patches, agroecological farming, agroforestry and managed relocations of high-risk species (*medium confidence*). Most innovation in adaptation has up to now occurred through advances in social and ecological infrastructures including disaster risk management, social safety nets and green/blue infrastructure (*medium confidence*). Meanwhile, many plans focus only on climate risk reduction, missing opportunities to advance co-benefits of climate mitigation and sustainable development, and risking compounding inequality and reduced well-being (*medium confidence*).

Financial barriers limit implementation of adaptation options in natural ecosystems, agriculture, fisheries, aquaculture and forestry as finance strategies are stochastically deployed. Meanwhile, instruments such as behavioural nudges, redirecting subsidies, taxes, regulation of marketing, insurance schemes have proven useful to strengthen societal responses beyond governmental actors (*medium confidence*). Developed-country climate finance leveraged for developing countries for mitigation and adaptation has shown an upward trend, but fallen short of the 100 USD billion per year 2020 target of the Copenhagen commitment, and less than 20% has been for adaptation.

19. 19. What are the main limits and key barriers to the implementation of adaptation options to climate change?

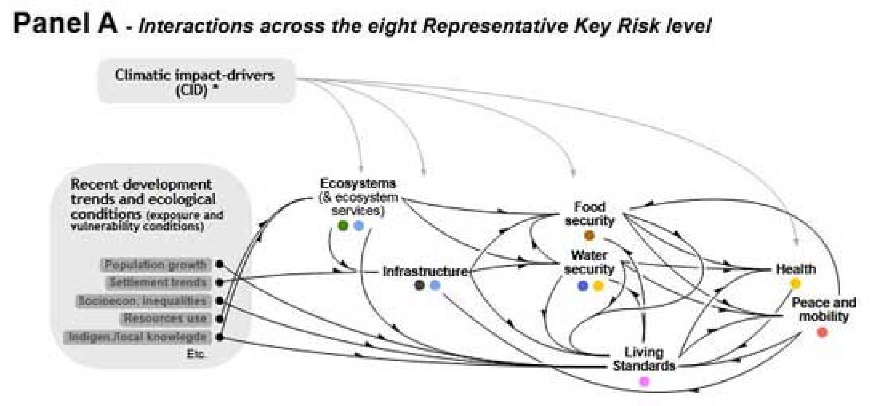
Ecosystem-based Adaptation is defined as the use of ecosystem management activities to increase the resilience and reduce the vulnerability of people and ecosystems to climate change. Taking account of interdisciplinary scientific information, Indigenous knowledge and local knowledge and practical expertise is essential for it to be effective (*high confidence*). Ecosystem protection and restoration can build resilience of ecosystems and generate opportunities to restore ecosystem services with substantial co-benefits (*high confidence*). Increasing the resilience of biodiversity and ecosystem services to climate change includes minimising additional stresses or disturbances, reducing fragmentation, increasing natural habitat extent, connectivity and heterogeneity, maintaining taxonomic, phylogenetic and functional diversity and redundancy; and protecting small-scale refugia where microclimate conditions can allow species to persist (*high confidence*).

In urban areas, trees and natural areas can lower temperatures by providing shade and cooling from evapotranspiration (*high confidence*). Restoration of ecosystems in catchments can also support water supplies during periods of variable rainfall and maintain water quality and combined with inclusive water regimes that overcome social inequalities, provide disaster risk reduction and sustainable development (*high confidence*).

Meanwhile, *System-based Adaptation* and other Nature-based Solutions are themselves vulnerable to climate change impacts (***very high confidence***) and there is indeed a serious risk of high-carbon ecosystems becoming sources of greenhouse gas emissions, which makes it increasingly difficult to halt anthropogenic climate change without prompt protection, restoration, adaptation and mitigation at a global scale.

20. 20. How to overcome the barriers of maladaptations to climate change?

Climate solutions for health, wellbeing and the changing structure of communities are complex, closely interconnected, and call for new approaches to sustainable development that consider interactions between climate, human and socio-ecological systems to generate climate resilient development (*high confidence*). Pursued in an inclusive and integrated manner, they enhance human and ecological well-being.



Interactions across the eight Reprsentative Key Risk level [see Annex 5, p. 33]

Adaptation can require system-wide transformation of ways of knowing, acting and lesson drawing to rebalance the relation between human and nature (*high confidence*). Decision frameworks that consider multiple objectives, scenarios, timeframes, and strategies can avoid privileging some views over others and help multiple actors to identify resilient and equitable solutions to complex, deeply uncertain challenges as well as explicitly dealing with trade-offs. A deliberate shift from primarily technological adaptation strategies to those that additionally incorporate behavioural and institutional changes, adaptation finance, equity and environmental justice, and that align policy with global sustainability goals, will thus facilitate transformational adaptation (*high confidence*).

The transitions to a just and climate resilient future call for transformations in existing social, technological and environmental systems that include shifts in most aspects of society and particularly the five systems on which AR6 is focused: societal, energy, land and ocean ecosystem, urban and infrastructure, and industrial.

Meanwhile, scientific assessments of climate change have traditionally framed solutions around the implementation of specific adaptation and mitigation options as mechanisms for reducing climate-related risks. They have given less attention to a fuller set of societal priorities and the role of non-climate policies, social norms, lifestyles, power relationships and worldviews in enabling climate action and sustainable development. Identifying and advancing synergies and co-benefits of mitigation, adaptation, and SDGs has occurred slowly and unevenly (*high confidence*)

A focus on climate risk alone does not enable effective climate resilience (*high confidence*). The integration of consideration of non-climate drivers into adaptation pathways can reduce climate impacts across food systems, human settlements, health, water, economies, and livelihoods (*high confidence*). Strengthened health, education, and basic social services are vital for improving population well-being and supporting climate resilient development (*high confidence*). Many forms of adaptation are more effective, cost-efficient, and also more equitable when organized inclusively (*high confidence*). Greater coordination and engagement across levels of government, business and community serves to move from planning to action, and from reactive to proactive adaptation (*high confidence*). Inclusion of all societal actors helps to secure credibility, relevance and legitimacy, while fostering commitment and social learning *(medium to high confidence)*, as well as equity and well-being, and reduces long-term vulnerability across scales (high evidence, medium agreement).

Transformation towards climate resilient development is advanced most effectively, when actors work in inclusive and enabling ways to reconcile divergent interests, values and worldviews, building on information and knowledge on climate risk and adaptation options derived from different knowledge systems (*high confidence*). Prospects for transformation towards climate resilient development increase when key governance actors work together in inclusive and constructive ways to create a set of appropriate enabling conditions (*high confidence*).

Because climate resilient development involves different actors pursuing plural development trajectories in diverse contexts, the pursuit of solutions that are equitable for all requires opening the space for engagement and action to a diversity of people, institutions, forms of knowledge, and worldviews. The interplay between worldviews and ethics, socio-political relations, institutions, and human behaviour influence public engagement by individuals and communities. These open up opportunities for meaningful engagement and co-production of pathways towards climate resilient development.

Through inclusive modes of engagement that enhance knowledge sharing and realize the productive potential of diverse perspectives and worldviews, societies could alter institutional structures and arrangements, development processes, choices and actions that have precipitated dangerous climate change, constrained the achievement of SDGs, and thus limited pathways to achieving climate resilient development.

Managing transition risk is a critical element of transforming society, increasingly acknowledging the importance of transparent, informed and inclusive decision-making and evaluation, including a role for Indigenous knowledge and local knowledge. Enabling environments share common governance characteristics, including the meaningful involvement of multiple actors and assets, alongside multiple centres of power at different levels that are well integrated, vertically, and horizontally (*high confidence*). Enabling conditions harness synergies, address moral and ethical choices and divergent values and interests, and support just approaches to livelihood transitions that do not undermine human wellbeing (*medium confidence*). Collaborative networks and institutions including among local communities and their governing authorities can help resolve conflicts (*high confidence*).

Factors motivating transformative adaptation actions include risk perception, perceived efficacy, socio-cultural norms and beliefs, previous experiences of impacts, levels of education and awareness (*medium confidence*). There are multiple possible pathways by which communities, nations and the world can pursue climate resilient development. Moving towards different pathways involves confronting complex synergies and trade-offs between development pathways, and the options, contested values, and interests that underpin climate mitigation and adaptation choices (***very high confidence***). Different actors, the private sector, and civil society, influenced by science, local and Indigenous knowledges, and the media are both active and passive in designing and navigating climate resilient development pathways. Some interventions may be robust in that they are relevant to a broad range of potential development trajectories and could be deployed in a flexible manner.

Opportunities exist to promote synergies between sustainable development, adaptation, and mitigation, but trade-offs are likely unavoidable, and managing trade-offs and synergies will be important (*high confidence*). System transitions in the five domains on which AR6 is focused are highly feasible. For example, for land ecosystem transitions, there is high confidence on the role of agroforestry to increase ecological and adaptive capacity, once economic, cultural barriers and potential land use change trade-offs are overcome. Carefully designed and implemented disaster risk management and climate services can increase the feasibility and effectiveness of adaptation responses to improve agricultural practices, income diversification, urban and critical services and infrastructure planning (***very high confidence***). Risk insurance can be a feasible tool to adapt to transfer climate risks and support sustainable development (*high confidence*). They can reduce both vulnerability and exposure, support post-disaster recovery, and reduce financial burden on governments, households, and business.

In such a systemic context, sustainable development is fundamental to capacity for climate action, including reductions in greenhouse gas emissions as well as enhancing social and ecological resilience to climate change. Increasing social and gender equity is an integral part of the technological and social transitions and transformation toward climate resilient development. Such transitions in societal systems reduce poverty and enable greater equity and agency in decision-making. They often require rights-based approaches to protect the livelihoods, priorities and survival of marginalised groups including Indigenous peoples, women, ethnic minorities and children (*high confidence*).

21. 21. Could more systemic views and management pratices play a role in the management of responses and adaptations to climate change challenges?

Under all emissions scenarios, climate change reduces capacity for adaptive responses and limits choices and opportunities for sustainable development. Evidence of maladaptation is increasing in some sectors and systems highlighting how inappropriate responses to climate change create long-term lock-in of vulnerability, exposure, and risks that are difficult and costly to change (***very high confidence***). Maladaptation occurs for many reasons including inadequate knowledge, short-term, fragmented, single-sectoral and/or non-inclusive governance planning and implementation (*high confidence*). Indigenous Peoples and disadvantaged groups such as low-income households and ethnic minorities, are especially adversely affected by maladaptation, which often deprives them of food and livelihoods and reinforces and entrenches existing inequalities (*high confidence*). Climate adaptation capacity is reduced and vulnerability is amplified by inequities and poverty; by population growth and high population density, by land use change, especially deforestation, soil degradation, and biodiversity loss, high dependence of national and local economies on natural resources for production of commodities, weak governance, unequal access to safe water and sanitation services, and a lack of infrastructure and financing (*high confidence*).

The key barriers to adaptation are limited resources as most of the adaptation options to the key risks depend on limited water and land resources (*high confidence*). Lack of private sector and citizens engagement, insufficient mobilisation of finance (including for research), lack of political leadership, limited research and/or slow and low uptake of adaptation science, and low sense of urgency are among the other key barriers. For example, critical urban adaptation capacity gaps include limited ability to identify social vulnerability and community strengths; the absence of integrated planning to protect communities. Further, how cities and settlements are able to adapt are constrained by governance capacity, the legacy of past urban infrastructure investment (*high confidence*) and the lack of access to innovative funding arrangements as well as limited capability to manage finance and commercial insurance (*medium confidence*).

Hard limits, which are those for which existing adaptation options will cease to be effective and additional options are not possible, will increasingly emerge at higher levels of warming (*high confidence*). Adaptation limits are shaped by constraints which can or cannot be overcome by adaptation actions and by the speed with which climate impacts unfold. Beginning at below 1.5°C, autonomous and evolutionary adaptation responses by more terrestrial and aquatic species and ecosystems will face hard limits, resulting in species extinction, loss of ecosystem integrity and resulting loss of livelihoods (*high confidence*). For agricultural production, soft and hard limits are related to water availability and the uptake and effectiveness of climate-resilient crops which are constrained by socio-economic and political challenges (*medium confidence*).

By not managing adaptation by combining and integrating the responses to all its constraints and limits, the systemic barriers constrain the implementation of adaptation options in particular in vulnerable sectors, regions and social groups (*high confidence*). This while there is increasing evidence on limits to adaptation which result from the interaction of adaptation constraints and the speed of change (*high confidence*). Across regions and sectors, the most significant determinants of soft limits to adaptation are financial, governance, institutional and policy constraints (*high confidence*). By contrast, integrated, systems-oriented solutions reduce competition and trade-offs, and include inclusive governance, behavioural (e.g., healthier diets with lower carbon and water footprints) and technical (e.g. novel feeds) responses (*high confidence*).

Multiple interacting factors help to ensure that adaptive communities have water and food security, including addressing poverty, social inequities, violent conflict, provision of social services such as water and sanitation, social safety nets, and vital ecosystem services. Differentiated responses based on water and food security level and climate risk increase effectiveness, such as social protection programmes for extreme events, medium term responses such as local food procurement for school meals, community seed banks or well construction to build adaptive capacity (*medium confidence*).

In particular, many urban adaptation plans focus narrowly on climate risk reduction and specific climate associated risks, missing opportunities to advance co-benefits with climate mitigation and sustainable development (*high confidence*). The urban adaptation gap shows that for all world regions current adaptation is unable to resolve risks to current climate change associated hazards. City and local governments remain key actors facilitating climate change adaptation in cities and settlements. Community based action is also critical. Multi-level governance opens inclusive and accountable adaptation space across scales of decision making, improving development processes through an understanding of social and economic systems, planning, experimentation and embedded solutions including processes of social learning.

Longer-term responses include strengthening ecosystem services, local and regional markets, enhanced capacity, and reducing systemic gender, land tenure, and other social inequalities as part of a rights-based approach (*medium confidence*). In the urban context, policies that account for social inclusion in governance and rights to green urban spaces will enhance urban agriculture's potential for food and water security and other ecosystem services.

Prioritisation of options and transitions from incremental to transformational adaptation are limited due to vested interests, economic lock-ins, institutional path-dependencies, and prevalent practices, cultures, norms, and belief systemsInclusive, equitable and just adaptation pathways are critical for climate resilient development. Such pathways require consideration of the United Nations' Sustainable Development Goals, gender, and Indigenous knowledge and local knowledge and practices. In human and managed systems, particularly in low-income settings, financial constraints are key determinants of adaptation limits (*high confidence*), while in natural systems key determinants for limits are inherent traits of the species or ecosystem (***very high confidence***).

22. 22. Should a specific focus be given to governance practices?

Maladaptation can be reduced by using the principles of recognitional, procedural, and distributional justice in decision making, responsibly evaluating who is regarded as vulnerable and at risk; who is part of decision-making; who is the beneficiary of adaptation measures, and integrated and flexible governance mechanisms that account for long-term goals (*high confidence*).

Integrated approaches such as the water/energy/food nexus and inter-regional considerations of risks can reduce the risk of maladaptation, building on existing adaptation strategies, increasing community participation and consultation, integration of Indigenous Knowledge and Local Knowledge, focusing on the most vulnerable small scale producers, anticipating risks of maladaptation in decision-making for long-lived activities including infrastructure decisions, and the impact of trade-offs and co-benefits (*high confidence*).

Indigenous Peoples have been faced with adaptation challenges for centuries and have developed strategies for resilience in changing environments that can enrich and strengthen other adaptation efforts (*high confidence*). Supporting indigenous self-determination, recognizing Indigenous Peoples' rights, and supporting Indigenous knowledge-based adaptation can accelerate effective robust climate resilient development pathways (***very high confidence***). Inclusion of interdisciplinary scientific information, Indigenous knowledge and practical expertise is essential to effective Ecosystem based adaptation (*high confidence*), and there is a large risk of maladaptation where this does not happen (*high confidence*).

Insufficient financing is a key driver of adaptation gaps (*high confidence*). Tracked private sector finance for climate change action has grown substantially since 2015, but the proportion directed towards adaptation has remained small (*high confidence*); in 2018 contributions were 0.05% of total climate finance and 1% of adaptation finance. For example, Africa faces severe climate data constraints, and inequities in research funding and leadership that reduce adaptive capacity (***very high confidence***). From 1990-2019 research on Africa received just 3.8% of climate related research funding globally, and 78% of this funding for Africa went to E.U. and North American based institutions and only 14.5% to African institutions.

Closing the adaptation gap requires thus moving beyond short-term planning to developing long term, concerted pathways and enabling conditions for ongoing adaptation to ensure timely and effective implementation (*high confidence*). A mix of infrastructure, nature-based, institutional and socio-cultural interventions can best address the risks. Flexible options enable responses to be adjusted as climate risk escalates and circumstances change which may increase exposure (*medium confidence*).

In particular to reduce coastal risk (e.g., due to salinization, drainage of rivers and excess water), protection has a high benefit-cost ratio during the 21st century but can become unaffordable and insufficient reaching technical limits (*high confidence*). Hard protection sets up lock-in of assets and people to risks and reaches limits by the end of the century or sooner, depending on the scenario, local sea-level rise effects and community tolerance thresholds (*high confidence*). Prospects for addressing climate-change compounded coastal hazard risk depend on the extent to which societal choices, and associated governance processes and practices, address the drivers and root causes of exposure and social vulnerability (*very high confidence*).

Urban adaptation measures have also many opportunities to contribute to Climate Resilient Development Pathways (*medium confidence*). They can enhance social capital, livelihoods, human and ecological health as well as contributing to low carbon futures. To close this adaptation gap, political commitment, persistence and consistent action across scales of government, and upfront mobilization of human and financial capital is key (*high confidence*), even when the benefits are not immediately visible. Decreasing maladaptation requires attention to justice and a shift in enabling conditions toward those that enable timely adjustments for damages to be avoided or minimised and opportunities seized (*high confidence*).

23.

The Agenda 2030 highlights the importance of multi-level adaptation governance, including non-state actors from civil society and the private sector. This implies the need for wider arenas of engagement for diverse actors to collectively solve problems and to unlock the synergies between adaptation and mitigation and sustainable development (*high confidence*). Meanwhile, prevailing governance efforts have not closed the adaptation gap (***very high confidence***), in part due to the complex interconnections between climate and non-climate risk and the limits of the predominant development and governance practices (*high confidence*).

Indeed, institutional fragmentation, under-resourcing of services, inadequate adaptation funding, uneven capability to manage uncertainties and conflicting values, and reactive governance across competing policy domains, collectively lock in existing exposures and vulnerabilities, creating barriers and limits to adaptation, and undermine climate resilient development prospects (*high confidence*). Governance arrangements and practices are thus presently ineffective to reduce risks, reverse path dependencies and maladaptation, and facilitate climate resilient development (***very high confidence***).

Better governance for climate resilient development involves diverse societal actors, including the most vulnerable, who can work collectively, drawing upon local and Indigenous knowledges and science and are supported by strong political will and climate change leadership (*medium confidence*).

Enablers for climate governance include better practices and legal reforms. Governance practices for climate resilient development will be most effective when supported by formal (e.g., the law) and informal (e.g., local customs and rituals) institutional arrangements providing for ongoing coordination between and alignment of local to international arrangements across sectors and policy domains (*high confidence*). Here also, climate governance arrangements and practices are enabled when they are embedded in societal systems that advance human well-being and planetary health (***very high confidence***). These will work best when they are coordinated within and between multiple scales and levels (institutional, geographical and temporal) and sectors, with supporting financial resource, are tailored for local conditions, gender-responsive and -inclusive, and are founded upon enduring institutional and social learning capabilities to address the complexity, dynamism, uncertainty and contestation that characterise escalating climate risk (*medium confidence*).

24.

The scheme describing the process applied to define a confidence level

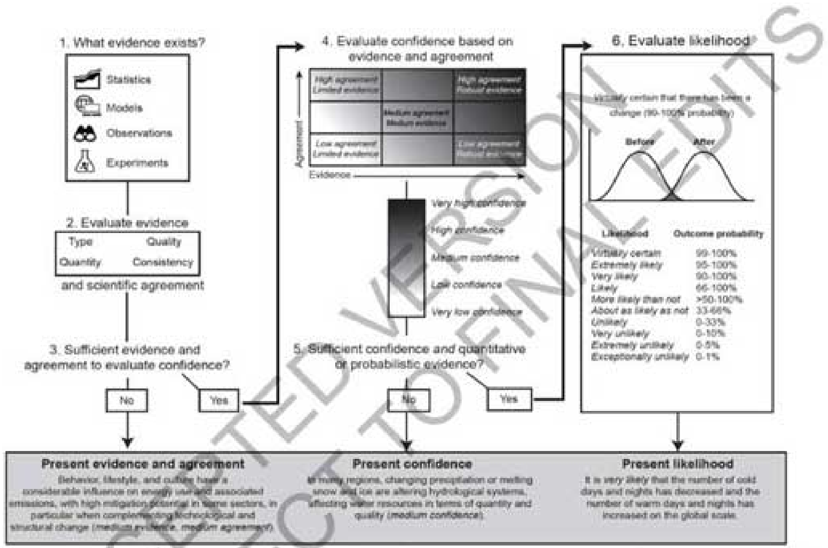
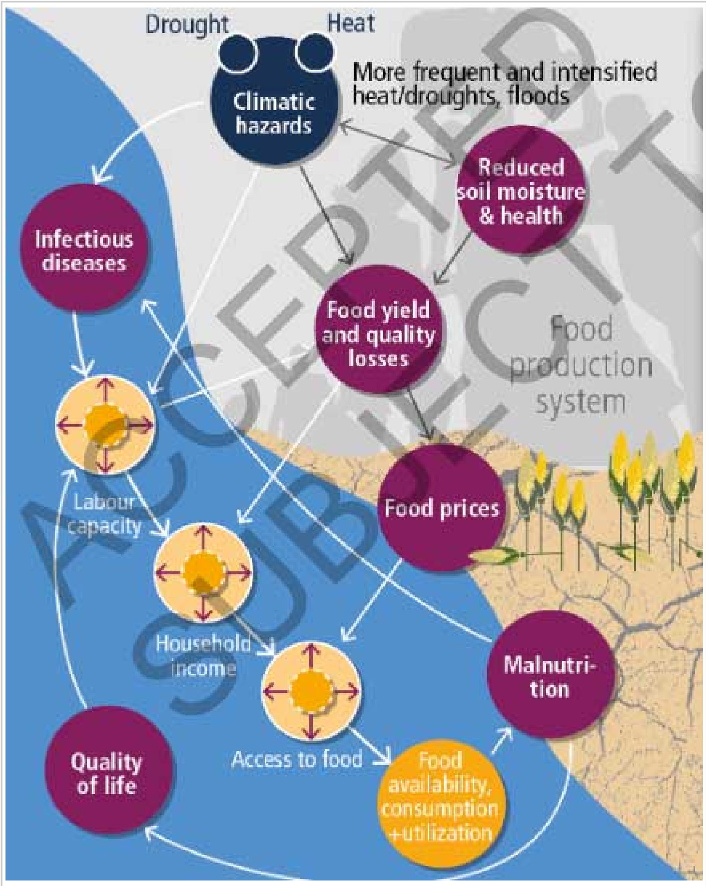


Figure TS.1: The IPCC AR5 and AR6 framework for applying expert judgment in the evaluation and characterisation of assessment findings. This illustration depicts the process assessment authors apply in evaluating and communicating the current state of knowledge. {Figure 1.6}

[see Annex 6, p. 34]

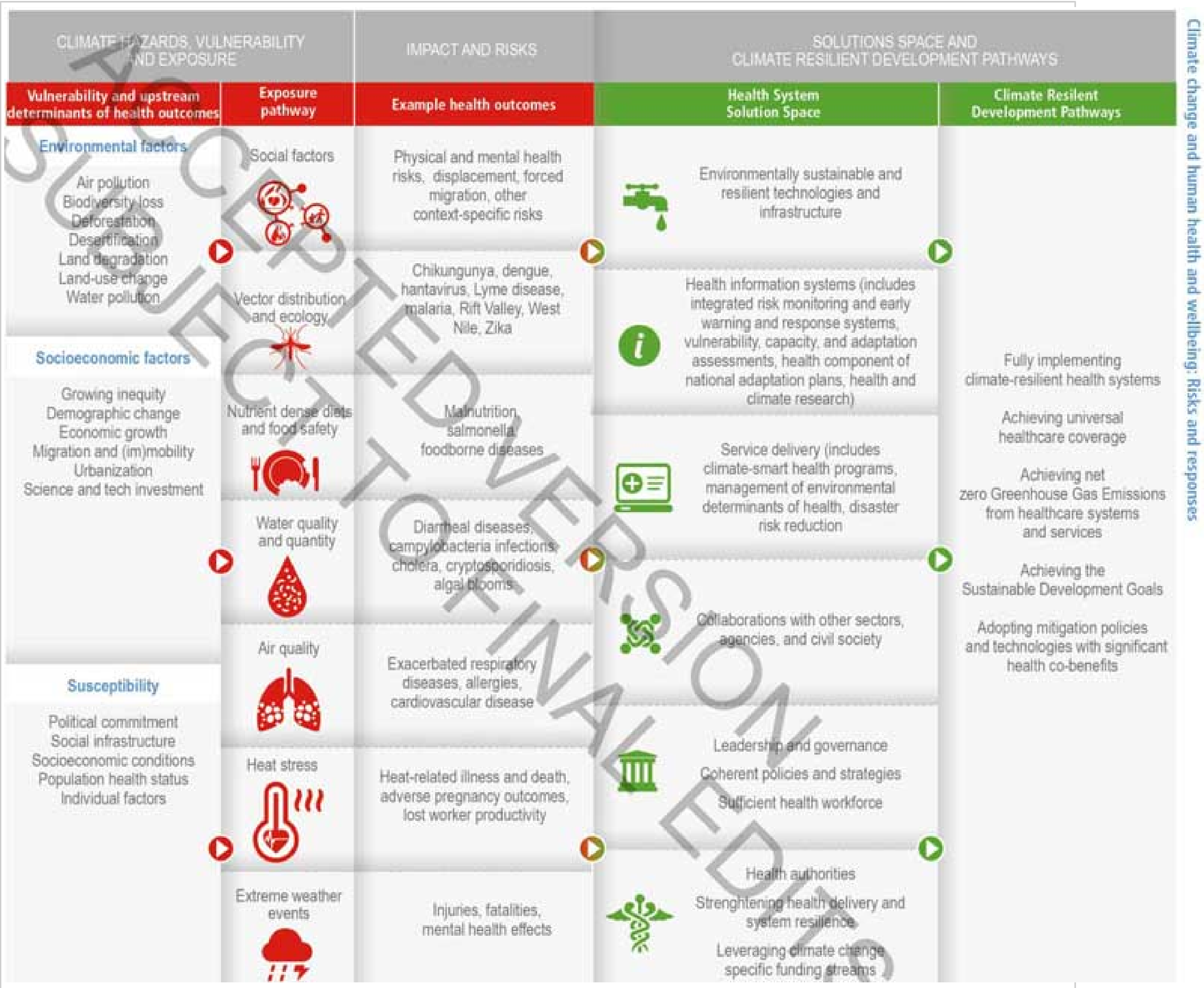
Annex

Annex 1:
Cascading impacts of climate hazards on food and nutrition



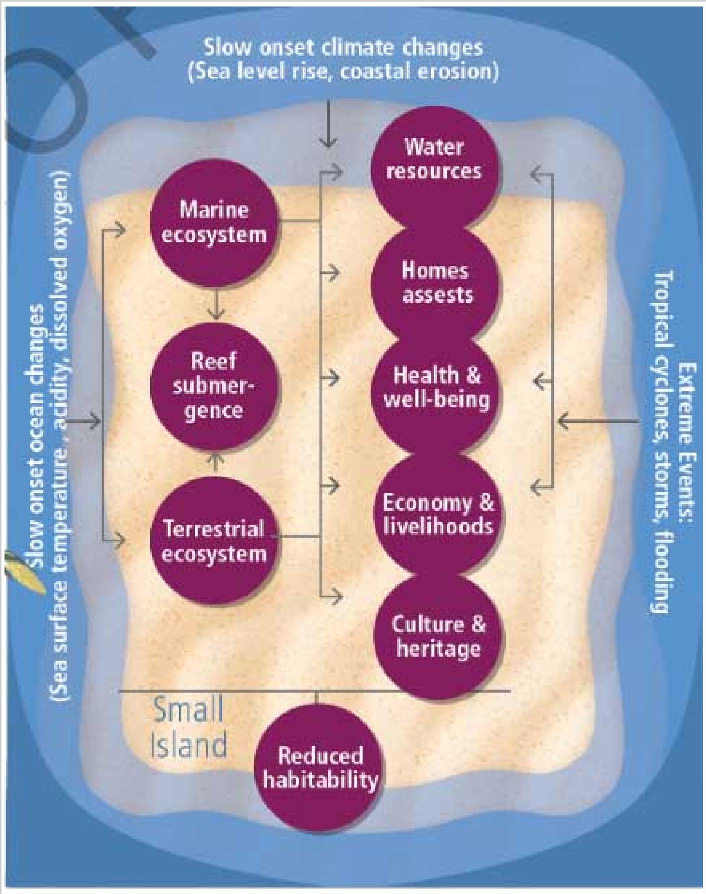
Source: IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability [see https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf]

Annex 2:
Climate change and human health and wellbeing: Risks and responses



Source: IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability [see https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf]

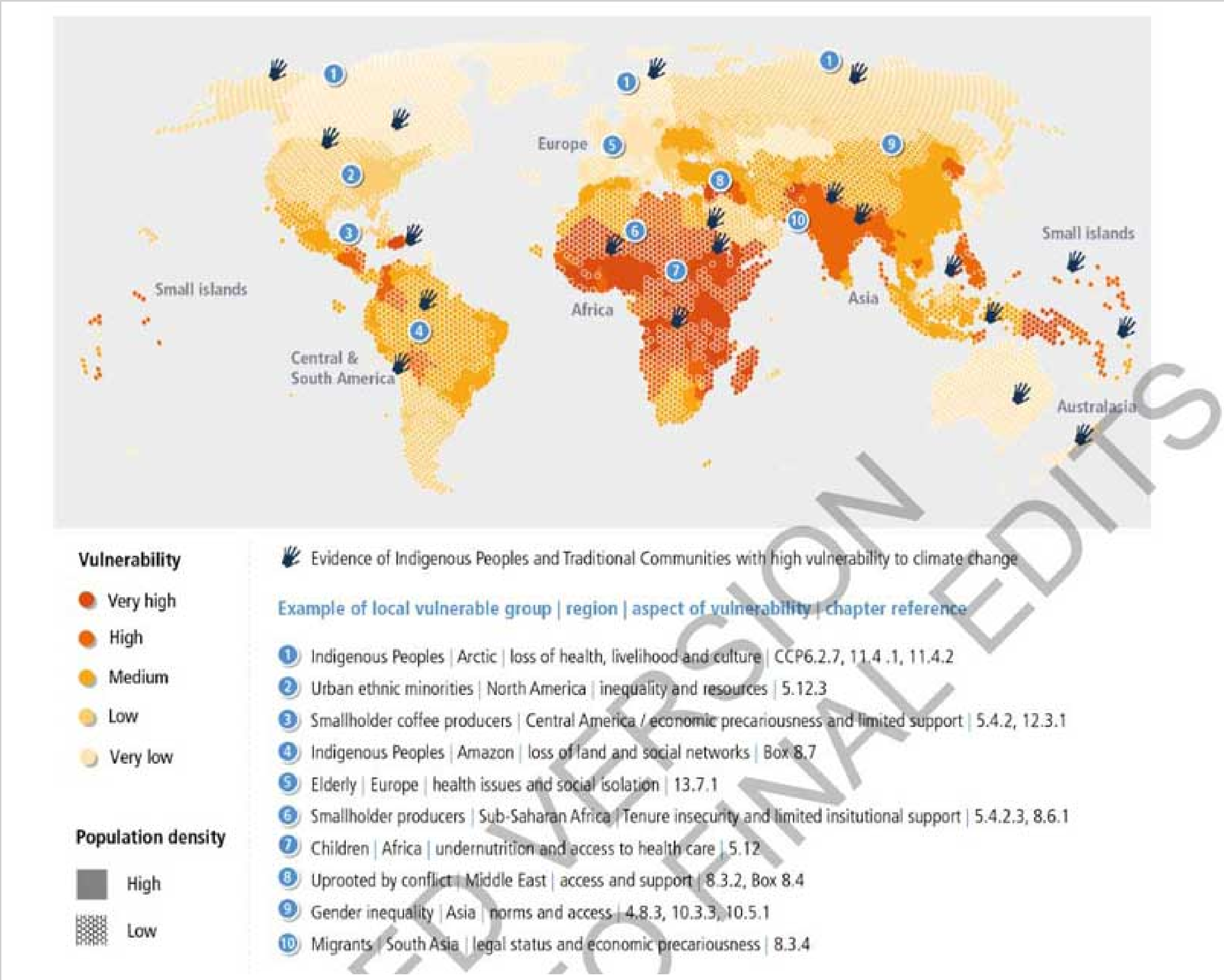
Annex 3:
Compound risks in coastal and island systems



Compound risks in coastal and island systems reduce habitabilit in coastal and island systems reduce habitability

Source: IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability [see https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf]

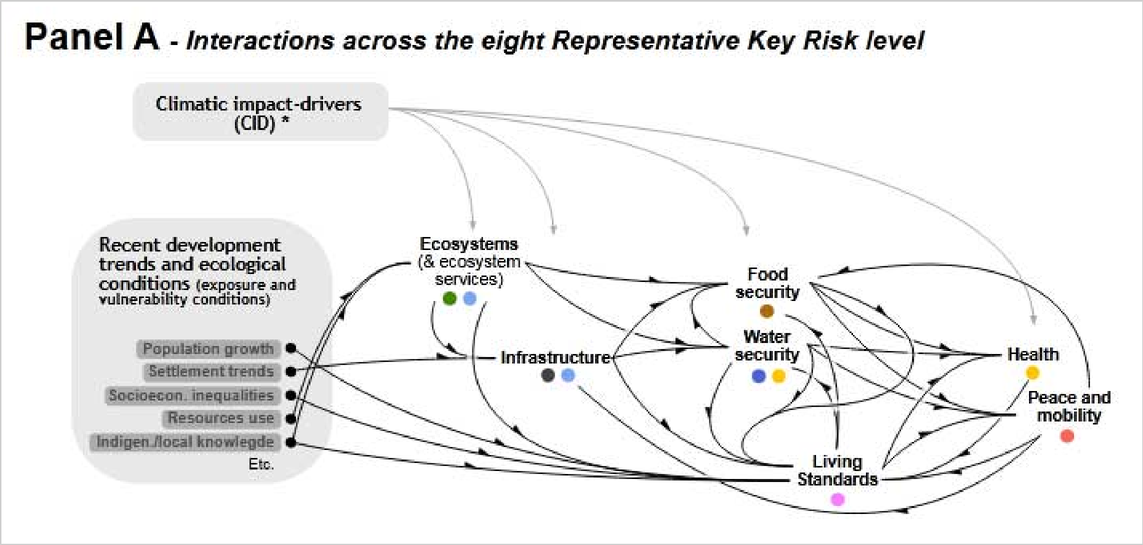
Annex 4:
Map of observed human vulnerability based on national averages.



This maps does not show local differences in vulnerability, below the map are examples of some local vulnerable populations and vulnerable Indigenous Peoples and Traditional Communities are highlightes

Source: IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability [see https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf]

Annex 5:
Panel A - Interactions across the eight Representative Key Risk level



Source: IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability [see https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf]

Annex 6:
Scheme describing the process applied to define a confidence level

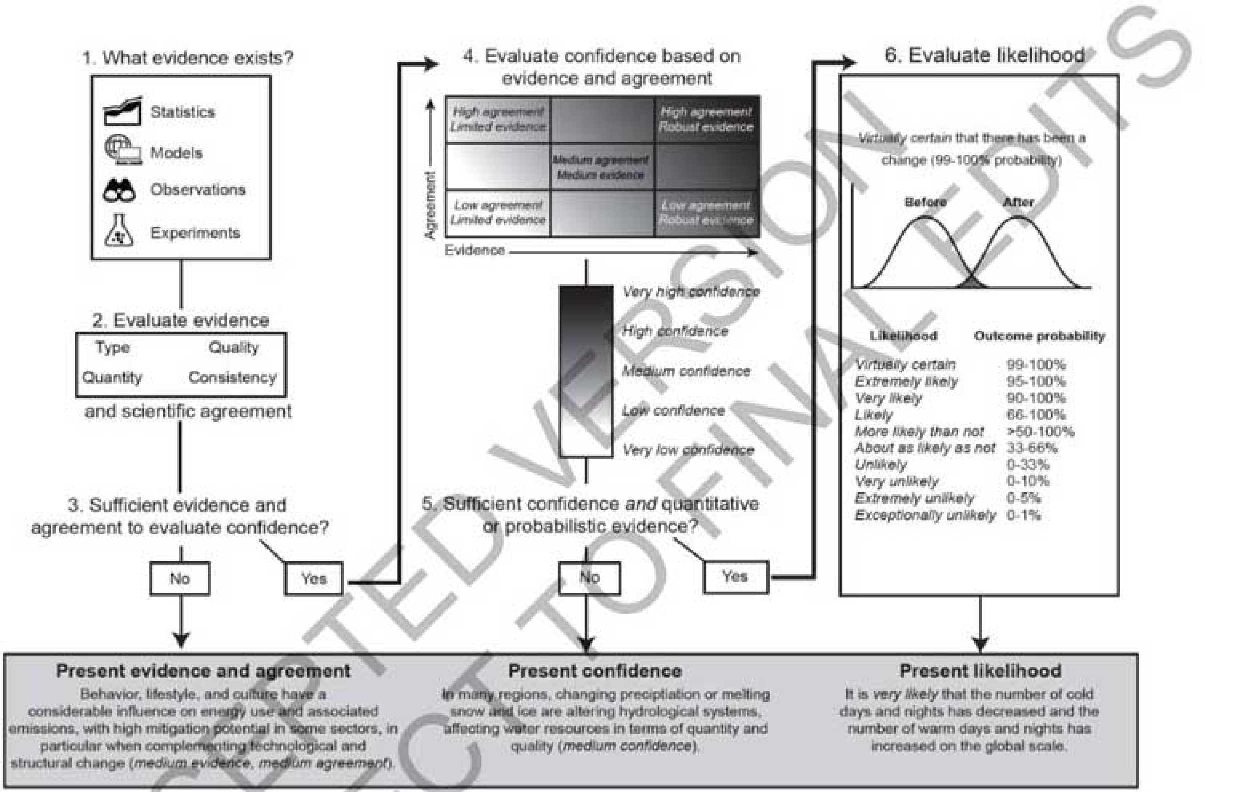
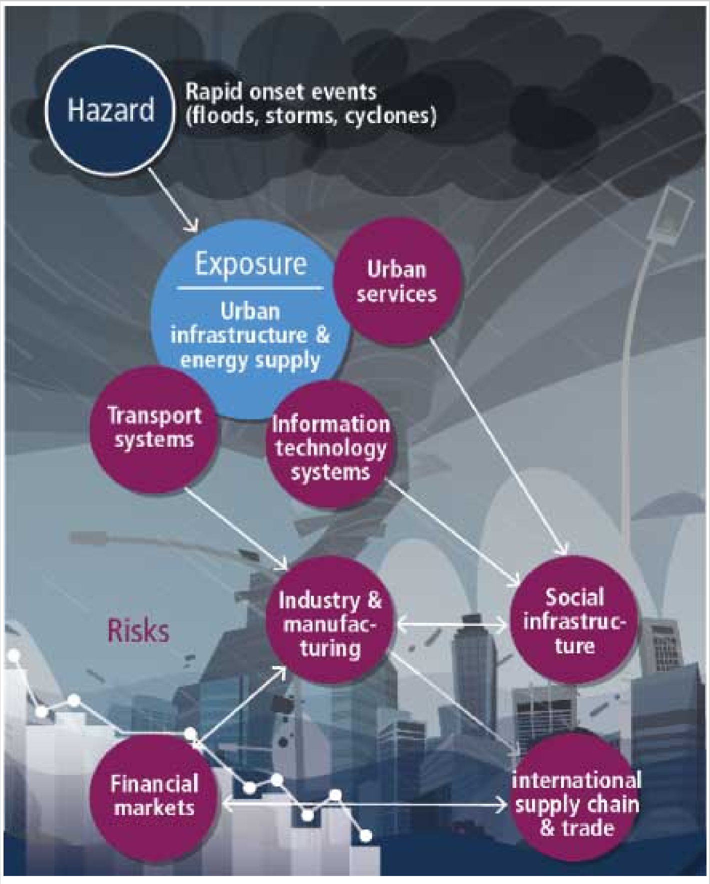


Figure TS.1: The IPCC AR5 and AR6 framework for applying expert judgment in the evaluation and characterisation of assessment findings. This illustration depicts the process assessment authors apply in evaluating and communicating the current state of knowledge. {Figure 1.6}

Source: IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability [see https://report.ipcc.ch/ar6wg2/pdf/ IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf]

Annex 7:

Urban infrastructure failures cascade risk and loss across and beyond the city



Source: IPCC Climate Change 2022: Impacts, Adaptation and Vulnerability [see https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf]