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Summary of IPCC's Special Report on Global Warming of 1.5° C

In the *Special Report on Global Warming of 1.5°C*, released on October 8, 2018, the Intergovernmental Panel on Climate Change (IPCC) explores the climate-related risks for natural and human systems for global warming at 1.5°C above preindustrial levels. It finds that the climate-related risks associated with warming of 1.5°C are higher than those associated with current warming (estimated as 1°C by end of 2017), but lower than those associated with warming of 2°C. Risks include sea level rise, species and habitat biodiversity loss, extreme temperatures, Arctic melting, food shortages and droughts, and increased poverty and health issues. Many land and ocean ecosystems, along with the services they provide, have already changed. Some of these risks are long-lasting and irreversible.

However, future climate-related risks depend on the rate, peak, and duration of warming. These future risks can be reduced by the upscaling and acceleration of far-reaching, multi-level, and cross-sectoral climate mitigation and by both incremental and transformational adaptation. By limiting the total cumulative global anthropogenic emissions of CO_2e since the preindustrial period, mitigation efforts aim to stay within our "total carbon budget." The report estimates the remaining carbon budget, for a 50 percent probability of limiting warming to 1.5°C is 580 billion metric tons (Gt) CO_2e (this falls to 420 billion Gt CO_2e for a 66 percent probability). World Resources Institute has noted that by 2011, we already consumed 52 percent of this budget, and we will exceed the budget by the end of 2045 if emissions rates continue unbated.[1]

Background

In December 2015, 195 nations adopted the Paris Agreement with the central aim of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels."[2] Additionally, parties agreed to "aim to reach global peaking of greenhouse gas (GHG) emissions as soon as possible." In addition to country commitments, the Agreement invited the IPCC to "provide a special report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways." The IPCC accepted the invitation to produce the Special Report in April 2016.

The IPCC, which is comprised of 195 member states, is the leading international body for the scientific assessment of climate change.[3] It provides policymakers with regular scientific assessments of three topic areas, divided by focus group: 1) the physical science basis of climate change; 2) the impacts of climate change,

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1 World Resources Institute. "The Carbon Budget." https://wriorg.s3.amazonaws.com/s3fs-public/WRI13-IPCCinfographic-FINAL_web.png.

2 United Nations, Framework Convention on Climate Change. "Adoption of the Paris Agreement" *Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015*, 29 Jan. 2016, https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf. President Trump announced in June 2017 that the U.S. would withdraw from the Agreement.

3 "Organization." *Intergovernmental Panel on Climate Change (IPCC)*, https://www.ipcc.ch/organization/organization.shtml.

including potential future risks and vulnerability; and 3) mitigation and adaptation strategies. To produce its reports, the IPCC mobilizes hundreds of scientists from diverse backgrounds.[4]

The Special Report synthesizes the relevant available scientific, technical, and socioeconomic literature relevant to the understanding of climate change. In total, 91 authors and review editors from 40 countries contributed to the report. The Special Report is the first of five reports the IPCC will release by 2022.[5]

Emissions Estimates and Impacts

The IPCC report estimates that anthropogenic emissions[6] have already caused approximately 1°C of global warming above pre-industrial levels. Due to the current global warming rate 0.2°C per decade caused by past and ongoing emissions, the IPCC states that global warming is *likely*, but not certain, to reach 1.5°C between 2030 and 2052.[7]

The report notes that climate models project robust increases between climate impacts associated with present-day global warming (i.e., 1°C), those associated with warming of 1.5°C, and those associated with warming of 2°C. These differences include increases in:

- **Physical changes,** such as temperature extremes, heavy precipitation events, droughts, and floods;
- **Ecological changes**, such as impacts on biodiversity, including species loss and extinction, and ecosystems, including changes in ocean temperatures, acidity, and oxygen levels;
- **Public health impacts,** such as disease and fatalities from heat and vector-borne diseases (e.g. malaria and dengue fever);
- **Agricultural impacts,** such as reduced cereal crop yield (e.g. wheat, rice) that affects food security; and
- **Water scarcity and stress**, including access to water supply and exposure to water stresses, particularly for small island developing states.

Additionally, the report highlights the geographical differences of climate impacts: warming is greater over land than over ocean; warming is two to three times higher in the Arctic; and risk intensity varies by region. A full list of differences can be found in the Appendix.

Pathways Limiting Global Warming to 1.5°C

The IPCC's summary of its full report focuses on four global warming pathways that explore the emissions reduction and temperature impacts of investment and technology development and policy scenarios. Three of these scenarios consist of no or low overshoot (i.e., temperatures do not exceed 1.5°C or remain below 1.6°C and return to 1.5°C by 2100) and the fourth consists of high overshoot (i.e., temperatures exceed 1.6°C for a few

4 Intergovernmental Panel on Climate Change (IPCC). "IPCC Press Release: Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments." 8 Oct. 2018, https://www.ipcc.ch/pdf/session48/pr_181008_P48_spm_en.pdf.

5 In May 2019, the IPCC will release methodology refinements to the 2006 IPCC guidelines for national GHG inventories. In September 2019, it will finalize two special reports on the impacts of climate change on the ocean and cryosphere, as well as on climate change, desertification, land degradation, sustainable land management, food security, and GHG fluxes in terrestrial ecosystems. In 2021, the IPCC will release the Sixth Assessment Report (AR6). The IPCC will release a synthesis report of these documents in April 2022.

6 Anthropogenic emissions include greenhouse gases, aerosols and their precursors. Note that many aerosols are "cooling" and reduce the greenhouse effect, reducing overall warming.

7 The level of confidence associated with each key finding is reported using IPCC calibrated language. We do not include this language in the summary.

decades but ultimately return to 1.5°C by 2100).[8] This 1.5°C report does not examine the scenario where global temperatures continue to rise above 1.5°C until the end of the 21st century.

These pathways have different implications for GHG emissions as well as for climate change impacts. For example, the longer the "overshoot," the greater the reliance on strategies that will need to remove CO_2 from the atmosphere in addition to reducing emissions. In addition, the report notes that a longer overshoot increases the risk for "irreversible" climate impacts including the collapse of polar ice shelves and accelerated sea level rise.

Each of these scenarios require significant societal and technological development. According to the report,

> "[p]athways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems [….] **These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options."** (emphasis added)

The report summarizes a range of behavioral changes and technology advancements that will be needed across all emitting sectors. While specific technologies and policies to reduce emissions consistent with 1.5°C vary across these scenarios, in general they share some key characteristics, including:

- *Rapid and profound near-term decarbonization of energy supply*: strong upscaling of renewables and sustainable biomass and reduction of unabated (no carbon capture and sequestration, or "CCS") fossil fuels, along with the rapid deployment of CCS lead to a zero-emission energy supply system by mid-century.
- *Greater mitigation efforts on the demand side*: all end-use sectors show marked demand reductions beyond the reductions projected for 2°C pathways. Of note, the demand reductions in modeling for 2030 and 2050 lie within the potential assessed by detailed sectorial bottom-up assessments.
- *Switching from fossil fuels to electricity in end-use sectors*: both in the transport and the residential sector, electricity covers markedly larger shares of total demand by mid-century. Comprehensive emission reductions are implemented in the coming decade: virtually all 1.5°C-consistent pathways decline net annual CO_2 emissions between 2020 and 2030, reaching carbon neutrality around mid-century.
- *Considerable shifts in investment patterns*: low-carbon investments in the energy supply side (energy production and refineries) are projected to average $1.6-3.8 trillion (2010 USD) per year globally to 2050. Investments in fossil fuels decline, with investments in unabated coal halted by 2030 in most available 1.5°C-consistent projections. The literature is less conclusive on required changes in investments in unabated gas and oil. Energy demand investments are a critical factor for which total estimates are uncertain.
- *Options are available to align 1.5°C pathways with sustainable development:* synergies can be maximized and risks of trade-offs limited or avoided through an informed choice of mitigation strategies. Pathways that focus on a lowering of demand show many synergies and few tradeoffs.
- *Carbon dioxide removal (CDR) at scale before midcentury*: by 2050, 1.5°C pathways project deployment of bioenergy with carbon capture and storage (BECCS) at a scale of 3 to 7 billion metric tons CO_2 per

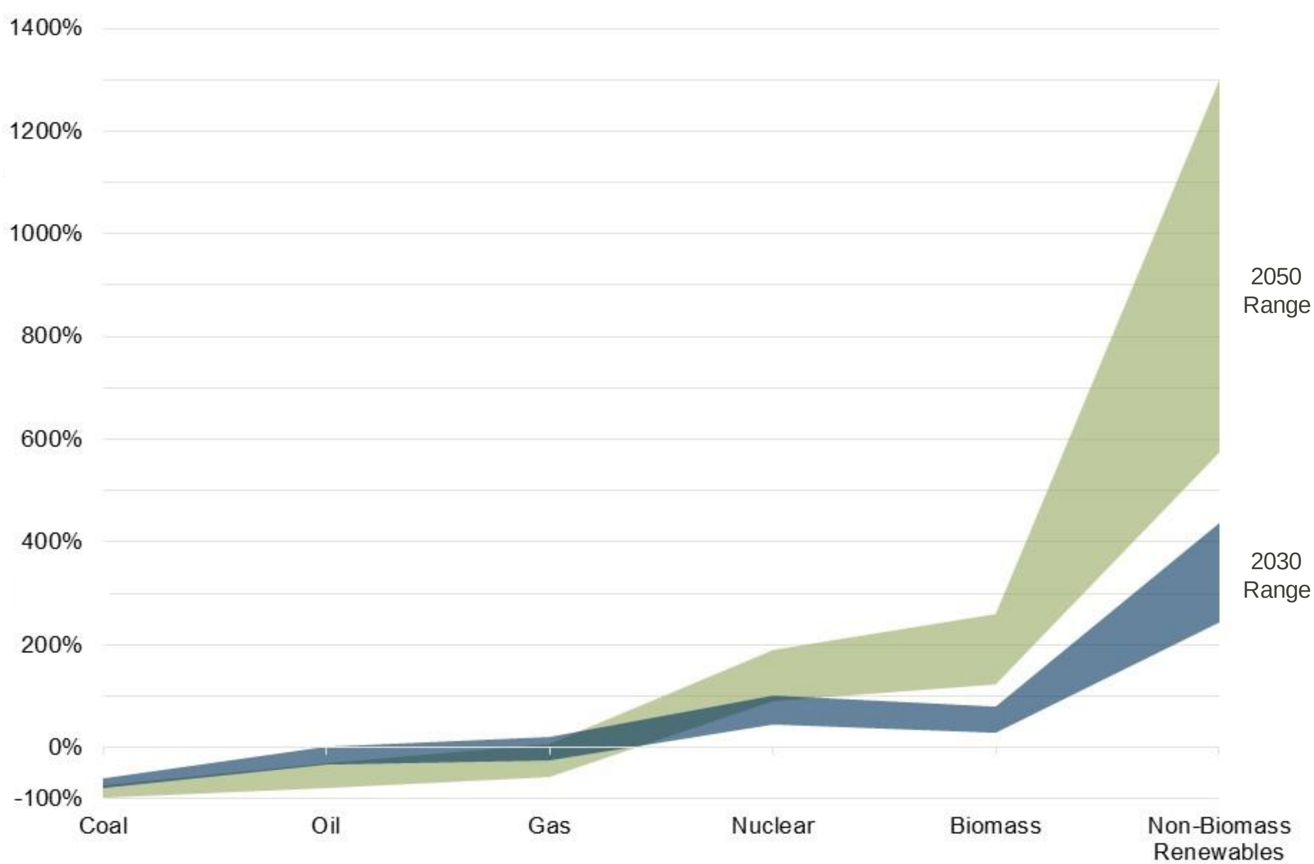
[8] Emission pathways are classified by their temperature trajectory over the 21st century: pathways giving at least 50 percent probability based on current knowledge of limiting global warming to below 1.5°C are classified as 'no overshoot'; those limiting warming to below 1.6°C and returning to 1.5°C by 2100 are classified as '1.5°C limited-overshoot'; while those exceeding 1.6°C but still returning to 1.5°C by 2100 are classified as 'higher-overshoot.'

year (range of medians across 1.5°C pathway models), depending on the level of energy demand reductions and mitigation in other sectors. Limited 1.5°C pathways do not use BECCS, but instead focus on terrestrial CDR in the agriculture, forestry, and other land-use sectors. Though all pathways utilize CDR to varying amounts and from varying sectors, the report cautions that reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR at rates and volumes that might not be achievable given considerable existing implementation challenges.

- *Compared to a 2°C scenario, additional reductions are mainly from CO_2*: Both CO_2 and non-CO_2 GHGs and aerosols are strongly reduced by 2030 and until 2050 in 1.5°C pathways. In addition to those reductions necessary to meet a 2°C scenario, however, the 1.5°C pathways require additional reductions. These occur in reductions of CO_2, as most of the mitigation potential of other GHGs and aerosols is already fully deployed to reach a 2°C pathway.

The report provides a summary of specific changes required in the energy sector in order to place the world on one of these 1.5°C emissions pathways. These findings indicate a sweeping transition in the sector away from fossil fuels and toward renewable and nuclear sources. Figure 1 summarizes these findings.

Figure 1: Changes in Electricity Sources to Achieve Summarized 1.5 °C Pathways
(*2030 and 2050, % change relative to 2010 levels*)



The report also includes key takeaways regarding changes necessary for non-electric sectors to achieve emissions reductions consistent with a 1.5°C scenario.[9] These include:

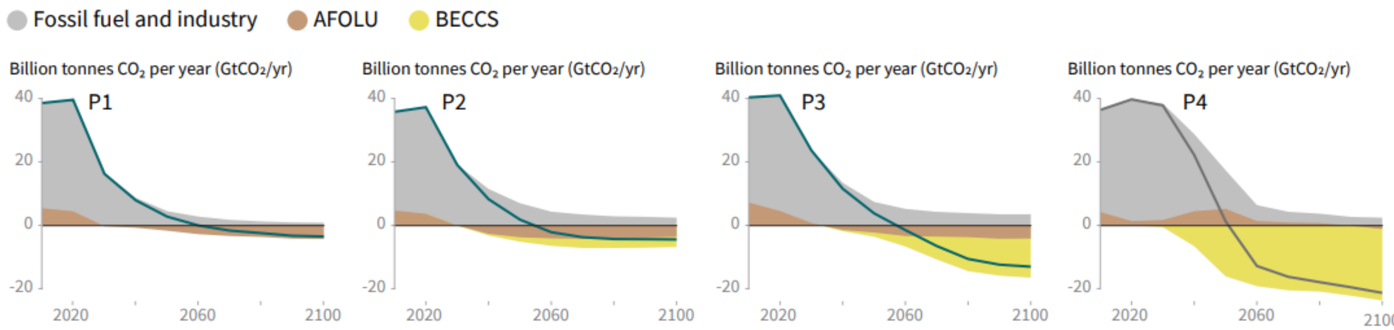
- The **transportation sector** accounted for 28% of global final-energy demand and 23% of global energy-related CO_2 emissions in 2014. Achieving deep emissions reductions will require technology-focused measures such as improvements in efficiency and fuel-switching as well as structural changes that avoid or shift transport activity (including strong use of transit and other more efficient forms of transportation, increasing vehicle load factors, and reductions in travel demand due to land use planning). However, the potential contributions of each of these activities varies highly among models.
- **Industry** will need to lower emissions 75% to 90% below 2010 levels by 2050. Broadly speaking, the industry sector's mitigation measures can be categorized in terms of the following five strategies: (i) reductions in the demand, (ii) energy efficiency, (iii) increased electrification of energy demand, (iv) reducing the carbon content of non-electric fuels, and (v) deploying innovative processes and application of CCS. [10] One modeling exercise estimated the relative contributions of these reduction strategies (grouped into slightly different categories): energy efficiency, 42%; innovative process and CCS, 37%; switching to low carbon fuels and feed-stocks, 13%; and material efficiency (including efficient production and use to contribute to demand reduction), 8%.
- In 2014, the **buildings sector** accounted for 31% of total global final-energy use, 54% of final-electricity demand, and 8% of energy-related CO_2 emissions (excluding indirect emission due to electricity). Emissions reductions consistent with a 1.5 °C scenario are driven by a clear tempering of energy demand and a strong electrification of the buildings sector. One model found that energy demand for space heating and cooling account for 54% of total reductions from the reference scenario, and shifts to high-performance lighting, appliances, and water heating equipment account for a further 24% of the total reduction. The report also notes that reductions in indirect building emissions will strongly depend on rapid carbonization of the electric sector.

Figure 2 summarizes the relative contributions of emissions reductions from industry and fossil fuel use (including CCS in those sectors), as well as deep CDR from the land use sector, across the primary four pathways considered in the summary report. Of note, AFOLU refers to sequestration from Agriculture, Forestry and Other Land Use and BECCS reflects Bioenergy with Carbon Capture and Storage.

[9] The land use sector, though not addressed in this summary, plays a critical role in meeting emissions targets. This is addressed in detail in Chapter 2 of the report.

[10] This category encompasses numerous sectors, including cement production, material industries (steel, non-ferrous metals, chemicals, non-metallic minerals, and pulp and paper), and manufacturing industries.

Figure 2: Contributions to Global Net CO_2 emissions (Four Illustrative Model Pathways)



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

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

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

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

(Note: AFOLU refers to sequestration from Agriculture, Forestry and Other Land Use while BECCS reflects Bioenergy with Carbon Capture and Storage)

Adaptation

In addition to limiting global warming, the report finds that adaptation efforts will prove essential. While sea level will continue to rise beyond 2100 even if global warming is limited to 1.5°C in the 21st century, the magnitude and rate depends on future emissions pathways. Most notably, a slower rate allows greater adaptation opportunities for both human and ecological systems. Adaptation options include:

- *Natural and managed ecosystems*: ecosystem-based adaptation, ecosystem restoration and avoided degradation and deforestation, biodiversity management, sustainable aquaculture, and local knowledge and indigenous knowledge;
- *Sea level rise*: coastal defense and hardening; and
- *Health, livelihoods, food, water, and economic growth*: in rural areas, this may include efficient irrigation, social safety nets, disaster risk management, risk spreading and sharing, community-based adaptation. In urban areas, adaption options include green infrastructure, sustainable land use and planning, and sustainable water management.

Conclusion

The IPCC's Special Report finds that limiting global warming to 1.5°C with no or limited overshoot will require "rapid and far-reaching transitions in energy, land, urban and infrastructure, and industrial systems," implying "deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options." The report estimates that to achieve a 2°C scenario, the annual average investment in the energy system must increase to $2.4 trillion, approximately 2.5 percent of global GDP. Costs could be three to four times greater under a 1.5°C scenario.

The report briefly discusses the “stringent and integrated policy interventions” necessary to achieve these outcomes. Of note, in addition to the technology innovations and policy needs, the report cites modeling finding that policies reflecting a high price on emissions will be necessary to achieve cost-effective 1.5°C-consistent pathways. Other policy interventions discussed include building codes, minimum performance standards, research and development innovation policies, technology policies (e.g., feed-in-tariffs), financing instruments, and land-use and transport planning.

In addition to the policies and emission reductions discussed throughout the report, it also calls for education, information, and community approaches to accelerate wide scale behavior changes. Cooperation and collective efforts at the international level among non-state public and private actors, institutional investors, the banking system, civil society, and scientific institutions would facilitate actions and responses consistent with limiting global warming to 1.5°C.

Appendix: Physical Risks Associated with 1.5ºC and 2ºC Warming Scenarios

Table 1. Summary of Physical Risks Associated with Warming Scenarios

Risk	1.5°C Warming Scenario	2°C Warming Scenario	Note
Extreme hot days in mid-latitudes warm by up to:	3°C	4°C	In a 2°C scenario, 420 million more people would be exposed to extreme heatwaves.
Extreme cold nights in high latitudes warm by:	4.5°C	6°C	
Number of hot days will increase in most land regions, highest in tropics.	✓	✓	
By 2100, global mean sea level rise	0.26-0.77 m	0.1 m greater than in 1.5°C	Reduction in 0.1 m with 1.5°C implies up to 10 mil fewer people would be exposed to related risks.
Marine ice sheet instability in Antarctica and/or irreversible loss of Greenland ice sheet	✓	✓	Could be triggered by both scenarios and could result in multi-meter rise in sea level over hundreds of thousands of years.
Species that will lose over half their climatically determined geographic range	6% of insects, 8% of plants, 4% of vertebrates	18% of insects, 16% of plants, 8% of vertebrates	
Global terrestrial land area projected to undergo a transformation of ecosystems	4%	13%	
Permafrost thawing		1.5-2.5 mil km^2 more thawing compared to the 1.5°C scenario	High-latitude tundra and boreal forests are particularly at risk of degradation and loss.
Probability of sea ice-free Arctic summer	1/century	1/decade	
Coral reef decline	70-90%	>99%	
Decrease in annual catch for marine fisheries	1.5 million tons	>3 million tons	
People exposed to climate-related risks and susceptible to poverty	Several hundred million fewer in 1.5°C scenario		By 2050
% of population exposed to increased water stress	50% lower in 1.5°C scenario		Particularly in small island developing states.

In addition to quantifying the above climate impacts in 1.5°C and 2°C scenarios, the IPCC report notes that the following climate impacts are generally projected to be higher at 2°C compared to 1.5°C global warming:

- Risk of drought and precipitation deficits (in some regions).
- Heavy precipitation associated with tropical cyclones.
- Heavy precipitation (aggregated at global scale), with the consequence of a larger fraction of the global land area affected by flood hazards.
- Risks associated with sea level rise, especially amplifying the exposure of small islands, low-lying coastal areas, and deltas. The slower rate of sea level rise at 1.5°C reduces these risks and enables greater opportunities for adaptation, management, and restoration.
- Impacts of biodiversity risks, such as forest fires and spread of invasive species.

- Impacts on terrestrial, freshwater, and coastal ecosystems, which will lead to fewer services to humans
- Increases in ocean temperatures as well as associated increases in ocean acidity and decreases in ocean oxygen levels.
- Risk of irreversible loss of many coastal and marine ecosystems. Both warming scenarios are projected to shift the ranges of many marine species to higher latitudes and increase the amount of damage to marine ecosystems.
- Level of ocean acidification, which will impact the growth, development, calcification, survival, and abundance of a broad range of species.
- Risks to fisheries and aquaculture: physiology, survivorship, habitat, reproduction, disease incidence, and risk of invasive species.
- Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth.
- Health effects: heat-related morbidity and mortality; ozone-related mortality; vector-borne diseases (malaria and dengue fever) and shifts in geographic range.
- Net reductions in yields of maize, rice, wheat, and potentially other cereal crops in Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon. Livestock will also be adversely affected.
- Risks to global aggregated economic growth (with the largest impacts in countries in the tropics and Southern Hemisphere subtropics should warming increase from 1.5°C to 2°C).
- Creating new and exacerbating current hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions.

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