BEFORE THE OIL AND GAS CONSERVATION COMMISSION
OF THE STATE OF COLORADO

	CAUSE NO.
PETITION FOR RULEMAKING TO ADOPT RULES TO EVALUATE AND ADDRESS THE CUMULATIVE AIR IMPACTS OF OIL AND GAS DEVELOPMENT	**DOCKET NO.**
	TYPE: PETITION FOR RULEMAKING

Petition for Rulemaking to Adopt Rules to Evaluate and Address Cumulative Air Impacts

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Petitioners WildEarth Guardians, 350 Colorado, Womxn from the Mountain, Physicians for Social Responsibility, The Larimer Alliance, and Sierra Club, hereby respectfully request and petition the Colorado Oil and Gas Conservation Commission for the promulgation of rules which, in consultation with the Colorado Department of Public Health and Environment (henceforth, "CDPHE"), will evaluate and address certain cumulative air impacts of oil and gas development to protect public health, safety, and welfare, and the environment and wildlife resources.

I. <u>Description of Petitioners</u>

WildEarth Guardians is a non-profit conservation organization headquartered in Santa Fe, New Mexico with offices across the western U.S., including in Wheat Ridge, Colorado. Guardians is dedicated to protecting and restoring wildlife, wild rivers, wild places, and health of the American West. Guardians and its members work to reduce harmful air pollution including greenhouse gas pollution in order to safeguard public health, welfare, and the environment. Guardians has more than 100,000 members and supporters, many of whom live, work, or recreate in Colorado.

350 Colorado is a 501(c)3 nonprofit organization with a mission to work locally toward building a global grassroots movement to solve the climate crisis and accelerate the transition to a sustainable future. 350 Colorado has over 20,000 members statewide working to address the root causes of the climate crisis, to address related issues such as air pollution, and to promote equitable and lasting solutions.

Womxn from the Mountain is a 501(c)3/501(c)4 organization with March On, founded by indigenous womxn. We are an inclusive women's group open to women, two-spirit, and commUNITY of all colors and backgrounds. Our goal is to empower our individual, spiritual, physical, emotional, and educational needs through equity, transformative education, and culturally responsive healing arts for Colorado indigenous and disproportionately impacted communities from the transformative lens of decolonization. Currently we are working as climate change organizers and cultural educators for disproportionately impacted communities to create protections and safety with cultural and trauma sensitivity from cumulative impacts of environmental racism on the Equity Analysis subcommittee for the Environmental Justice Action Taskforce CDPHE.

PSR (Physicians for Social Responsibility) Colorado is a 501-c-3 organization composed of health professionals and allies working to protect human life and the environment from the greatest threats to health and survival. We engage in education, advocacy, and actions to elevate the voice of health professionals to protect the public, and specifically the most vulnerable population, from the present and future health impacts of fossil fuel production, distribution and use; the existential climate crisis; and exposures to radionuclides and other toxic substances. PSR Colorado advocates at the State and local level for solutions to reliance on fossil fuels and nuclear energy.

The Larimer Alliance for Health, Safety and Environment is an activist alliance (established as 501-c-4 organization) committed to strengthening local and state policies and rules to protect public health, safety, and the environment in matters of oil & gas development impacting Larimer County, in accordance with Colo. S.B. 19-181.

The Sierra Club of Colorado is a powerful collective of grassroots changemakers working together across the state to advance climate solutions, act for justice, get outdoors, and protect lands, water, air, and wildlife. We believe in the power of working together to make change happen.

II. Introduction

Colorado has a large oil and gas industry, which has a heavy concentration of operational activity in northern central Colorado in an area known as the Denver-Julesburg Basin – an area that heavily overlaps with some of the most densely populated regions of the state as well as an area of Severe ozone nonattainment.

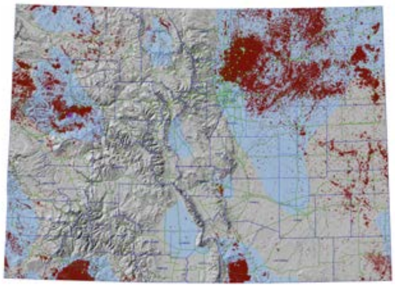

Fig. 1. Oil and gas wells

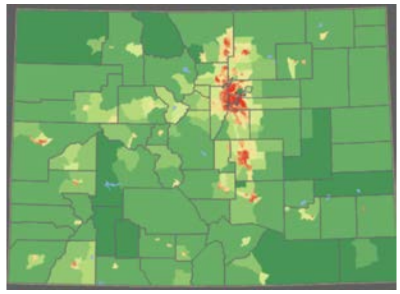

Fig. 2. Population density

Fig. 3. O_3 nonattainment area

The oil and gas industry, due to the number and concentration of facilities (which include point sources such as wells, tanks, flares, compressor stations, and separators), the size of these facilities, their spread across the landscape, the need for heavy machinery, and the rate of emissions of ozone precursors, GHGs, and hazardous air pollutants (particularly from pre-production activities), has many 'cumulative impacts.' This Petition specifically does not contemplate that a single rulemaking could address all of the cumulative impacts of oil and gas production. The breadth and technical specificity of cumulative impacts of oil and gas production, in the opinion of Petitioners, make it unimaginable that every impact could be addressed simultaneously. Therefore this Petition focuses on the request for adoption of rules that address the cumulative impacts from air emissions, with proposed modifications to existing rules which evaluate cumulative impacts in order to better assure accurate data and analysis, as well as the inclusion of rules to evaluate and address the disproportionate impact of oil and gas production particularly on communities of color including indigenous communities, and regions experiencing higher than average warming. The impacts from any one proposed facility, location, Oil and Gas Development Plan, or Comprehensive Area Plan must be considered alongside the background rate of impacts from existing oil and gas operations, as well as historical and existing non-oil and gas sources, to understand the potential cumulative impacts.

The Colorado Oil and Gas Conservation Commission has engaged in preliminary rulemaking which heavily focused on increasing the state's understanding of cumulative impacts from oil and gas production. Now it must engage in additional rulemaking — as it stated that it would — to take additional steps to address those impacts which are causing immense harm to Colorado's health and air quality, and financial burdens from increased regulations which fall across the entire state far beyond the oil and gas industry which is primarily responsible for the impacts.

III. <u>Statement of Basis and Purpose</u>

This statement sets forth the basis and purpose for amendments ("Addressing Cumulative

Impacts Rulemaking") to the Colorado Oil and Gas Conservation Commission ("Commission" or "COGCC") Rules of Practice and Procedure, 2 C.C.R. § 404-1 ("Rules").

On January 14, 2019 the Colorado Supreme Court held in *COGCC v. Martinez* that the duty of the Oil and Gas Conservation Commission was:

> (1) to foster the development of oil and gas resources, protecting and enforcing the rights of owners and producers, and (2) in doing so, to prevent and mitigate significant adverse environmental impacts to the extent necessary to protect public health, safety, and welfare, but only after taking into consideration cost-effectiveness and technical feasibility.

433 P.3d 22, 25 (Colo. 2019). Less than three months later the state legislature passed SB 19-181, completely upending the previous version of the Act. In addition to removing the Commission's duty to 'foster' development, it instructed the Commission to prioritize public health, safety, and welfare, and the environment and wildlife in decision-making.' C.R.S. § 34-60-106(2.5)(a). Protecting people and the environment, and avoiding impacts to them (including cumulative impacts), is the first responsibility of the Commission. C.R.S. § 34-60-106(2.5)(a) requires the Commission – whenever exercising its authority – to "protect and minimize adverse impacts to public health, safety, and welfare, the environment, and wildlife resources and shall protect against adverse environmental impacts on any air, water, soil, or biological resource resulting from oil and gas operations."

The term "minimize adverse impacts" was amended to remove the words "wherever reasonably practicable" and replace it with "to the extent necessary and reasonable to protect public health, safety, and welfare, the environment, and wildlife resources, to: (a) Avoid adverse impacts from oil and gas operations; on wildlife resources; and (b) Minimize and mitigate the extent and severity of those impacts that cannot be avoided." Therefore, the first operative word in (2.5)(a) is "protect" and the first operative word in the definition of 'minimize' is "avoid." Importantly, *id.* at (2.5)(b) redefines 'waste' of oil and gas oil to *exclude* any resources that are left undeveloped in order to protect people and the environment. The Act therefore specifically contemplates that it will be necessary and reasonable in some circumstances to deny applications where an activity would cause harm to public health, safety, and welfare, and the environment.

SB 19-181 also amended the Act to instruct the Commission to perform specific rulemaking, including one or more rulemmakings to "adopt rules that . . . in consultation with the Department of Public Health and Environment, *evaluate and address* the potential cumulative impacts of oil and gas development." C.R.S. § 34-60-106(11)(c)(II) (emphasis added). The legislature did not provide a specific definition of 'cumulative impacts,' nor did the Commission adopt one during its Mission Change rulemaking. However the term "cumulative impacts" has been well defined in environmental law for decades. *See*, *e.g.*, 40 CFR 3 § 1508.7 ("Cumulative impact is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time."). The Commission should formally adopt the federal definition of cumulative impacts because determining the extent of cumulative impacts is a difficult enough task even when the definition is clear.

The COGCC has conducted extensive rulemaking procedures since SB 19-181 was signed into law, including a 'Mission Change, Cumulative Impacts, and Alternative Location Analysis Rulemaking,' which re-wrote much of the regulations governing oil and gas permitting and production. With regard to cumulative impacts, in that rulemaking the Commission deliberately and explicitly focused on information gathering to better understand what impacts oil and gas production is having on Colorado's people and environment. It adopted rules to *evaluate* cumulative impacts, which include the requirements of Rules 304 and 314 for operators to report certain data to be included in a comprehensive database (the Cumulative Impacts Data Evaluation Repository, or CIDER). During Mission Change, the Commission repeatedly acknowledged the need for, and their full intention to embark upon the adoption of, additional regulations to *address* the cumulative impacts of oil and gas production in an iterative manner.

> The Commission intends to use data from CIDER, in cooperation with CDPHE and other partners, to undertake basin-wide, statewide, and other studies to evaluate cumulative impacts to relevant resources at appropriate scales. . . . **The Commission also does not intend for the 200–600 Mission Change Rulemaking to be the final, or only, rulemaking to evaluate and address cumulative impacts**, and the Commission will continue to coordinate with CDPHE and other partners to evaluate data in the CIDER database and other information salient to evaluating and addressing cumulative impacts.

Cause No. 1R Docket No. 200300071, 200–600 Mission Change, Cumulative Impacts, and Alternative Location Analysis Rulemaking, *Statement of Basis, Specific Statutory Authority, and Purpose*, 63 (Nov. 23, 2020) [hereinafter "Mission Change SBP"], *available at* https://docs.google.com/document/d/1R-GS88pBa1uiDr1-EIQhN8NmUFwKdb1S (emphasis added).

> Although many of the Commission's Rules adopted in the . . . Mission Change Rulemakings **are intended to evaluate cumulative impacts**, Rules 423.d, 424.f, 426.e, and 427.e are among the most targeted regulations intended to address cumulative impacts to individual resources. [They] each represent the Commission's **first regulatory effort to address cumulative impacts**, and . . . .. and recognizes that because of their novelty, the implementation of these cumulative impact regulatory standards **should be an iterative work in process in collaboration with relevant stakeholders**.

Id. at 167 (emphasis added). The most salient portion of the SBP addressed a Petition for Rulemaking submitted by an organization called Our Children's Trust during the pendency of the Mission Change rulemaking, pointing to certain portions of rules adopted by the Mission Change rulemaking and elsewhere that related to that Petitioner's concerns. *Id.* at 250–255. In particular, the Commission reiterated that "The Commission **also does not intend for [this] to be the final, or only, rulemaking to evaluate and address cumulative impacts**." *Id.* at 253 (emphasis added).

The Mission Change rulemaking, to the extent that it adopted rules to 'address' cumulative impacts, primarily did two things: 1) it asked operators to propose mitigation measures for their anticipated impacts, and 2) adopted rules that generally require operators to act in a more environmentally responsible way. The rules do not, however, establish any cumulative air emission or pollution thresholds beyond which a different set of rules, or approval criteria would apply. For one example, the Commission is still approving many large new Oil and Gas Development Plans and Comprehensive Area Plans that will add thousands of tons of new ozone forming pollution within the 'Severe' Denver Metro-North Front Range nonattainment area,[1] without adding permit conditions that could prevent these new facilities from exacerbating this existing ozone problem.

[1]In the past 12 months the COGCC has approved 30 Oil and Gas Development Plans and one Comprehensive Area Plan. These 30 OGDPs report emissions of NOx from activities during pre-production and through the first year of production at over 3,835 tons. The single CAP approved estimated in its application that it would emit as much as 469 tons per year of NOx, and although this was revised sharply downward in its final approved Plan neither number would create a binding limit under current regulations. Current man-made in-state NOx contributes 164 tons per day from all sources including on and off-road vehicles, lawn and garden equipment, and all industrial sources combined, meaning that in twelve months the COGCC has approved enough new oil and gas development activity to add almost an entire months' worth of NOx pollution to the state's already Severe ozone nonattainment. *See* the COGCC website for approved OGDP applications docket numbers 211100213, 210800130, 210700120, 211000207, 211000200, 210900171, 211200238, 210900146, 210900153, 210700117, 210900145, 210600095, 220300043, 220200033, 211100224, 210600089, 210600105, 210700111, 210400052, 210600096, 210400033, 210600094, 210500068, 210400038, 210500081, 210300017, 210500082, 210300019, 210900150, and 210800138, and approved CAP application docket number 211200237.

The first annual Report on the Evaluation of Cumulative Impacts, required by Rule 904.a, was published in January of 2022. [hereinafter "2022 Cumulative Impacts Report"] *available at* https://cogcc.state.co.us/documents/library/ Cumulative_Impacts/2021_COGCC_CI_Report_ 20220114.pdf. It contains data submitted by operators in applications for seven Oil and Gas Development Plans filed in 2021 as well as data "compiled with contributions from the CDPHE's Air Pollution Control Division (APCD) and Colorado Parks and Wildlife (CPW), and . . . their reports and/or recent presentations to the Commission." *Id*. Reported impacts included water usage, impacts to wildlife, land use, air quality (including methane, VOCs and ozone, and HAPs emissions), and greenhouse gas emissions. The Report did not contain sections on the various localized "nuisance" impacts that are currently addressed in Commission Rules, such as dust, light, or noise pollution.[2]

Despite being the focus of the cumulative impact evaluations contained in the 2022 Report, current Commission rules currently fail to address known cumulative air impacts. That is, while cumulative impact data (at least with regard to many air emissions) is being reported and analyzed, the Commission has not adopted rules that set any cumulative impacts threshold that considers whether excessive background impacts render proposed new activity inappropriate, or require that operators take steps sufficient to prevent their additional impacts from increasing an already-unacceptable cumulative background level of impacts. The current rules also fail to require specific attention to disproportionately impacted communities in Rule 904, and fail to assure that operators' self-reported anticipated air emissions data have sufficient reliability.[3]

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[2] Dust mitigation generally is addressed by Rule 427, and cumulative dust impacts are addressed in subsection e. of that rule: while other portions address the need to minimize dust pollution, sub e. specifically incorporates "other sources" of dust in the area. Light pollution, likewise, is addressed by Rule 424, which requires that operators use best management practices to reduce it. Subsection f. of that rule requires that operators reduce light intensity from all oil and gas sources to meet a specific threshold. Noise pollution is controlled by Rule 423, and states that all noise measurements are cumulative. It sets especially strict compliance rules for operators in areas where ambient noise is already very high.

[3] Commission rules require operators to file a Form 2B, Cumulative Impacts Data Identification, containing quantitative evaluation of the incremental increase in seven criteria pollutants and nine Hazardous Air Pollutants estimated for the entire proposed Oil and Gas Development Plan, including stationary and mobile sources for pre-production and the first year of production. Rule 303.a.5.B.i. and B.ii. However, the Rules do not prescribe how the emission will be quantified or provide any consequences for operators whose estimations are later found to be inaccurate, or even require operators to update the Form 2B if that occurs. The Mission Change SBP, p.68, indicates that AQCC will monitor actual emissions after construction, and that the combined data will be used to "inform both agencies' permitting decisions prior to a location being constructed." However it is unclear how actual monitoring *after* construction will 'inform' the COGCC's permitting decision '*prior* to a location being constructed,' and without any cumulative impact thresholds in place.

Ozone Formation

The Mission Change Statement of Basis and Purposed states that operators are required "to estimate emissions of nitrogen oxides, carbon monoxide, and volatile organic compounds because they each contribute to tropospheric ozone formation and independently have adverse health impacts in high concentrations." Mission Change SBP at 67. Although its reliability could be improved, the Commission is receiving the data it needs from operators to understand the cumulative impacts of oil and gas production on regional ozone formation. However, the Commission has not yet adopted rules to address the cumulative emissions of ozone precursors, of which the oil and gas production industry is the largest in-state, anthropogenic contributor.[4] Operators have reported that their proposed projects will add *many* thousands of tons of additional ozone forming pollutants annually, within the existing ozone nonattainment area, and the Commission has given its blessing.

At a regional level (including the counties of Denver, Arapahoe, Jefferson, Douglas, Adams, Boulder, Broomfield, Larimer, and Weld) , Colorado has had an ongoing problem with ground level ozone pollution for approximately 15 years. Ground level ozone is an extremely reactive gas that attacks living tissue (human, animal, and plants alike) through its strong oxidizing potential. It can trigger premature death, asthma attacks, cardiovascular events, and lead to permanent lung damage particularly in children, elderly, and individuals who perform physical activity outdoors for work or play. Its danger is not overstated. As more data on the hazards of ground level ozone has been accumulated, the EPA revised the health based National Ambient Air Quality Standard (NAAQS) for ozone downward three times: in 1997 the 0.12 ppm standard was revised to 0.08 ppm, in 2008 it was revised again to 0.075 ppm, and in 2015 it was revised again to 0.070 ppm. Appendix A contains a more in depth – although nowhere near exhaustive – look at the damage to health, ecosystems and agriculture that ozone causes. In addition to damaging human health and the environment, the ongoing ozone pollution problem damages Colorado's reputation for natural beauty and healthfulness, and tightening EPA controls around ozone brings increasingly large numbers of facilities (oil and gas or otherwise) into "major source" status, dramatically increasing statewide environmental compliance costs. Ongoing nonattainment also hits all Coloradans' fuel costs directly, by triggering a federal requirement that gas stations in Colorado sell a more refined grade of gasoline.

[4] Oil and gas production contributes approximately 40% of the VOCs (more than twice as much as the next highest category of emitter) and approximately 30% of the NO_x, which makes it the largest 'stationary source' category and a larger source than any category of mobile source including light duty vehicles. *See* Regional Air Quality Council, *Where Ground-Level Ozone Comes from in Colorado*, *available at* https://simplestepsbetterair.org/get-smart/ 6

The oil and gas industry is *by far* the primary in-state anthropogenic[5] source of ozone-forming pollution in Colorado according to data put forth by both the CDPHE and the Regional Air Quality Council (RAQC).[6]

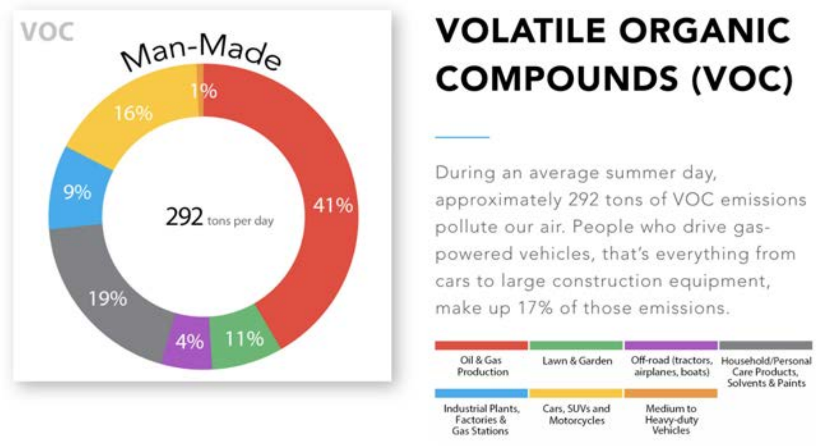

Fig. 4. Sources of man-made VOC emissions in Colorado. Source: Regional Air Quality Council, *Where Ground-Level Ozone Comes from in Colorado*, available at https://simplestepsbetterair.org/get-smart/

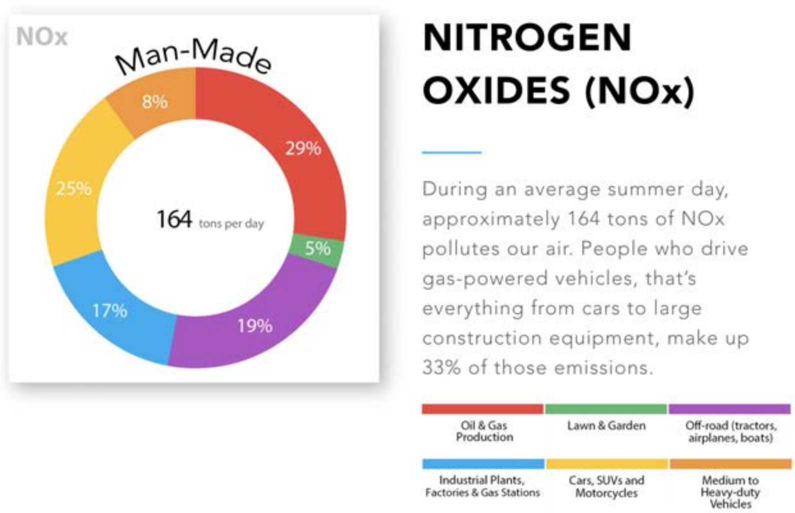

Fig. 5. Sources of man-made NOx emissions in Colorado. Source: *Id.*

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[5] Colorado has an obligation to meet the ozone NAAQS, regardless of the influence of external or unavoidable factors such as topographical/atmospheric interactions (such as inversions), wildfires, higher than average solar intensity, vegetation, or international pollution.

[6] During a presentation given to the Commission on December 8, 2021, CPDHE reported that while 'light duty vehicles' contributed 5.7 ppb to summertime ozone formation, oil and gas sources (including 'area sources,'point sources, and tanks) contributed at least 8.6 ppb. In other words, the oil and gas industry contributes 150% as much to nonattainment as all of the passenger cars in the state. This information is also contained in the RAQC presentation "Ozone Plan Development Overview," slide 14. https://drive.google.com/file/d/1D5t-lJxQaeFI7fbEDXwf_5i2mGkzeMfK/view. This contradicts information presented to the Commission which was cited in the 2022 COGCC Report on the Evaluation of Cumulative Impacts: Rule 904.a. at 15 (Jan. 2022).

Colorado's nonattainment region has been classified as "Serious" nonattainment for the 2008 ozone National Ambient Air Quality Standard (NAAQS), the older health-based standard set by the federal Environmental Protection Agency, but is soon to be reclassified as "Severe."[7] 2021 was the worst year on record in Colorado for ozone pollution.[8] In 2021 the number of days that Colorado's DMNFR exceeded the ozone NAAQS was almost 40% higher than 2018, which itself had the second-highest number of daily exceedances since 2013.[9] These days are measured from May 31 through August 31, which is considered the "ozone season" in Colorado. The Mission Change rulemaking acknowledged ozone as a cumulative impact of the oil and gas industry, and included ozone-forming precursors as emissions to be reported to the CIDER database. Mission Change SBP at 248. In its 2022 report on cumulative impacts the Commission noted that a combination of factors exacerbated the 2021 ozone season's particular intensity, including wildfire smoke and high atmospheric pressure. 2022 COGCC Report on the Evaluation of Cumulative Impacts: Rule 904.a. at 15 (Jan. 2022). However this begs the question of why the Commission did not take any actions to control oil and gas emissions to a greater extent during these external events, which were not only observable but readily apparent to anyone breathing the summer air in Colorado in 2022. Particularly distressing is the Commission's conclusion of this section of the report that "Decreasing ozone concentrations in the DM/NFR is a continued priority *for the APCD*." *Id.* at 16.

The COGCC is tasked with evaluating and addressing the cumulative impacts of oil and gas development. COGCC must adopt its *own* rules that will, *in consultation with* the CDPHE, evaluate and address the contribution of oil and gas production activities to Colorado's ongoing ozone crisis.

<u>Greenhouse Gas Emissions</u>

It is indisputable that climate change is a cumulative impact of oil and gas operations and that it is already harming the health of Coloradans, our ecosystems, our agriculture and our recreation

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[7] U.S. EPA, *Determinations of Attainment by the Attainment Date, Extension of the Attainment Date, and Reclassification of Areas Classified as Serious for the 2008 Ozone National Ambient Air Quality Standards*, 87 Fed. Reg. 21,825 (April 13, 2022). *See also* CDPHE. 2022. "Ozone and Air Quality Fact Sheet" https://oitco.hylandcloud.com/CDPHERMPop/docpop/docpop.aspx, CDPHE. N.d. "Severe Ozone Planning. https://cdphe.colorado.gov/severe-ozone-planning. EPA has agreed to a September 15, 2022 deadline for finalizing this determination. Colorado is also out of attainment for the later 2015 ozone NAAQS, which has a lower threshold. These two standards apply concurrently, and will continue to do so until and unless Colorado meets the 2008 standard, at which time the designation of nonattainment for the 2015 standard will remain in place until the lower threshold is met.

[8] APCD. 2021. "2021 Ozone Season Review." https://drive.google.com/file/d/1EUbRAy2D0bb1hAr7tcLBEgsjALrsUeXu/view

[9] RAQC. 2021. "Ozone Plan Development Overview," slide 10. https://drive.google.com/file/d/1D5t-lJxQaeFI7fbEDXwf_5i2mGkzeMfK/view

industry, and is the cause of several of the largest disasters in recent Colorado history. See Appendix B for more information about climate change impacts and the role of oil and gas, including details about how climate change is impacting Indigenous Peoples, low-income communities, and communities of color. *See* Appendix C for information on disproportionate local warming impacts in numerous Colorado counties: Western Colorado has warmed more than twice the national average, with communities already experiencing warming of 1.5 to 2.4 degrees Celsius. Rule 904 and the Cumulative Impacts Report acknowledge climate change as a cumulative impact by requiring an evaluation of the cumulative greenhouse gas emissions. Despite this acknowledgement and despite the extensive evaluations of climate change impacts that have been conducted by Colorado, national and international governmental bodies, the rules do not address these impacts.

Colorado's oil and gas production is a large source of climate-altering greenhouse gas emissions, before end-uses are even considered. The gap between current and planned extraction by oil and gas operators and the Intergovernmental Panel on Climate Change's figure for the remaining global "carbon budget" (the total amount of remaining greenhouse gas emissions that scientists believe we can release to the atmosphere while maintaining some chance of avoiding global ecological catastrophe) is known as the "production gap."[10] It is called the production gap because every fossil fuel producer must begin to ramp down production of fossil fuels to stay within this planetary budget, yet nearly every producer is planning on increasing production instead. Furthermore, Colorado's projected production is increasing on a steeper curve than the global forecasted growth, especially between 2020 and 2030, as illustrated in the following figures. Colorado is not only acting with reckless disregard for global climate breakdown, its recklessness exceeds the rest of the world. Globally, only a small increase in production is anticipated. The Production Gap Report data shows that global production of oil, under climate pledges, is expected to rise by 13.4% and global production of gas, under climate pledges, is expected to rise by 18.5%.[11] In Colorado, under our greenhouse gas reduction plan, the state anticipates increasing its oil production by 75% by 2030 (nearly double), and increasing gas production by 33% in the same time period.

[10] UN Environment Programme. 2021. *Production Gap Report*. https://productiongap.org/2021report/

[11] Data available at https://productiongap.org/2021report/, "download Chapter 2 data."

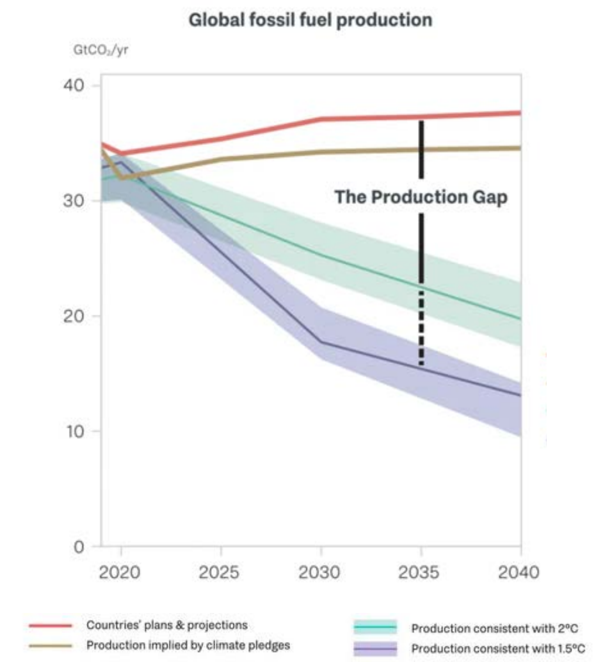

Fig. 4. The Global Production Gap[13]

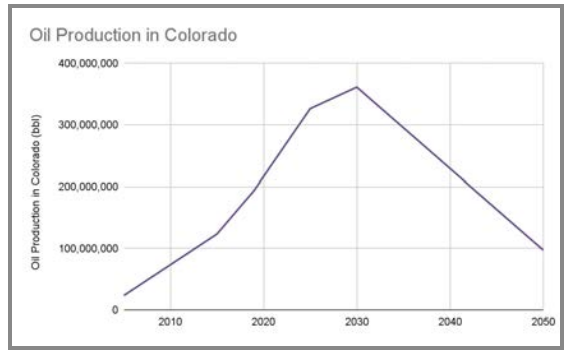

Fig. 5. Projected CO oil production[12]

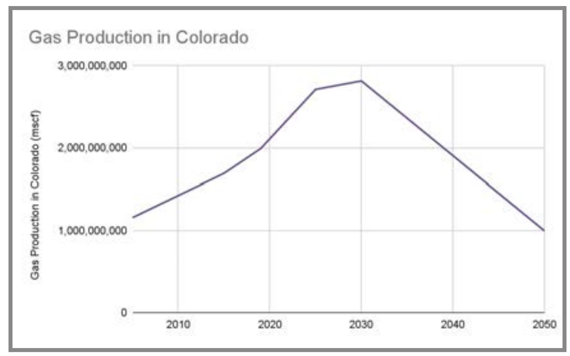

Fig 6. Projected CO gas production[14]

Climate change is a global threat that is being caused cumulatively by actions of a multitude of locales, regions and nation-states. Its impacts are felt on multiple levels from local to national and global, and its solutions must also be instigated at all levels. Many nations who suffer the most from climate change have contributed the least. Those who have already benefited have an increased responsibility to do more not only to stop adding to the problem, but to take additional remedial steps such as carbon *removal*. Colorado, which in addition to emitting more than its global 'share' of emissions has seen its own local warming exceeding global averages, bears a share of responsibility larger than its share of population to be part of the solution. With the goal of keeping warming under 1.5 degrees Celsius, our state has committed to decreasing its carbon emissions by 26% by 2025, 50% by 2030 and 90% by 2050 from 2005 levels, as part of House Bill 19-1261 Climate Action Plan to Reduce Pollution. In 2021, Governor Polis put forward the "Colorado Greenhouse Gas Pollution Reduction

[12] Colorado Energy Office, GHG Pollution Reduction Roadmap, report drafts and modeling assumptions: production forecasts, *available at* https://drive.google.com/file/d/1J-gylkTbmbmknsQcfNRTlF1EbdwBxjVx/view?usp=sharing.
[13] Global production gap graphs from UN Environment Programme. 2021. *Production Gap Report*, available at https://productiongap.org/2021report/.
[14] Colorado Energy Office, production forecasts, *supra* fn. 12.

Roadmap," (hereinafter "Roadmap") *available at* https://drive.google.com/file/d/1jzLvFcrDryhhs9ZkT_UXkQM_0LiiYZfq/.

The Roadmap estimated that in 2020, the oil and gas industry's direct upstream emissions contributed nearly 27 MMT CO_2e. Under the Roadmap, the oil and gas sector needs to reduce emissions farther than other sectors – 60% by 2030, from 20.17 MMT to only 8. Roadmap at 97. It estimated that Air Quality Control Commission rulemaking on methane emissions and COGCC rulemaking to eliminate routine flaring, requiring the general 'minimization' of emissions, and reporting requirements would remove 12.2 MMT of GHG emissions annually by 2030. However, according to the AQCC, the methane emissions reductions actually achieved by its methane rulemaking will reduce GHG emissions from the oil and gas sector by only about 4.8 MMT annually, meaning that there remains 7.4 MMT of GHG emissions reductions that must be achieved by COGCC and AQCC, and there is no "low hanging fruit" of emissions reductions that are available that would allow this to occur while Colorado continues to accelerate oil and gas production activities.

Additionally, there are many reasons why Petitioners believe that Colorado is undercounting the fugitive emissions from the oil and gas industry. For example, investigations performed by Earthworks reveal undiscovered sources of fugitive emissions at nearly every site it investigated. *See*, *e.g.*, Earthworks, *End-of-Year Update on Chronic Pollution in Colorado* (Dec. 10, 2021), *available at* https://earthworks.org/blog/update-an-end-of-year-update-on-chronic-pollution-in-colorado/ (reporting on the number of citizen-generated complaints and supporting data in emissions reporting required prior to state acknowledgement and initiation of pollution abatement); PSE Healthy Energy, *Contextualizing Quantitative Optical Gas Imaging Samples of Methane Emissions from Oil and Gas Activities in Colorado, New Mexico and Texas* (May 2020), *available at* https://www.psehealthyenergy.org/wp-content/uploads/2020/07/Earthworks-QOGI-Methane-Final-2020.05.pdf (emissions discovered by Earthworks reveals that states including Colorado are likely undercounting emissions from oil and gas sources).

Disproportionately Impacted Communities

Disproportionately Impacted ("DI") communities have historically borne a much larger share of the burden of pollution, and also tend to suffer worse impacts due to location in environmentally vulnerable areas, older and less resilient infrastructure, residents' relatively lower financial means for disaster 'hardening' and recovery, urban 'heat island' effects, statistically significant lower tree cover, and more.[15] Colorado now has statutory requirements to address this issue, righting wrongs where

[15] *See* U.S. EPA, *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts* (Sept. 2021),

possible and in particular *discontinuation* of ongoing disproportionate harm, yet this remains a gap in the Commission rules for evaluating and addressing cumulative impacts. HB21-1266 established goals which include ". . . to modify proposed state action in response to received public input to decrease environmental burdens or increase environmental benefits for *each* (emphasis added) disproportionately impacted community." C.R.S. § 24-4-109 (1). Though Rules 303.a.(5).B.ii.dd and 314.e.(10).G now require operators to report when proposed new facilities are within or nearby a DI community, these rules are wholly inadequate in evaluating unjust burdens, which are themselves a cumulative impact in which present conditions are compounded by historical buildup of pollution and other related social injustices such as access to housing and health care. Rules to address these impacts have not been promulgated, much less rules that would 'decrease environmental burdens or increase environmental benefits,' as intended by HB21-1266.

IV. Proposed Rules

Existing rule language in red, where applicable.

Definitions, in 100 series:

Cumulative Impacts: Cumulative impacts result when the effects of an action are added to or interact with other effects in a particular place and within a particular time. It is the combination of these effects, and any resulting environmental degradation, that should be the focus of cumulative impact analysis. While impacts can be differentiated by direct, indirect, and cumulative, the concept of cumulative impacts takes into account all disturbances since cumulative impacts result in the compounding of the effects of all actions over time. Thus the cumulative impacts of an action can be viewed as the total effects on a resource, ecosystem, or human community of that action and all other activities affecting that resource no matter what entity (federal, non-federal, or private) is taking the actions.

Equity Analysis: Equity analysis is intended to help the Commission assess where certain communities are overburdened with pollution and sources of environmental risk, and avoid decisions that unfairly contribute to or perpetuate disproportionate environmental harms. An Equity Analysis quantifies, where possible, the cumulative impacts to disproportionately impacted communities. These impacts include both historical and existing sources of pollution and disparate resource allocation, including but not limited to oil and gas production, traffic/transportation, waste disposal, refining,

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available at https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.

Risk Management Plan facilities and superfund sites, impacts on housing, and infrastructure resilience, and includes a report on the lived experience of the community.

Rule 303.a.(5) (existing rule language in red)

B.ii.dd Whether the proposed Oil and Gas Development Plan includes any proposed Oil and Gas Locations within a Disproportionately Impacted Community. Operators shall provide an Equity Analysis, meeting state and community recommendations of analysis, with community engagement of known overburdened communities for each proposed Oil and Gas Location within, adjacent, and contiguous to a Disproportionately Impacted Community.

E. Baseline monitoring. Operator shall conduct and provide an analysis of existing Cumulative Impacts including a baseline background for federally regulated Hazardous Air Pollutants and NAAQS substances. The analysis must use CDPHE data where available and 3rd-party monitoring where CDPHE data does not exist. Operators shall provide an analysis of how proposed OGDP will add to the current cumulative levels of NAAQS substances and HAPs.

F. Ensuring Data Accuracy in Evaluating Cumulative Impacts. An operator is limited to the cumulative impacts, including the amount of air emissions, reported to the Commission in its Cumulative Impacts Analysis.

i. An operator must immediately notify the Commission through an updated Form 2B, Cumulative Impacts Data Evaluation, if its actual impacts, including emissions rates, exceed its earlier reported projected emissions. The updated Form 2B does not require updates for information which is unchanged.

ii. Because approval of applications depends on an accurate understanding of expected impacts and includes consideration of avoidance, mitigation, and compensatory actions, any permit or approval is revocable at the discretion of the Commission if the cumulative impacts of an Oil and Gas Development Plan are found to exceed those reported at the time of application.

Rule 304.c. (existing rule language in red)

(19) Cumulative Impacts Plan. A plan documenting how the Operator will address cumulative impacts to resources identified pursuant to Rule 303.a.(5) that includes:

A. A description of all resources AND COMMUNITIES to which cumulative adverse impacts are expected to be increased, AND, IF POSSIBLE A QUANTIFICATION OF SUCH INCREASE;

B. A description of specific measures taken to avoid or minimize the extent to which cumulative adverse impacts are increased, AND, IF POSSIBLE A QUANTIFICATION OF SUCH AVOIDANCE;
C. A description of all measures taken to mitigate or offset cumulative adverse impacts to any of the resources AND COMMUNITIES, AND, IF POSSIBLE A QUANTIFICATION OF SUCH MITIGATION OR OFFSETTING; and
D. Additional information determined to be reasonable and necessary to the evaluation of cumulative impacts by the Operator, the Director, CDPHE, CPW, or the Relevant Local Government.

Rule 314

314.b.3. If the Commission approves a CAP, the Operator need not separately evaluate cumulative impacts for each individual Oil and Gas Development Plan proposed within the CAP, as would otherwise be required by Rule 303.a.(5), as long as the Cumulative Impacts Analysis includes the same or more information and requirements for avoidance, mitigation, and compensation as would have been required for those individual OGDPs.

314.e.(10).B. Baseline monitoring. Operator shall conduct and provide an analysis of existing Cumulative Impacts including federally regulated Hazardous Air Pollutants and criteria pollutants. Because pollutant threshold criteria contain temporal elements, each analysis shall determine whether exceedances do or are likely to occur according to the standard set for each pollutant. The analysis must use CDPHE data where available and 3rd-party monitoring where CDPHE data does not exist. Operators shall provide an analysis of how proposed OGDP will add to the current cumulative levels of criteria pollutants and HAPs.

314.e.(10).G. Disproportionately Impacted Communities. The census block groups of any Disproportionately Impacted Communities within or within 2000 ft. of the CAP, and an Equity Analysis for each such Disproportionately Impacted Community.

Rule 904. - Evaluating Cumulative Impacts

a.(1.5) An Equity Analysis of cumulative impacts to disproportionately impacted communities, particularly communities identified by the EPA's EJScreen as 80th percentile or above for any pollutant, risk, or identified proximity of concern, that includes both historical burdens and existing impacts, including but not limited to oil and gas production, transportation, waste disposal, refining pollution from transportation and industry sources, impacts on housing, and includes a report on the lived experience of the community.

Rule 904.5 (Proposed) - "Addressing Cumulative Impacts"

a. Where available data show that a proposed project or facility would emit a pollutant in an area where impacts from existing sources of that pollutant exceed state, federal, or local standards, that project or facility shall not be approved.

b. Where available data show that a proposed project or facility would emit a pollutant, and the projected future cumulative levels of that pollutant are anticipated to at times exceed state, federal, or local standards, that project or facility shall not be approved unless either

(1) the timing of the project and facility operations will not result in an increase of that pollutant until background levels fall to a level where emissions from the facility or project are not likely to cause or cumulatively contribute to any exceedance, or
(2) the applicant for the project or facility can demonstrate that it has secured permanent offsets within the relevant affected area such that no net increase in exposure will occur in the affected area.

c. Where the U.S. EPA's EJscreen or similar state environmental justice mapping tool determines that a community is at or above the 80th percentile for any environmental indicator, including but not limited to exposure to particulate matter, ozone, air toxics risk, or proximity risk from superfund, hazardous waste, underground storage tank, or traffic, the Director shall reject and the Commission shall not approve any additional sources contributing to that pollution or risk within that community.

d. Where an area has been designated as nonattainment for the National Ambient Air Quality Standard for ozone, no pre-production activities, including drilling, completion, recompletion, or stimulation, may be conducted within that nonattainment area between May 31 and August 31.

e. No pre-production activities, including drilling, completion, recompletion, or stimulation, liquids unloading, pigging, or venting, may occur at any time or location where that activity is likely to cause or contribute to the exceedance of any pollution threshold set by the state, federal, or local government, unless immediately and urgently required in less than a 24 hour timeframe to prevent serious harm to employees, the public, or the environment and reported to the Director.

f. Where a proposed project or facility is located in an area or watershed that has already warmed 1.5 degrees Celsius (2.8 degrees Fahrenheit), or a county listed in Table 904.5-1, that project or facility may not be approved;

g. The Director shall not accept and the Commission shall not approve applications for Comprehensive Area Plans, Oil and Gas Development Plans, Form 2A Location Assessments, or Form 2 Applications for Permit to Drill, if the state has determined that it is not reaching statewide greenhouse gas emissions reductions targets. The Commission may resume issuance of these approvals only upon a formal showing by the CDPHE that the state's greenhouse gas emissions reduction inventory shows attainment with the target emissions reductions.

Table 904.5-1. Colorado Counties with Average Warming Above 1.5°C (2.7°F) or More Over 125-year period, 1895–2019.

Average Annual Warming		**County**
Celsius	**Fahrenheit**	
1.5	2.7	Kit Carson County
1.5	2.7	Gunnison County
1.6	2.9	Routt County
1.6	2.9	La Plata County
1.6	2.9	Logan County
1.6	2.9	Adams County
1.6	2.9	Montezuma County
1.6	2.9	Jackson County
1.7	3.1	Hinsdale County
1.7	3.1	Yuma County

1.8	3.2	Washington County
1.9	3.4	Weld County
1.9	3.4	Dolores County
2	3.6	Garfield County
2	3.6	Larimer County
2	3.6	San Juan County
2.1	3.8	Delta County
2.1	3.8	Morgan County
2.1	3.8	Moffat County
2.2	3.8	San Miguel County
2.3	4.1	Ouray County
2.3	4.1	Mesa County
2.4	4.3	Rio Blanco County
2.4	4.3	Montrose County
Source 2ºC: Beyond the Limit, Washington Post Pulitzer Prize winning series, which analyzed warming between 1895 and 2019. Data available at: https://github.com/washingtonpost/data-2C-beyond-the-limit-usa		

V. Statement of Statutory Authority

The Commission's authority to promulgate the proposed rules comes from the following sources:

Section 34-60-102(1)(a) states:

It is declared to be in the public interest and the Commission is directed to: (I)

> Regulate the development and production of the natural resources of oil and gas in the state of Colorado in a manner that protects public health, safety, and welfare, including protection of the environment and wildlife resources.

Section 34-60-102(1)(b) states, in relevant part:

> It is the intent and purpose of this Article 60 to permit each oil and gas pool in Colorado to produce up to its maximum efficient rate of production, subject to the protection of public health, safety, and welfare, the environment, and wildlife resources and the prevention of waste as set forth in Section 34-60-106 (2.5) and (3)(a) . . . .

Section 34-60-103(11) states, in relevant part:

> "Waste", as applied to gas:
> (b) Does not include nonproduction of gas from a formation if necessary to protect public health, safety, and welfare, the environment, or wildlife resources as determined by the Commission.

Section 34-60-103(12) states, in relevant part:

> "Waste", as applied to oil:
> (b) Does not include nonproduction of oil from a formation if necessary to protect public health, safety, and welfare, the environment, or wildlife resources as determined by the Commission.

Section 34-60-105(1)(a) states:

> The commission has jurisdiction over all persons and property, public and private, necessary to enforce this article 60, the power to make and enforce rules and orders pursuant to this article 60, and to do whatever may reasonably be necessary to carry out this article 60.

Section 34-60-106(1)(f) states, in relevant part:

> That no operations for the drilling of a well for oil and gas shall be commenced without first: (B) Obtaining a permit from the commission, under rules prescribed by

the commission.

Section 34-60-106(2) states:

> The commission may regulate:
> (a) The drilling, producing, and plugging of wells and all other operations for the production of oil or gas;
> (b) The stimulating and chemical treatment of wells; and
> (c) The spacing and number of wells allowed in a drilling unit.

Section 34-60-106(2.5) states:

> (a) In exercising the authority granted by this Article 60, the Commission shall regulate oil and gas operations in a reasonable manner to protect and minimize adverse impacts to public health, safety, and welfare, the environment, and wildlife resources and shall protect against adverse environmental impacts on any air, water, soil, or biological resource resulting from oil and gas
> operations.
> (b) The nonproduction of oil and gas resulting from a conditional approval or denial authorized by this subsection (2.5) does not constitute waste.

Section 34-60-106(11)(a)(II) states:

> [The commission shall] Promulgate rules, in consultation with the department of public health and environment, to protect the health, safety, and welfare of the general public in the conduct of oil and gas operations. The rules shall provide a timely and efficient procedure in which the department has an opportunity to provide comments during the commission's decision-making process. This rule-making shall be coordinated with the rule-making required in section 34-60-128(3)(d) so that the timely and efficient procedure established pursuant to this subsection (11) is applicable to the department and to the division of parks and wildlife.

Section 34-60-106(11)(c) states, in relevant part:

> The Commission shall adopt rules that: (II) In consultation with the Department of Public Health and Environment, evaluate and address the potential cumulative

impacts of oil and gas development.

VI. Request for Rulemaking

Petitioners, for the aforementioned reasons, basis, and purpose, hereby request that the Colorado Oil and Gas Conservation Commission grant this request for the proposed rulemaking pursuant to Rule 529 and the State Administrative Procedure Act, C.R.S § 24-4-101 *et seq*.

Respectfully submitted this August 30, 2022,

/s Katherine Merlin
Katherine Merlin, CO Atty. Reg. 45672
WildEarth Guardians
3798 Marshall St., Ste. 8
Wheat Ridge, CO 80033
(720) 965-0854
kmerlin@wildearthguardians.org

/s Heidi Leathwood
Heidi Leathwood, Climate Policy Analyst
350 Colorado
P.O Box 607
Boulder, Colorado 80306
(720)839-2549
heidi@350colorado.org

/s Renée Millard-Chacon
Renée Millard-Chacon, Co-Founder and Executive Director
Womxn from the Mountain
11016 Lima St.
Henderson, CO 80640
(720) 224-4204

reneemchacon@gmail.com

/s Barbara Donachy, MPH
Secretary, PSR Colorado Board of Directors
2216 Race Street
Denver, Colorado 80205
(720) 989-4185
2770 Arapahoe Road, Ste 132-683
Lafayette, Colorado 80026

/s Ramesh Bhatt
Ramesh Bhatt, Conservation Chair
Colorado Sierra Club
536 Wynkoop St #200
Denver, CO 80202
(720) 859-333-4537
bhattlex@gmail.com

/s Doug Henderson
Larimer Alliance for Health, Safety and Environment
401 E Prospect St
Ft Collins, CO 80525
(970) 227 9250
dhender@gmail.com

Appendix A

Impacts of Ozone on Human Health, Ecosystems and Agriculture, and Climate Change

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I. Human Health

The 2013 EPA review of 2006-2012 research concluded ozone is a serious threat to health, leading them to strengthen the National Ambient Air Quality Standard in 2015.[16] The 2020 EPA review of literature shows that short-term exposure to ozone causes respiratory effects, is likely to cause metabolic effects, and may cause early death, cardiovascular effects, and central nervous system effects. Long-term exposure to ozone is likely to cause respiratory effects and may lead to cardiovascular effects, metabolic effects, early death, effects on fertility and reproduction as well as pregnancy and birth outcomes.[17] Although the EPA recognizes the danger of long-term exposure, they do not set a separate standard for it. The WHO, on the other hand, sets guidelines for long-term average exposure in addition to their short-term exposure guidelines.

The WHO guidelines for both short- and long-term ozone, updated in 2021, are also based on a comprehensive literature review.[18] WHO recommendations for short-term exposure are more stringent than the EPA 2015 threshold: EPA's 2015 standard uses a 70 ppb requirement while WHO's guideline is set at 100 $\mu g/m^3$ (50 ppb) (WHO 2021,[18] p. 110). The WHO guidelines are based for the most part on risk of early death (WHO 2021,[18] p. 176). Several studies provide more specificity on increased mortality rates. Lim et al. found that long-term exposure is associated with increased risk of death from cardiovascular disease, ischemic heart disease, respiratory disease, and COPD.[19] Zanobetti and Schwartz found that long-term ozone exposure leads to increased risk of mortality for people with

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[16] U.S. Environmental Protection Agency. 2013. *Integrated Science Assessment for Ozone and Related Photochemical Oxidants*, 2013. EPA/600/R-10/076F, quoted by the American
Lung Association at https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/ozone

[17] U.S. Environmental Protection Agency. 2020. *Integrated Science Assessment for Ozone and Related Photochemical Oxidants, Executive Summary*. p. 6. https://ordspub.epa.gov/ords/eims/eimscomm.getfile?p_download_id=541232

[18] World Health Organization. 2021. *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization.
https://apps.who.int/iris/handle/10665/345329. See pp. 97-111

[19] Lim, Chris C et al. "Long-Term Exposure to Ozone and Cause-Specific Mortality Risk in the United States." American journal of respiratory and critical care medicine vol. 200,8 (2019): 1022-1031. doi:10.1164/rccm.201806-1161OC.

congestive heart failure, myocardial infarction, COPD, and diabetics.[20] Short-term exposure is associated with increased risk of death from all non-accidental causes, cardiovascular diseases, hypertension, coronary diseases, and stroke.[21]

Fann et al. look at effects on mortality from both ozone and particulate matter, specific to oil and gas.[22] They predict with 95% confidence that by 2025, the US will see an annual average of 970 ozone-related excess deaths, 1000 heart- and lung-related hospital admissions, 3600 emergency room visits, 100,000 lost work days, and more than a million cases of exacerbated respiratory issues. They find that Colorado is one of the states that will suffer the largest share of these (Fann et al. 2018, 8099). Fann et. al. predict that, in Colorado in 2025, 25-49 (average 37) premature deaths will be attributable to particulate matter and 18-49 (average 34) to ozone, for a combined average of 1.9 premature deaths per 100,000 people, directly attributable to the PM and Ozone caused by the oil and natural gas sector. (Id., 8100). This is 210% of the national average deaths per 100,000 people, which is predicted to be 0.9 (Id.).

Additional short- and long-term impacts mentioned by the EPA[2] and by the American Lung Association[23] include risks of increased hospitalization, risks to children and teens (onset of asthma in children, worsening of asthma in children, lower birth weight and decreased lung function in newborns) risks to people who play and work outside (decreased lung function, injury and structural changes to the airway), risks to cognitive function, and risks to reproductive systems (preterm birth, sperm count and quality). Below is a small sampling of studies for each category.

Increased hospitalization

A systematic review and meta-analysis determined that short term effects of ozone caused an increase of hospitalization for asthma at a rate of 1.009 per 5 ppb increase.[24] In effect this means a 15

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[20] Zanobetti A, Schwartz J. Ozone and survival in four cohorts with potentially predisposing diseases. Am J Respir Crit Care Med. 2011 Oct 1;184(7):836-41. https://pubmed.ncbi.nlm.nih.gov/21700916/ doi: 10.1164/rccm.201102-0227OC.

[21] Yin, Peng, Renjie Chen, Lijun Wang, Xia Meng, et al. 2017. "Ambient Ozone Pollution and Daily Mortality: A Nationwide Study in 272 Chinese Cities" *Environmental Health Perspectives*. 125 no. 11. https://doi.org/10.1289/EHP1849

[22] N. Fann et al. 2018. "Assessing Human Health PM2.5 and Ozone Impacts from U.S. Oil and Natural Gas Sector Emissions in 2025," *Environmental Science & Technology*, 52 no. 15: 8095–8103, https://doi.org/10.1021/acs.est.8b02050

[23] American Lung Association. 2020. "Ozone." Last updated April 20, 2020. Accessed June 11, 2022. https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/ozone

[24] Zheng, X. Y., H. Ding, L.N. Jiang, S.W. Chen, et al. 2015. "Association between Air Pollutants and Asthma Emergency Room Visits and Hospital Admissions in Time Series Studies: A Systematic Review and Meta-Analysis." *PloS one*. *10* no. 9. https://doi.org/10.1371/journal.pone.0138146

ppb change in the ozone level would affect hospitalization rates and ER visits for asthma by 2.7% (up or down respectively). A "systematic review and meta-analysis indicate that short-term ambient level ozone exposure was associated with increased risk of COPD hospitalizations."[25] Children with asthma are especially at risk of increased hospitalization from ozone (see below.)

Exacerbation of existing asthma

There are numerous studies on the short-term effects of ozone on children and teens, especially with regard to asthma. A systematic review of 27 epidemiological studies concluded that children may be at higher risk from ozone because of their immature immune systems, increased durations of time spent outside, and increased air exchange relative to body mass, as compared to adults.[26] One study that looked at the effects of ozone on asthma found that children aged 6-18 consistently had the highest risk, and that each 22 ppb increase of ozone resulted in a 19- 20% risk of both ICU and general hospital admissions.[27] At least two studies found an increase in emergency room visits in children after increased short-term exposure to ozone, but not adults (Byrwa-Hill et al. 2020[28], and Chen et al. 2016[29]). Chen et al. found an 11.7% increase in risk of asthma hospital admissions per 10 ppb increment in ozone level.

Onset of asthma

A Canadian study of 1 million children showed a 10 ppb increase in ozone was associated with 38% increase in asthma onset.[30]

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[25] Gao, H. et al. 2020. "A Systematic Review and Meta-Analysis of Short-Term Ambient Ozone Exposure and COPD Hospitalizations." *International Journal of Environmental Research and Public Health*, 17 no. 6: 2130. https://doi.org/10.3390/ijerph17062130.

[26] Zheng, X. Y., H. Ding, L.N. Jiang, S.W. Chen, et al. 2015. "Association Between Air Pollutants and Asthma Emergency Room Visits and Hospital Admissions in Time Series Studies: A Systematic Review and Meta-Analysis." *PloS one*. *10* no. 9. https://doi.org/10.1371/journal.pone.0138146

[27] Silverman, Robert A. and Kazuhiko Ito. 2010. "Age-Related Association of Fine Particles and Ozone with Severe Acute Asthma in New York City." Journal of Allergy and Clinical Immunology. 125 no. 2: 367-373. https://www.sciencedirect.com/science/article/abs/pii/S009167490901642X

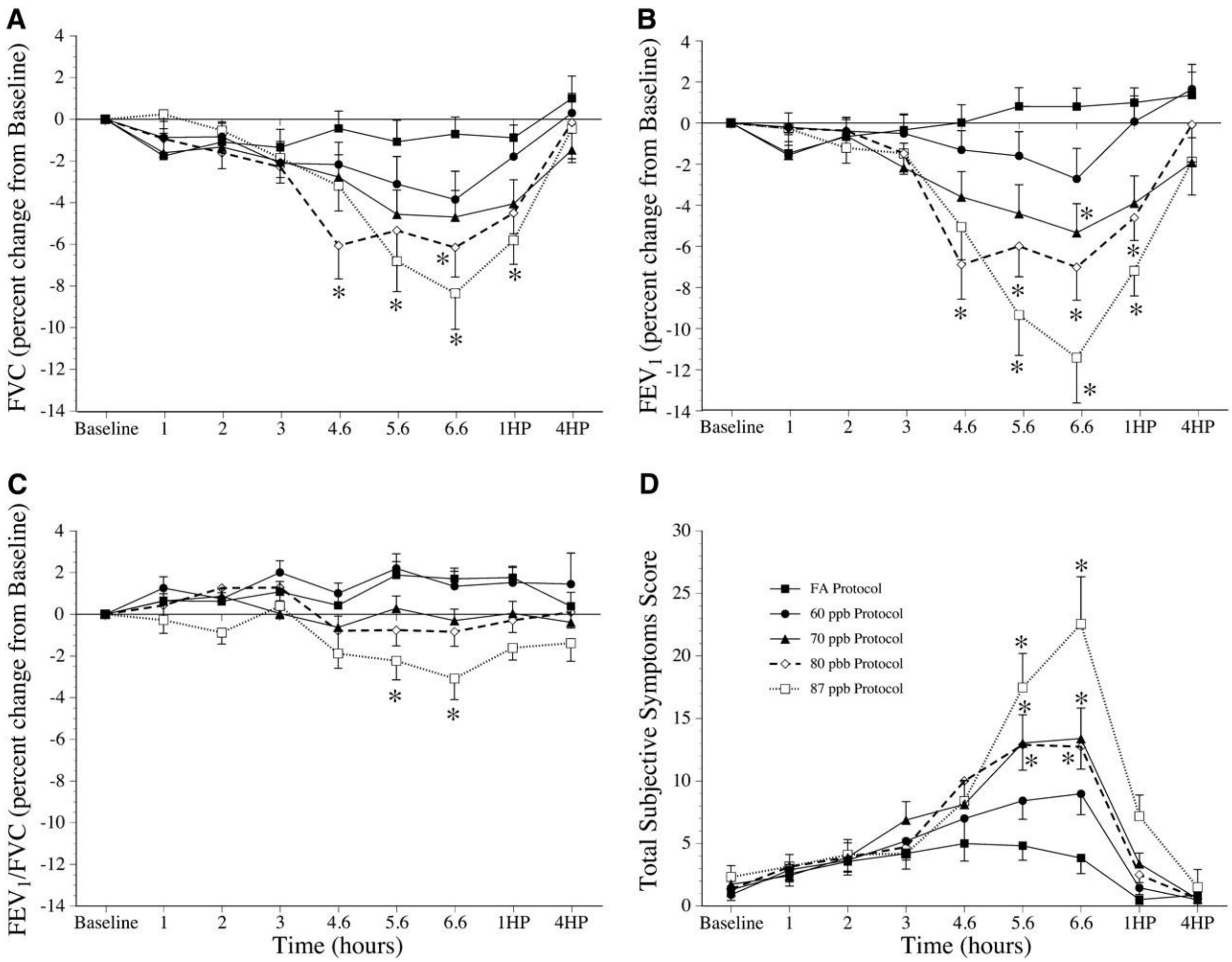
[28] Byrwa-Hill B.M., A. Venkat, A.A. Presto, J.R. Rager, et al. 2020. "Lagged Association of Ambient Outdoor Air Pollutants with Asthma-Related Emergency Department Visits within the Pittsburgh Region." *International Journal of Environmental Research and Public Health*. 2020;17:8619. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7699695/

[29] Chen, K., G. Glonek, A. Hansen, S. Williams, et al. 2016. "The Effects of Air Pollution on Asthma Hospital Admissions in Adelaide, South Australia, 2003-2013: Time-Series and Case-Crossover Analysis." *Clinical and Experimental Allergy*. 46 no. 11: 1416-1430. https://pubmed.ncbi.nlm.nih.gov/27513706/

[30] Tétreault L.F., M. Doucet, P. Gamache, M. Fournier, et al. 2016. "Childhood Exposure to Ambient Air Pollutants and the Onset of Asthma: an Administrative Cohort Study in Québec." *Environmental Health Perspectives*. 124:1276–82.

Lung function

Schelegle et al. found that healthy adults suffered a decrease in lung function from ozone exposure at about 70 ppb, increasing with the concentration of ozone.[31] The study analyzed various metrics of lung function while exercising for 6.6 hours in controlled chambers with ozone concentrations at 60 ppb, 70 ppb, 80 ppb and 87 ppb. See graphs below.



Cognitive decline

Chen and Schwartz found a decline in attention and short-term memory equivalent to 5.3 years of normal aging for each 10 ppb increase in annual ozone average.[32] Cleary's results suggest

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[31] Schelegle E.S., C.A. Morales, W.F. Walby, S. Marion, et al. 2009. "6.6-hour Inhalation of Ozone Concentrations from 60 to 87 Parts per Billion in Healthy Humans." *American Journal of Respiratory and Critical Care Medicine*. 180 no. 3):265–272 Aug 1;180(3):265-72. doi: 10.1164/rccm.200809-1484OC

[32] Chen J.C. and J. Schwartz . 2009. "Neurobehavioral Effects of Ambient Air Pollution on Cognitive Performance in US Adults." *Neurotoxicology*. 30 no. 2:231-9. doi: 10.1016/j.neuro.2008.12.011

acceleration in cognitive impairment during the early stages of dementia.[33] Gao et al. also link cognitive decline to ozone.[34]

Risks to reproduction

Sokol et al. found exposure to ozone lowered sperm concentration, but no other studied air pollutants had the same effect.[35] Hansen et al. found a similar but less significant effect.[36] Several more studies exist but the consensus is that this issue needs further study.

In 2021, a systematic review and meta-analysis of research concluded that "increased ozone exposure during early pregnancy is associated with preterm birth across studies."[37]

Agriculture, Ecosystems and Climate Change

The 2020 EPA Integrated Science Assessment (ISA) shows that ozone damages plants, causing reduced yield and quality of agricultural crops, and damaging ecosystems.[38] The ISA determined ozone causes visible foliar (leaf) injury, reduced vegetation growth, reduced plant reproduction, reduced yield and quality of agricultural crops, reduced productivity in terrestrial ecosystems, alteration of belowground biogeochemical cycles, alteration of terrestrial community composition; and likely causes increased tree mortality, alteration of herbivore growth and reproduction, alteration of plant-insect signaling, reduced carbon sequestration in terrestrial ecosystems, and alteration of ecosystem water cycling.[23] Ozone has been shown to cause "radiative forcing" that contributes to climate change, and likely causes temperature, precipitation and related climate variables.[39]

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[33] Cleary, Ekaterina Galkina, Manuel Cifuentes, Georges Grinstein, Doug Brugge, et al. 2018. "Association of Low-Level Ozone with Cognitive Decline in Older Adults." *Journal of Alzheimer's Disease*. 61 no. 1:67-78. DOI: 10.3233/JAD-170658

[34] Gao, Qi, Emma Zang, Jun Bi, Robert Dubrow, Sarah R. Lowe, Huashuai Chen, Yi Zeng, Liuhua Shi, Kai Chen. 2022. "Long-term ozone exposure and cognitive impairment among Chinese older adults: A cohort study." *Environment International*. 160. DOI: 10.1016/j.envint.2021.107072

[35] Sokol, R.Z., P. Kraft, I.M. Fowler, R. Mamet, et al. 2006. "Exposure to Environmental Ozone Alters Semen Quality." *Environmental Health Perspectives*. 114 no. 3:360-5. doi:10.1289/ehp.8232

[36] Hansen, C., T.J. Luben, J.D. Sacks, A. Olshan, et al. 2010. "The Effect of Ambient Air Pollution on Sperm Quality." *Environmental Health Perspective*. 118 no. 2:203-9. doi:10.1289/ehp.0901022

[37] Rappazzo, K.M., J.L. Nichols, R.B. Rice, T.J. Luben. 2021. "Ozone Exposure During Early Pregnancy and Preterm Birth: A Systematic Review and Meta-Analysis. *Environmental Research*. 198:111317. doi:10.1016/j.envres.2021.111317

[38] U.S. Environmental Protection Agency. 2020. *Integrated Science Assessment for Ozone and Related Photochemical Oxidants, Executive Summary*. p. 13. https://ordspub.epa.gov/ords/eims/eimscomm.getfile?p_download_id=541232

[39] Id. p. 15.

Additionally, climate change itself affects ozone levels. “Unless offset by additional reductions of ozone precursor emissions, there is high confidence that climate change will increase ozone levels over most of the United States, particularly over already polluted areas, thereby worsening the detrimental health and environmental effects due to ozone.”[40]

[40] U.S. Global Change Research Program. 2018. *Fourth National Climate Assessment, Chapter 13*. https://nca2018.globalchange.gov/chapter/13/

Appendix B

Climate Change and the Cumulative Impact of Oil and Gas

Table of Contents:

[Introduction](#)
[General climate change impacts on public health, safety, welfare and environment](#)
[Colorado-specific climate change impacts](#)
[Fossil Fuels' contribution to climate change](#)
[Greenhouse gas emissions from Oil and Gas operations in Colorado](#)

I. Introduction

The impacts of climate change, both in Colorado and around the world, are increasingly severe, pervasive, and all-encompassing. Climate change is an existential crisis. Its impacts occur on local, regional and global levels, in a web of interrelated and inseparable factors that affect one another, including human health and safety, degradation of ecosystems and loss of biodiversity, and even the choices humans make in their responses.

This Appendix draws heavily from the "Summary for Policymakers" of what is widely recognized as the most up-to-date and comprehensive source on climate change: the 2022 report from the IPCC working group II. The 2022 full report is by 270 authors from 67 countries, has 675 contributing authors, contains over 34,000 cited references, and had 62,418 expert and government review comments (IPCC n.d.). Also cited in this Appendix are U.S. and Colorado sources including Center for Disease Control (CDC) reports, Environmental Protection Agency (EPA) reports, the National Climate Assessment (NCA), and reports by the State of Colorado, as well as primary sources (peer-reviewed research studies). References are listed alphabetically at the end of the Appendix, with in-text citations in author/date format. In order to fully convey the depth of what is known about current impacts and future risks of climate change, the IPCC "Summary for Policymakers" is also attached to this petition as Appendix D.

II. General climate change impacts on public health, safety, welfare, and the environment

Health

According to the United States Center for Disease Control and Prevention (CDC), the public health impacts of climate change have been largely unaddressed even though there is a wide variety of global organizations addressing many other implications of climate change (CDC n.d.). Considerable evidence exists for the following health impacts of climate change: heat stress from heat waves; injuries and drowning from extreme weather events; vector-, food- and water-borne diseases from droughts, floods and increased mean temperature; food/water shortages and malnutrition from drought and ecosystem change; respiratory disease exacerbations from increases in ground-level ozone, airborne allergens and other air pollutants; and mental health issues from extreme events and climate change generally. (CDC n.d.) Compounding these impacts, climate-caused extreme weather events such as floods disrupt health services (IPCC 2022, B.1.4).

Climate change is expected to continue to worsen air quality, especially particulate matter and ozone, due to changes in temperature, humidity, precipitation, intensity and length of warm seasons, and increases in wildfires and windblown dust (EPA 2021, 20). Declining air quality has serious health impacts: particulate matter was estimated to have caused more than 8 million deaths globally in 2018 (Vohra et al. 2021), and ozone is associated with major health risks including hospitalization and death, as described in Appendix A. Low-income communities and people of color are more likely to be affected by air pollution, and this disparity exists across states, across income levels and in both rural and urban locations (Tessum et al. 2021).

Mora et al. analyzed more than 3,200 scientific works and determined that 218 diseases–over half of 375 infectious diseases studied–have become more dangerous due to climate change, finding that there are more than 1,000 ways that climate change has spurred disease transmission. Rising temperatures are the biggest cause of increased disease transmission; other factors include precipitation, floods, drought, and habitat change and disruption (Mora et al. 2022).

Human health, safety, and well-being are inextricably tied to the many factors described below in this Appendix. For instance, changes to ecosystems and biodiversity can affect people's ability to produce food, leading to malnutrition and food scarcity. Changes to the climate can affect livelihood and economic security, leading to impacts on health and well-being. People and societies are making choices which degrade ecosystems, which then increases their vulnerability to climate change. Extreme heat, other extreme events, rise in temperature average, decrease in food security, ecosystem degradation, and other factors can lead to widespread climate-induced migration, which stresses societies and leads to political instability, further endangering individuals and society.

Ecosystem Degradation and Biodiversity Loss

Damage to ecosystems and biodiversity loss has already occurred due to climate change, and are key risks for every region (IPCC 2022, B.4.1)

> 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 climate change impacts are larger than estimated in previous assessments (high confidence). 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). 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). 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).[41]

Existing impacts are already substantial, and many ecosystems are at high or very high risk of further biodiversity loss, due to near-term warming and increased frequency, severity, and duration of extreme events. (IPCC 2022, B.3.1). Every increment of global warming will accelerate these risks (IPCC 2022, B.4.1). Loss of ecosystems has cascading effects on people globally, especially Indigenous Peoples and local communities who are directly dependent on the ecosystem to meet basic needs. (IPCC 2022, B.2.1).

[41] IPCC 2022, B.1.2.

Oceans and wetlands

Oceans absorb both heat and carbon, leading to profound changes in the ability of the oceans and wetlands to support animal and human life. Acidification, warmer temperatures, rise in sea level, and changes in salinity are among the effects, causing degradation of coral reefs, species range shifts, timing changes that are disruptive, loss of coastal land, and coastal flooding. [source-EPA I think]

Ocean surface heat has risen over 15 joules since 1990 (EPA 2022(a)). To put that in context, 1 joule is equal to 17 times the total amount of energy used by all the people on Earth for one year (EPA n.d.(a)). Sea level rise is resulting from the rise in ocean temperature, both through melting of ice and the expanded volume of warmer water (EPA 2022(a)). Higher temperatures are also causing greater frequency and intensity of tropical storms, leading to changes in ocean currents, which disrupts and damages ecosystems (EPA 2022(a)).

The absorption of carbon dioxide by the oceans has increased ocean acidity, interfering with some marine animals' ability to build their shells and skeletons; this affects ocean ecosystems, fish populations and the people who depend on them (EPA 2022(b)). Coral reef ecosystems are especially at risk from this acidification, and they are also impacted by warming, sea level rise, and changes in storm patterns and ocean currents, all of which are caused by climate change (NOAA 2021).

The rise of sea level is already affecting coastal ecosystems and communities, destroying wetlands, contributing to coastal flooding, eroding shorelines, forcing salt-water into estuaries and groundwater, and damaging infrastructure (EPA 2022(c)). A 2019 study shows that by 2050, if we do not mitigate global warming, the sea will permanently cover land currently occupied by 150 million people, with an additional 300 million people living on land that will flood annually: this impact would affect thousands of square miles of land in the U.S. alone (Kulp and Strauss 2019). On the U.S. Atlantic coast, 10 million people live in a coastal floodplain, at risk from increasing storms and by continued sea level rise (EPA 2022(d)).

As coastal wetlands are swallowed by rising sea level, coastal areas will become even more vulnerable to storms: healthy wetlands are a crucial buffer from storm and wave damage (EPA 2022(d)). Entire ecosystems contained in these wetlands are also at risk (EPA 2022(d)). About 35% of the world's wetlands were lost between 1970 and 2015, and the loss is accelerating since 2000 (United Nations 2018).

Food and water security

Millions of people have already been exposed to food insecurity and reduced water security due to climate change (IPCC 2022, B.1.3). Water demand has increased 1% per year since 1980, while climate change will dramatically reduce water supplies (Institute for Economics and Peace 2020, 76). More than 2 billion people live in countries with high water stress, and about 4 billion experience severe water scarcity for at least one month out of the year (Institute for Economics and Peace 2020, 4). Water scarcity affects food security: it reduces agricultural food production, which is also impacted by extreme weather and climate events such as floods. Food production from the ocean has been impacted by ocean acidification and ocean warming (IPCC 2022, B.1.3). Disruptions to agricultural and oceanic food production affect local food security and livelihoods and also impact the global food supply. If we fail to keep warming under 1.5 degrees Celsius, food security risks will worsen, due to increases in frequency, intensity and severity of droughts, floods and heat waves, and continued sea level rise (IPCC 2022, B.4.3).

Extreme and slow-onset events caused by climate change

Climate and weather extremes such as extreme heat, heavy precipitation, drought, and fire weather are occurring with greater intensity and frequency and are attributed to human-induced climate change (IPCC 2022). Vulnerable areas in parts of Africa, South Asia, Central and South America, Small Island Developing States, and the Arctic are hit hardest: between 2010 and 2020, extreme events killed 15 times more people in vulnerable areas than in other parts of the world (IPCC 2022, B.2.4). Weather and climate extremes are causing economic and societal impacts globally through supply chains, markets, and natural resource flow (IPCC 2022, B.5.3).

Slow-onset impacts attributed to climate change include increasing temperature means, desertification, regional decrease in precipitation, loss of biodiversity, land and forest degradation, glacial retreat, sea level rise and salination, and ocean acidification (IPCC 2022, B.1.1). Accelerating sea level rise will lead to submergence and loss of coastal communities (IPCC 2022, B.3.1): a billion people are expected to be at risk from coastal climate hazards in the next few decades (IPCC 2022, D.3.3).

Climate migration and political instability

Impacts of climate change lead to greater rates of migration. As coastal and marine ecosystems experience biodiversity loss and as oceanic and agricultural food production is affected due to heat and lack of water, people migrate (The White House 2021). Exposure to danger from extreme heat also forces migration as does gradual mean temperature rise. Extreme weather events such as tropical storms and both coastal and inland flooding lead to sudden, forced migration. Currently, an average of 30 million people annually migrate due to extreme weather events and conflicts, the two largest causes of forced migration (The White House 2021, 7).

Climate change impacts are a destabilizing force in themselves to vulnerable countries (White House 2021), and this instability can be compounded by conflict, resource scarcity, and migration. Conflict is often correlated with or caused by climate change (The White House 2021, p. 7). An estimated 2.26 billion people live in areas with high or very high exposure to climate hazards, of which, 1.24 billion reside in 40 countries with already low levels of peacefulness (Institute of Economics and Peace 2020, 71). Massive climate migrations are highly likely to lead to increased political instability around the globe (The White House 2021). Migration, political instability, and conflict have ramifications for not only health and safety but also for food security world-wide (Mehrabi et al. 2022), as we are currently seeing with the threat of food shortages from the Russian invasion of Ukraine.

III. Colorado-specific impacts of climate change

Colorado's Greenhouse Gas Pollution Reduction Roadmap summarizes the impacts of climate change in Colorado: decreased snowpack and earlier runoff, less water availability, lower water quality, risks of increased flooding, increased drought and drier soil, decreased crop yields, smaller herd size, increased insect, disease and drought impacts on trees and crops, increased risk of wildfires, increased area burned, heat-related health risks, health impacts from ozone, increased risk of asthma and other respiratory diseases, increased risk of vector-borne diseases, wildlife population impacts, and increases in invasive species.

Disproportionately Impacted Communities

As discussed above, the most vulnerable people and systems are disproportionately affected by adverse impacts of climate change. This global pattern of unequal distribution of impacts can also be seen in the U.S., including Colorado. The EPA found that low-income people and people of color are more likely to a) live in areas where they suffer health impacts from air quality associated with climate change (such as asthma onset for children and death from older adults), b) lose labor hours for extreme weather, and c) risk death from extreme temperatures (EPA 2021) all creating an inequitable health and safety impacts for generations..

Heat extremes and air pollution affect cities more severely, with economically and socially marginalized residents experiencing more of these effects (IPCC 2022 B.1.5). For Colorado, with 90% of its people residing in cities, this disproportionate effect also holds true. A 2021 study shows that in

U.S. cities, including in Denver and Colorado Springs, people of color are more likely to be exposed to heat intensity in urban "heat islands" (Hsu et al. 2021) People with lower incomes and people of color are more likely to lack air conditioning (Mann and Schuetz 2022). Vulnerable populations are more likely to be exposed to climate extremes at work, especially in outdoor jobs, and to lack adequate access to health care (Jordan 2022). Historically overburdened by the health impacts of pollution and other systemic injustices, climate change exacerbates existing health conditions for DI communities who have fewer resources to deal with them.

In the aftermath of extreme weather events white counties showed an increase in wealth, while predominantly non-white communities saw a wealth decline (Howell and Elliott 2018). Economic impacts caused by climate change can further these disparities and create worsening health and safety harms to the most overburdened DIC.

Certain geographical areas of Colorado are being impacted more severely by warming with a rate of warming double the national average, at 1.5 to 2.4 average annual warming. Many of these counties are oil and gas producing counties, and this region is in the Colorado River Basin, exacerbating drought conditions (see Appendix XX).

Indigenous People

People have been living in Colorado since time immemorial. At the time of colonization the land we call Colorado was and continues to suffer educational erasures and environmental harms of these communities and their living descendants : the Ute, Arapaho, Cheyenne, Apache, Shoshone, and several tribal nations up to 48 known have relations to these homelands. These people continue to exist and resist despite a century and a half of attempts to dispossess them of their land, lives, and culture which continue to today, and are legitimized by the settler-imposed legal system which evolved to justify and facilitate these dispossessions and over burdens creating continued harms as the original DIC. Colorado has two federally recognized tribes, and an estimated population of 54,000 Indigenous people (Sadler 2020). The Fourth National Climate Assessment finds that Native Americans are at high risk from climate change, often experiencing the worst effects because of higher exposure, higher sensitivity, and lower adaptive capacity for historical, socioeconomic, and ecological reasons (Gonzales et al. 2018). The effects of climate change are compounded by the historical relegation of Indigenous peoples to lands with limited water, and struggles with federal water rights (Gonzales et al. 2018). Further, climate change affects traditional plant and animal species, sacred places, traditional building materials, and other material cultural heritage, which affects the overall health and well-being of

Indigenous peoples, who rely on these vulnerable species and materials for their livelihoods, subsistence, cultural practices, ceremonies, and traditions (Gonzales et al. 2018).

Drought

As of 2014, Colorado had already warmed over 1.1 degrees Celsius (Lukas et al. 2014). The higher temperatures and early spring warmth associated with this change in the climate has caused decreases in snowpack and its water content, all of which exacerbate hydrologic drought (Gonzales et al. 2018), and indeed Colorado and the West are currently experiencing the worst mega-drought in 1200 years (Williams et al. 2022). In the Colorado River Basin, high temperatures have contributed to lower runoff and the record-setting streamflow reductions that occurred between 2000 and 2014 (Gonzales et al. 2018). In 2022, below-average snowpack, above average temperatures, low run-off forecasts, and dry soil and atmosphere continue: "Aridification is a trend that has been observed in the Colorado River Basin over the last 22 years, and the 'mega-drought,' as it has come to be called, is not abating," says Dave Kanzer, Director of Science and Interstate Matters in the Colorado River District (Colorado River District 2022). In 2022, Lake Powell has sunk so low that the capability of the hydropower production of Glen Canyon Dam is threatened (Colorado River District 2022). Hydrologic conditions in the entire River Basin are facing strain, and local reservoirs are not expected to fill (Colorado River District 2022). Higher temperatures will cause more frequent and severe droughts in the Southwest, and lead to drier conditions for the region in the future (Gonzales et al. 2018).

Wildfires

Climate change has caused an increase in wildfire season length, wildfire frequency, and burned area (USGCRP 2018). Between 1984 and 2015, the area in the West burned by wildfires was twice what it would have been without climate change (Gonzales et al. 2018), and the frequency, intensity and acreage of wildfires has increased since then. In Colorado, the 20 largest fires in recorded history all occurred since 2000, with the three largest in 2020, and in 2020 over 650,000 acres burned–the largest amount on record (Office of Governor Polis 2021, 10). Wildfires directly and indirectly impact the health of Coloradans as described in "*Health*" section below. Wildfire has also exacerbated the spread of invasive plant species and damaged habitat (Gonzales et al. 2018). Areas damaged by wildfire are vulnerable to events such as the I-70 mudslide disaster in 2021[42] and the 2013 flood triggered by a

[42] According to Assistant State Climatologist Becky Bolinger, soils in areas that have suffered from wildfires almost repel water, because the fire has changed the soil composition, preventing water from getting into the soil as it normally would. This leads to increased flood danger even with lower amounts of rainfall. (see https://coloradosun.com/2021/07/23/mudslides-along-colorado-burns-scars-could-cause-disasters-all-summer/).

1000-year rainfall event in Northern Colorado, which was exacerbated by hillsides previously burned and weakened by wildfires.

Ecosystems and Biodiversity

Colorado has forest, freshwater, mountain and terrestrial ecosystems, systems which are at risk of biodiversity loss according to the IPCC (IPCC 2022). In addition to the wildfire-related harm to ecosystems described above, climate change leads to biodiversity loss in Colorado ecosystems in many other ways. For instance, as species need to move to higher elevations to escape heat exposure and find food, the food chain is disrupted, and eventually species will run out of habitat (University of Colorado n.d.). Earlier snowmelt exposes wildflowers to more frequent frost kills, leading to a much smaller population of mountain wildflowers that birds, insects and mammals depend on for food and shelter (University of Colorado n.d.). Rising water temperature and the changing chemistry of alpine lakes and streams are making it harder for trout, amphibians, water bugs and aquatic plants to survive, and their decline will destabilize entire ecosystems (University of Colorado n.d.). Climate change has also contributed to increased forest pest infestations. Bark beetle infestations, due in part to winter warming and drought caused by climate change, killed 7% of western U.S. forest area from 1979 to 2012 (Gonzales et al. 2018). Forest ecosystems will continue to be at risk from climate change impacts as "further increases in heat and drought could kill many more trees, especially affecting piñon pine, whitebark pine, and tall old-growth trees. Drought hastens tree mortality over a wide range of temperatures" (Gonzales et al. 2018).

Health

In the United States, direct and indirect impacts of climate change on human health are a public health emergency, according to the American Public Health Association (APHA 2017). Nationwide, extreme weather events such as floods and wildfires directly injure people, and also disrupt the health system, which can worsen pre-existing conditions (American Public Health Association and Complexly 2022). Higher heat averages and heat waves are leading to more heat related illnesses, especially in agricultural workers, who are already 20% more likely to suffer from this issue. Increased allergens are exacerbating chronic respiratory illnesses (APHA 2017). Fleas, ticks and mosquitos multiply, increasing the risk of vector-borne diseases, such as West Nile Virus, and Lyme Disease in Colorado (APHA 2017). Higher temperature and heavy rainfall increase bacteria growing on crops, increasing the risk of food-borne illness (APHA 2017). Temperature changes and major weather events disrupt the food distribution chain, raising prices, with the limited and expensive food leading to greater rates of food insecurity (APHA 2017).

All of the national impacts described above, and general impacts of climate change described in section I affect Coloradans, either directly or indirectly, but considering information specific to Colorado gives a more complete picture. The Colorado Health Institute examines rising temperature, worsening air quality, and extreme weather and how they are already impacting the lives and health of Coloradans (Colorado Health Institute 2022).

Rising heat has serious implications for health in Colorado. The number of extreme heat days, the average state temperature, and the number and severity of heat waves have all increased (CHI 2022). Nine of Colorado's twelve warmest years on record have occurred since 2000 (Office of Governor Polis 2021, 8) Extreme heat can cause heat stress/heat stroke, and exacerbate asthma, kidney disease, cardiovascular disease, respiratory illness, and complications of diabetes. conditions (CHI 2022). As climate change continues and worsens, the Southwest region of the US, including Colorado, is predicted to have the highest increase of risk of heat-associated premature deaths in the country (Gonzales et al. 2018). Western Colorado has already warmed double the national average, with average annual warming from 1.5 to 2.4 degrees Celsius (see Appendix C). It is not only the extreme daytime temperatures that impact health. On the whole, nighttime highs are rising faster than the daytime highs, and this has an even bigger effect on human health, animal health, crop health and plant health (Trent 2022). Warmer water temperatures caused by rising heat are causing more frequent occurrences of large-scale blooms of algae in Colorado's larger water bodies, some of which create toxins dangerous to humans, animals, and the ecosystem (State of Colorado 2018). Rising temperatures in Colorado also impact health by causing drought, worsening air pollution, and changing ecosystems.

The southeast, south-central and western slope regions of Colorado are particularly likely to have dust storms, which are made markedly worse by climate-caused drought (State of Colorado 2018). The increased particulate matter caused by blowing dust presents a health risk, and at high levels can be fatal (State of Colorado 2016). Climate change also impacts other air pollutants such as carbon dioxide and leads to an increase in allergens (Colorado Health Institute 2022). The effect of climate change on ozone is discussed in Appendix A. All Coloradans are at risk from this increased air pollution caused by climate change, but especially DI communities and vulnerable populations including children, people with asthma, people with respiratory illnesses, people with allergies, people with COPD and other cardiovascular diseases, with risks including increased hospitalization and death (Colorado Health Institute 2022).

Wildfires are increasing in Colorado, as discussed above, and are impacting health in many ways. There are the obvious impacts of burning and killing people. They impact water quality, water supply, and increase deadly air pollution (Colorado Health Institute 2022). They cause heart issues, and respiratory problems including lung cancer, chest pain, asthma and COPD and also cause PTSD, impacting mental health (Colorado Health Institute 2022). The number of Coloradans living in wild-land urban interface areas with high risk has more than doubled from 2000-2012 to over 2 million people (Colorado Health Institute 2022). Colorado's wildfires also lead to indirect effects on health. Firefighting foam contains PFAS (U.S. Firefighters Administration 2020), which according to the CDC may lead to lowered immune system, increased cholesterol levels, changes in liver enzymes, increased risk of high blood pressure or pre-eclampsia in pregnant women, decrease in infant birth weight, and increased risk of kidney or testicular cancer (ATSDR 2022). Some fire departments in Colorado have taken advantage of the State's PFAS buyback program, but 159 facilities still use or store PFAS as registered by the State (CDPHE 2022). Wildfires can pollute drinking water, as happened in Fort Collins after a 2012 wildfire, when fire-caused debris including cancer-causing trihalomethane entered the water system (Gonzales et al. 2018).

IV. Fossil fuels' contribution to climate change

Research on the atmospheric warming associated with carbon dioxide and fossil fuels developed for more than a century before the government reports and fossil fuel companies' internal reports, briefings, and speeches in the 1960s, 70s, and 80s concerning the connection between fossil fuels and dangerous global warming (Franta 2021). The warming effect of carbon dioxide was first noticed in 1856 by Eunice Newton Foote: "An atmosphere of [carbon dioxide] would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature…must have necessarily resulted" (Foote 1856). In 1938, Guy Callendar published research pointing to a 0.003 degree Celsius temperature rise per year, associated with the burning of fossil fuels (Callendar 1938). By 1958, American Charles David Keeling had built a sensor for measuring CO2 in the atmosphere, and over the next few decades systematically monitored CO2 levels, proving that CO2 levels were steadily rising (American Chemical Society National Historic Chemical Landmarks n.d.). In the 1970s the Keeling group studied carbon isotopes to determine that the cause of the rising CO2 was the burning of fossil fuels (Id.).

Despite early knowledge and understanding, both by governments and fossil fuel executives, of the likely danger of global warming to both human society and the environment, the production and burning of fossil fuels continued unabated, and indeed increased. After a 1980 briefing at the American Petroleum Institute's (API) "CO2 and Climate Change" task force, in which Stanford scientist John Lauerman told the API that continuing to burn fossil fuels would have "globally catastrophic effects" by 2060, the API called on governments to triple coal production worldwide and insisted there would be no negative effects (Franta 2021). 34.81 billion metric tons of carbon dioxide have been emitted into the atmosphere from 1750 to 2020, most of them since 1970 (Tiseo 2022), resulting in a 48% increase of carbon dioxide levels in the atmosphere since the industrial revolution began in 1750, with methane levels doubling during the same time period (EPA 2022(f)). Carbon levels have risen from 310 ppb in 1958, when Keeling began monitoring, to 414 ppb in 2021, higher levels than any time in the past 800,000 years (Id.). The increase of carbon levels in the atmosphere is accelerating. The National Oceanic and Atmospheric Administration reports that the CO2 level in 2021 was 414.7, an increase of 2.66 over 2020, marking the 10th straight year that annual levels increased more than 2 ppb–the fastest sustained rate of increase since monitoring began 63 years ago (NOAA 2022).

"Fossil fuels – coal, oil and gas – are by far the largest contributor to global climate change, accounting for over 75 percent of global greenhouse gas emissions and nearly 90 percent of all carbon dioxide emissions" (United Nations n.d.). Between 1980 and 2000 about 75% of the human caused emissions of CO_2 were from burning fossil fuels (IPCC 2001). In the US in 2019, fossil fuels contributed 94% of total US carbon dioxide emissions, and 80% of total U.S. greenhouse gas emissions from human activity. "Burning fossil fuels changes the climate more than any other human activity" (EPA 2022(e)).

It is not only the burning of fossil fuels but also their release into the atmosphere during pre-production, extraction, transmission, and refining that contributes to greenhouse gas emissions. Methane, with a global warming potential 84 times greater than CO_2, has increasingly been to blame for greenhouse gas emissions increases. 2020 and 2021 mark a record rise in annual methane levels, with increases of 15.3 ppb in 2020 and 17 ppb in 2021 (NOAA 2022). The main global sources of anthropogenic methane are agriculture and fossil fuel production, especially fracking (Id.). The primary method of oil and gas extraction in Colorado, fracking is a major contributor to the rise of global methane emissions, especially in the U.S: fracking in the U.S. has contributed about one-third of the total increased emissions from *all sources globally* between 2008 and 2018 (Howarth 2019). Colorado, as the 5th highest producer of oil and the 7th highest producer of gas in the U.S. bears a large part of that responsibility.

V. Greenhouse gas emissions from oil and gas operations in Colorado

According to the 2021 Colorado Greenhouse Gas Inventory Report ("Inventory"), in 2019 "Natural Gas and Oil Systems" were the 4th highest emitting sector in Colorado at 20.260 MMT CO_2e, producing about 16% of Colorado's greenhouse gas emissions (Taylor 2021). This percentage likely underestimates the true responsibility of Colorado's Oil and Gas emissions for warming, considering that the emissions from "Natural Gas and Oil Systems" were essentially 100% methane, and the Inventory uses the outdated GWP factor of 25 for methane instead of the more accurate factor of 84 used in the IPCC 5th Assessment report (Taylor 2021, 8). Using the more accurate GWP factor would show more accurately the CO_2 equivalent emissions from oil and natural gas in Colorado, resulting in a far larger share of statewide emissions.

Although Colorado law does not yet require out-of-state combustion of Colorado-produced oil and gas to be counted as 'statewide' emissions, it is important to consider the responsibility of the oil and gas sector in this context. Most of the emissions from combustion of Colorado's oil and gas takes place outside Colorado[43], thus are currently not counted as in-state emissions. Combustion of the oil produced in 2019 in Colorado and exported was estimated to create 37.8 MMT CO_2e, and combustion of the gas produced in 2019 in Colorado and exported was estimated to create 71.74 MMT CO_2e, for a total of 109.54 MMT CO_2e.[44] Combined with the 20.260 MMT CO_2e from in-state oil and gas operations, oil and gas operations were responsible, directly and indirectly, for at least 129.8 MMT CO_2e of greenhouse gas emissions in 2019, whereas all other in-state sources combined equal only 105.914 MMT CO_2e (Taylor 2021, 5).

Conclusion

Oil and gas operations in Colorado are one of the largest contributors of in-state greenhouse gas emissions. Climate change, which is a known cumulative effect of greenhouse gas emissions, is already causing impacts to public health, safety, welfare and the environment world-wide, and also in Colorado. Global emissions of carbon dioxide, methane, and other greenhouse gases continue to rise,

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[43] 66% of Colorado's gas is exported, according to the EIA data chart "Natural Gas Annual Supply and Disposition by State," available at https://www.eia.gov/dnav/ng/ng_sum_snd_dcu_sCO_a.htm, and "most" of Colorado's oil is exported. https://www.greeleytribune.com/2017/08/13/the-long-and-winding-road-weld-countys-oil-travels-the-distance-to-local-worldwide-markets/ 90% is the figure used for calculations in this Appendix. it was the original figure contained in the Greeley Tribune article of 2017, cited in blogs and whitepapers by Jeremy Nichols and Micah Parkin at the time. This article was revised in 2020 to say "most." Colorado currently produces a monthly average of 13,098,000 bbl of oil, according to EIA "crude oil production" available at https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_m.htm. This equates to 911. 64 trillion annual btu, whereas Colorado's annual petroleum consumption is 459 trillion btu, according to EIA's Total End-Use Energy Consumption Estimates, 2020, available at https://www.eia.gov/state/seds/sep_sum/html/pdf/sum_use_tx.pdf, meaning Colorado exported roughly half of the petroleum it produced in 2020.

[44] The *2021 Greenhouse Gas Emissions Inventory Update*, on p. 75, cites emissions of 75.6 MMT CO_2e through fuel combustion of oil and 108.7 MMT CO_2e for combustion of gas. Multiplying by a conservative factor of 50% for oil and 66% for gas shows combusted emissions of exported oil is 37.8 MMTCO_2e and combusted emissions of exported gas is 71.74 MMT CO_2e. https://drive.google.com/file/d/1SFtUongwCdZvZEEKC_VEorHky267x_np/view

making it increasingly likely that the world will reach catastrophic levels of warming, and intensifying the urgent need to act. Without mitigation leading to an immediate decrease in emissions, the climate crisis will continue to worsen, multiplying the risks to people and the environment.

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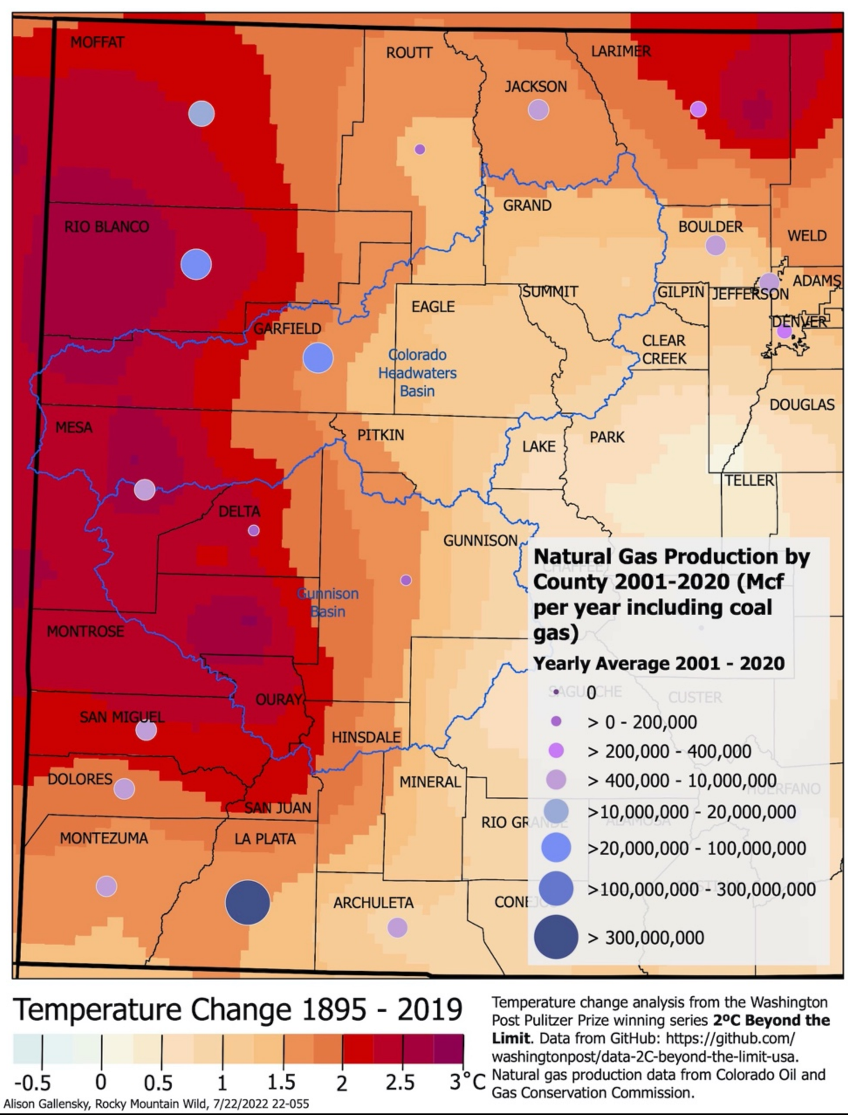
Appendix C: Colorado Local Warming

The ecological, economic, and public health impacts of climate are already being felt in Colorado, often to a disproportionate degree. Western Colorado has been disproportionately impacted by climate change and is the nation's climate hotspot, having warmed more than 2 degrees Celsius (nearly 4 degrees Fahrenheit), double the global average. See Map 1 below. Rio Blanco County has warmed the most at 2.4°C, along with Montrose County. [1] The Western Slope has seen some of the most extreme warming in State and the country, and is the source of the majority of the State's water, with 60% of the Front Range's water coming from headwaters located on the Western Slope.

Map 1: Western Colorado Temperature Change



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[1] Eilperin, Juliet, "2°C Beyond the Limit: This giant climate hot spot is robbing the West of its water," The Washington Post, August 7, 2020 available at: https://www.washingtonpost.com/graphics/2020/national/climate-environment/climate-change-colorado-utah-hot-spot/

Greenhouse gas emissions are directly related to Colorado's increasing temperatures.[2] Seventy-six percent of oil and gas producing counties in Colorado (19 of 24 counties) have warmed 1.5°C or more. See Table 1 below. Half of the oil and gas producing counties in western Colorado have warmed more than 2°C, and the remaining half has already warmed more than 1.5°C.[3] Four of the eight counties that make up the Colorado River Basin have warmed more than 1.5°C The Colorado River Basin is a climate hotspot in the Western United States, having warmed an average of 2.1 degrees Celsius, faster than the global average, resulting in extreme drought, threatening water supplies for seven states and Mexico. The viability of Lake Mead and Lake Powell, which provide the water necessary to power the Glen Canyon and Hoover hydroelectric dams all depend on the Colorado River. For every degree of Celsius warming, the Colorado River declines nearly 10%.[4] The Colorado River has lost 32 million acre feet—a 19 percent decline-- in the last 22 years, as a result of climate change.[5]

Table 1: Colorado Counties That Have Warmed 1.5°C (2.7°F) or More Over 125-year period, 1895-2019

Annual Warming (Celsius)	Annual Warming (Fahrenheit)	County
1.5	**2.7**	**Kit Carson County**
1.5	**2.7**	**Gunnison County**
1.6	**2.9**	**Routt County**
1.6	**2.9**	**La Plata County**
1.6	**2.9**	**Logan County**
1.6	**2.9**	**Adams County**
1.6	**2.9**	**Montezuma County**
1.6	**2.9**	**Jackson County**
1.7	3.1	Hinsdale County
1.7	**3.1**	**Yuma County**
1.8	**3.2**	**Washington County**
1.9	**3.4**	**Weld County**
1.9	**3.4**	**Dolores County**
2	**3.6**	**Garfield County**
2	**3.6**	**Larimer County**

[2] NOAA National Centers for Environmental Information | State Climate Summaries 2022, available at: HTTPS://STATESUMMARIES.NCICS.ORG/CHAPTER/CO/

[3] *Colorado Warming and Gas Production Map* available at: tinyurl.com/COWarming

[4] Udall, B. and J. Overpeck. The twenty-first century Colorado River hot drought and implications for the future, *Water Resour. Res.*, 53, 2404– 2418, (2017). https://doi.org/10.1002/2016WR019638

[5] Brad Udall presentation, October 1, 2021 at the Colorado River District 2021 Annual Seminar. https://www.coloradoriverdistrict.org/2021-seminar/

2	3.6	San Juan County
2.1	**3.8**	**Delta County**
2.1	**3.8**	**Morgan County**
2.1	**3.8**	**Moffat County**
2.2	3.8	San Miguel County
2.3	4.1	Ouray County
2.3	**4.1**	**Mesa County**
2.4	**4.3**	**Rio Blanco County**
2.4	4.3	Montrose County
Red text indicates oil and gas producing counties 19 of 24 counties (79%) that have warmed 1.5 C or more are oil and gas producing counties *Source 2°C: Beyond the Limit, Washington Post Pulitzer Prize winning series, which analyzed warming between 1895 and 2019. Data available at: https://github.com/washingtonpost/data-2C-beyond-the-limit-usa*		

The Gunnison River Basin, which is the largest tributary to the Colorado River has warmed an average of 2.1°C. Six of the seven counties that make up the Gunnison River Basin have warmed over 1.6°C. With the region's snowpack shrinking and melting earlier, the ground absorbs more heat. In addition, early snowmelt results in more water evaporation and less water availability for agriculture and wildlife later in the season. The impacts of these changes are widespread across forests, wildlife, and human communities, threatening the area's resilience in the face of continued warming. These impacts also have significant impact to local economies that are reliant on consistent snowfall, not only for recreational pursuits, but also for agricultural and residential water supplies. Forty million people downstream of the Colorado River's headwaters rely on the River's water. The Draft 2023 Colorado Water Plan clearly and unequivocally states Colorado's dire water situation due to climate change.[6]

A recent peer-reviewed study in the journal Nature Climate Change found that 42% of the 22-year megadrought we are experiencing in the West is attributed to human-caused climate change.[7] Without human-caused climate change, the megadrought *would have ended early* on because 2005 and 2006 would have been wet enough to break it, according to the study's authors[8]. Human-caused climate change is changing the baseline conditions. The current drought is the worst in 1200 years.

Not only are baseline conditions changing, but Western Colorado is warming faster than Colorado's hazard mitigation modeling assumptions. Colorado's Hazard Mitigation Plan modeled the impact of climate change on key hazards including flood, wildfire, drought, heat exhaustion.

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[6] 2023 Draft Colorado Water Plan, available at: https://engagecwcb.org/colorado-water-plan

[7] Williams, A.P., Cook, B.I. & Smerdon, J.E. Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. *Nat. Clim. Chang.* (2022). https://doi.org/10.1038/s41558-022-01290-z

[8] Borenstein, Seth, "West megadrought worsens to driest in at least 1,200 years", AP News, February 14, 2022, available at: https://apnews.com/article/climate-science-west-megadrought-f02449c2db4f0ebeb1557bb39504c62d

Climate change impacts were modelled by location, extent/intensity, frequency, and duration.[9] Colorado's model is based on 30-year warming of 2 degrees Fahrenheit (1.1 degrees Celsius), and 50-year warming of 2.5 degrees Fahrenheit (1.4° Celsius).[10] While, on average the State has warmed 1.4°C over a 125-year period, the Western Slope has warmed disproportionately, as mentioned above.[11] Colorado has developed the Future Avoided Cost Explorer: Colorado Hazards, which is an interactive model of projected economic damage by sector due to climate change. The climate scenarios, are current (1.4°C), average state warming of 2.1°C (Moderate) and 2.3°C (More Severe). Hazards modeled are drought, wildfire and flood, and sectors include agriculture, infrastructure, recreation. The model time period is 2050, and estimated annual damage costs for counties that have warmed 1.5°C or more are between $228.6 million and $555.1 million. See Table 2 below.

Today, in 2022, Western Slope warming has dangerously exceeded the State's moderate, and more severe climate models, to the point that the cost estimates, let alone the human toll, are now likely severely under-estimated. Eleven of the top 20 largest wildfires in Colorado have occurred in the last 7 years (since 2016).[12] Over the last decade, Colorado has experienced billions of dollars in damages due to wildfire, flood and drought.[13] Between 2012 and 2022, Colorado was affected by a number of billion-dollar disaster events totaling $18.6 billion.[14] See Figure 1.

Local warming has already surpassed the modeling assumptions behind the mitigation plans, and the mitigation plans do not include climate change prevention. Cumulative emissions from oil and gas operations, especially in areas that have already exceeded warming thresholds would further stress Colorado's resources and ability to respond to climate change impacts.

In addition, to water and hazard mitigation connections, higher temperatures brought on by climate change accelerate the formation of ground-level ozone in the Denver Metro area. Ground-level ozone is a public health issue linked to a number of acute health effects, including eye and nose irritation, exacerbations of chronic respiratory diseases like asthma and chronic obstructive pulmonary disease (COPD), and adverse effects on lung function.[15] In addition, both short- and long- term exposures to ozone at concentrations below the current regulatory standards are associated with increased deaths from both respiratory and cardiovascular disease. Recognizing the influence of temperature for catalyzing chemical reactions, some researchers have found a climate penalty factor ranging between 1 and 3 ppb ozone per degree Celsius change. [16] High heat is also a

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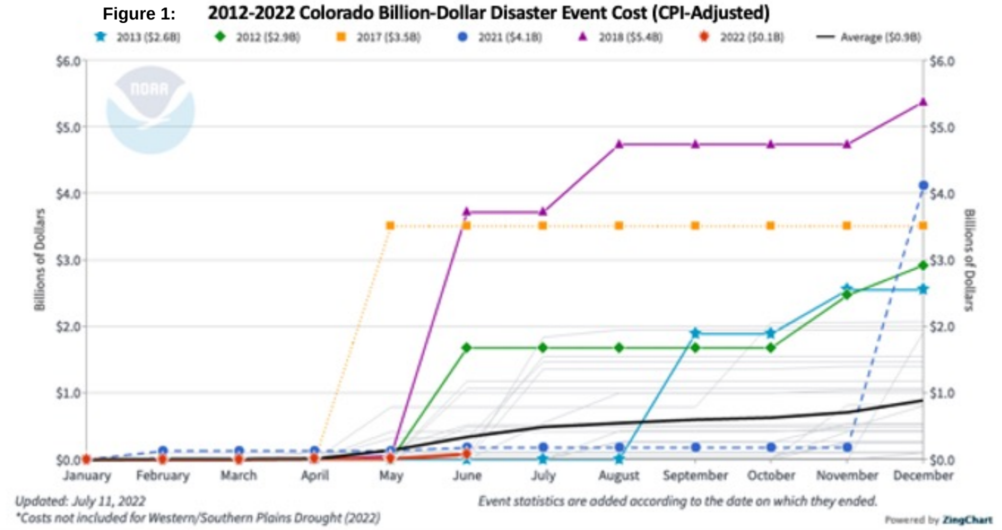
[9] 2018-2023 Colorado Hazard Mitigation Plan, at 160.
[10] Id. at 48
[11] *2°C: Beyond the Limit*
[12] https://dfpc.colorado.gov/wildfire-information-center/historical-wildfire-information
[13] Hazards, Colorado Water Conservation Board, *available at: https://cwcb.colorado.gov/focus-areas/hazards accessed July 22, 2022.* Roberts, Michael, *Marshall Fire Update by the Awful Numbers,* Westword, January 7, 2022, https://www.westword.com/news/marshall-fire-damage-and-cost-boulder-update-13177208
[14] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73
[15] James L. Crooks, Rachel Licker, Adrienne L. Hollis and Brenda Ekwurzel, *The ozone climate penalty, NAAQS attainment, and health equity along the Colorado Front Range,* Journal of Exposure Science & Environmental Epidemiology (2022) 32:545–553; https://doi.org/10.1038/s41370-021-00375-9
[16] Id.

threat-multiplier, that puts other coexisting medical conditions in crisis, including cardiovascular, respiratory, and diabetes disease.[17]

Figure 1: 2012-2022 Colorado Billion-Dollar Disaster Event Cost (CPI-Adjusted)



Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73

[17] Ingold, John, *Officially, heat deaths are not very common in Colorado. The reality is more complicated,* The Colorado Sun, August 1, 2022, available at: https://coloradosun.com/2022/08/01/colorado-heat-deaths-climate-change/

Table 2: Colorado Future Avoided Cost Estimate*				
Hazards: Drought, Flood, Wildfire	**Temperature Scenario**			**Actual warming in Celsius (1895-2019)**
	Current (1.4° C)	**Moderate (2.1° C) in 2050**	**More Severe (2.3°C) in 2050**	
Adams County	$ 25,000,000	$ 27,000,000	$ 48,000,000	**1.5**
Delta County	$ 2,900,000	$ 6,000,000	$ 10,000,000	**1.5**
Dolores County	$ 1,100,000	$ 1,900,000	$ 1,900,000	**1.6**
Garfield County	$ 17,000,000	$ 42,000,000	$ 53,000,000	**1.6**
Gunnison County	$ 5,500,000	$ 16,000,000	$ 22,000,000	**1.6**
Hinsdale County	$ 350,000	$ 420,000	$ 1,300,000	**1.6**
Jackson County	$ 1,100,000	$ 1,600,000	$ 3,400,000	**1.6**
Kit Carson County	$ 12,000,000	$ 22,000,000	$ 24,000,000	**1.6**
La Plata County	$ 19,000,000	$ 40,000,000	$ 61,000,000	**1.7**
Larimer County	$ 22,000,000	$ 30,000,000	$ 45,000,000	**1.7**
Logan County	$ 11,000,000	$ 17,000,000	$ 20,000,000	**1.8**
Mesa County	$ 19,000,000	$ 39,000,000	$ 43,000,000	**1.9**
Moffat County	$ 4,200,000	$ 5,800,000	$ 8,400,000	**1.9**
Montezuma County	$ 8,300,000	$ 13,000,000	$ 15,000,000	**2**
Montrose County	$ 5,200,000	$ 12,000,000	$ 14,000,000	**2**
Morgan County	$ 12,000,000	$ 19,000,000	$ 26,000,000	**2**
Ouray County	$ 1,100,000	$ 2,300,000	$ 4,000,000	**2.1**
Rio Blanco County	$ 4,400,000	$ 7,200,000	$ 8,700,000	**2.1**
Routt County	$ 6,600,000	$ 16,000,000	$ 19,000,000	**2.1**
San Juan County	$ 150,000	$ 320,000	$ 1,400,000	**2.2**
San Miguel County	$ 3,700,000	$ 13,000,000	$ 13,000,000	**2.3**
Washington County	$ 10,000,000	$ 12,000,000	$ 16,000,000	**2.3**
Weld County	$ 27,000,000	$ 36,000,000	$ 52,000,000	**2.4**
Yuma County	$ 10,000,000	$ 32,000,000	$ 45,000,000	**2.4**
	$ 228,600,000	**$ 411,540,000**	**$ 555,100,000**	
Red text indicates oil and gas producing counties				
* Cost estimate is expected annual damage based on equal distribution of damage per year over time and in 1995 dollars.				
Source: Future Avoided Cost Explorer: Colorado Hazards, available at: https://storymaps.arcgis.com/stories/4e653ffb2b654ebe95848c9ba8ff316e				

Appendix D

Summary for Policymakers

SPM

Summary for Policymakers

Drafting Authors: Hans-O. Pörtner (Germany), Debra C. Roberts (South Africa), Helen Adams (UK), Carolina Adler (Switzerland/Chile/Australia), Paulina Aldunce (Chile), Elham Ali (Egypt), Rawshan Ara Begum (Malaysia/Australia/Bangladesh), Richard Betts (UK), Rachel Bezner Kerr (Canada/USA), Robbert Biesbroek (The Netherlands), Joern Birkmann (Germany), Kathryn Bowen (Australia), Edwin Castellanos (Guatemala), Guéladio Cissé (Mauritania/Switzerland/France), Andrew Constable (Australia), Wolfgang Cramer (France), David Dodman (Jamaica/UK), Siri H. Eriksen (Norway), Andreas Fischlin (Switzerland), Matthias Garschagen (Germany), Bruce Glavovic (New Zealand/South Africa), Elisabeth Gilmore (USA/Canada), Marjolijn Haasnoot (The Netherlands), Sherilee Harper (Canada), Toshihiro Hasegawa (Japan), Bronwyn Hayward (New Zealand), Yukiko Hirabayashi (Japan), Mark Howden (Australia), Kanungwe Kalaba (Zambia), Wolfgang Kiessling (Germany), Rodel Lasco (Philippines), Judy Lawrence (New Zealand), Maria Fernanda Lemos (Brazil), Robert Lempert (USA), Debora Ley (Mexico/Guatemala), Tabea Lissner (Germany), Salvador Lluch-Cota (Mexico), Sina Loeschke (Germany), Simone Lucatello (Mexico), Yong Luo (China), Brendan Mackey (Australia), Shobha Maharaj (Germany/Trinidad and Tobago), Carlos Mendez (Venezuela), Katja Mintenbeck (Germany), Vincent Möller (Germany), Mariana Moncassim Vale (Brazil), Mike D Morecroft (UK), Aditi Mukherji (India), Michelle Mycoo (Trinidad and Tobago), Tero Mustonen (Finland), Johanna Nalau (Australia/Finland), Andrew Okem (SouthAfrica/Nigeria), Jean Pierre Ometto (Brazil), Camille Parmesan (France/USA/UK), Mark Pelling (UK), Patricia Pinho (Brazil), Elvira Poloczanska (UK/Australia), Marie-Fanny Racault (UK/France), Diana Reckien (The Netherlands/Germany), Joy Pereira (Malaysia), Aromar Revi (India), Steven Rose (USA), Roberto Sanchez-Rodriguez (Mexico), E. Lisa F. Schipper (Sweden/UK), Daniela Schmidt (UK/Germany), David Schoeman (Australia), Rajib Shaw (Japan), Chandni Singh (India), William Solecki (USA), Lindsay Stringer (UK), Adelle Thomas (Bahamas), Edmond Totin (Benin), Christopher Trisos (South Africa), Maarten van Aalst (The Netherlands), David Viner (UK), Morgan Wairiu (Solomon Islands), Rachel Warren (UK), Pius Yanda (Tanzania), Zelina Zaiton Ibrahim (Malaysia)

Drafting Contributing Authors: Rita Adrian (Germany), Marlies Craig (South Africa), Frode Degvold (Norway), Kristie L. Ebi (USA), Katja Frieler (Germany), Ali Jamshed (Germany/Pakistan), Joanna McMillan (German/Australia), Reinhard Mechler (Austria), Mark New (South Africa), Nicholas P. Simpson (South Africa/Zimbabwe), Nicola Stevens (South Africa)

Visual Conception and Information Design: Andrés Alegría (Germany/Honduras), Stefanie Langsdorf (Germany)

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Table of Contents

A: Introduction 5

Box SPM.1 | AR6 Common Climate Dimensions, Global Warming Levels and Reference Periods 7

B: Observed and Projected Impacts and Risks 8

Observed Impacts from Climate Change 9
Vulnerability and Exposure of Ecosystems and People 12
Risks in the near term (2021–2040) 13
Mid to Long-term Risks (2041–2100) 14
Complex, Compound and Cascading Risks 18
Impacts of Temporary Overshoot 19

C: Adaptation Measures and Enabling Conditions 20

Current Adaptation and its Benefits 20
Future Adaptation Options and their Feasibility 21
Limits to Adaptation 26
Avoiding Maladaptation 27
Enabling Conditions 27

D: Climate Resilient Development 28

Conditions for Climate Resilient Development 29
Enabling Climate Resilient Development 29
Climate Resilient Development for Natural and Human Systems 31
Achieving Climate Resilient Development 33

A: Introduction

This Summary for Policymakers (SPM) presents key findings of the Working Group II (WGII) contribution to the Sixth Assessment Report (AR6) of the IPCC[1]. The report builds on the WGII contribution to the Fifth Assessment Report (AR5) of the IPCC, three Special Reports[2], and the Working Group I (WGI) contribution to the AR6 cycle.

This report recognizes the interdependence of climate, ecosystems and biodiversity[3], and human societies (Figure SPM.1) and integrates knowledge more strongly across the natural, ecological, social and economic sciences than earlier IPCC assessments. The assessment of climate change impacts and risks as well as 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 pandemic.

The scientific evidence for each key finding is found in the 18 chapters of the underlying report and in the 7 cross-chapter papers as well as the integrated synthesis presented in the Technical Summary (hereafter TS) and referred to in curly brackets {}. Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence using the IPCC calibrated language[4]. The WGII Global to Regional Atlas (Annex I) facilitates exploration of key synthesis findings across the WGII regions.

The concept of risk is central to all three AR6 Working Groups. 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.

Across all three AR6 working groups, **risk**[5] provides a framework for understanding the increasingly severe, interconnected and often irreversible impacts of climate change on ecosystems, biodiversity, and human systems; differing impacts across regions, sectors and communities; and how to best reduce adverse consequences for current and future generations. In the context of climate change, risk can arise from the dynamic interactions among climate-related **hazards**[6] (see Working Group I), the **exposure**[7] and **vulnerability**[8] of affected human and ecological systems. The risk that can be introduced by human responses to climate change is a new aspect considered in the risk concept. This report identifies 127 key risks[9]. {1.3, 16.5}

The vulnerability of exposed human and natural systems is a component of risk, but also, independently, an important focus in the literature. Approaches to analysing and assessing vulnerability have evolved since previous IPCC assessments. Vulnerability is widely understood to differ within communities and across societies, regions and countries, also changing through time.

Adaptation[10] plays a key role in reducing exposure and vulnerability to climate change. Adaptation in ecological systems includes autonomous adjustments through ecological and evolutionary processes. In human systems, adaptation can be anticipatory or reactive, as well as incremental

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1 Decision IPCC/XLVI-3, The assessment covers scientific literature accepted for publication by 1 September 2021.

2 The three Special Reports are: 'Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5)'; 'Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL)'; 'IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)'.

3 Biodiversity: Biodiversity or biological diversity means the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.

4 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Assessed likelihood is typeset in italics, e.g., *very likely*. This is consistent with AR5 and the other AR6 Reports.

5 Risk is defined as the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems.

6 Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. Physical climate conditions that may be associated with hazards are assessed in Working Group I as climatic impact-drivers.

7 Exposure is defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected.

8 Vulnerability in this report 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.

9 Key risks have potentially severe adverse consequences for humans and social-ecological systems resulting from the interaction of climate related hazards with vulnerabilities of societies and systems exposed.

10 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. In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this.

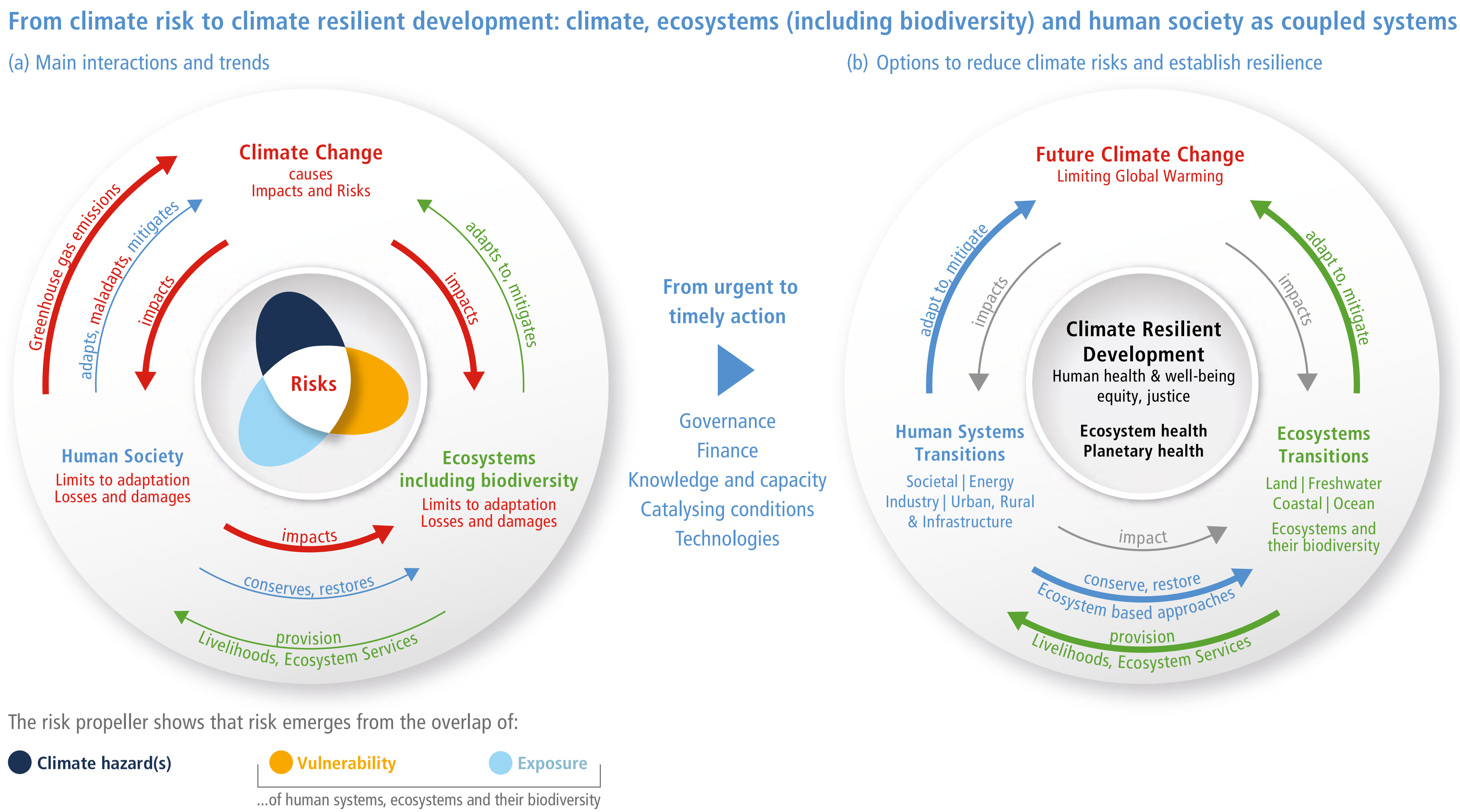

Figure SPM.1 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, offer opportunities for the future.

(a) Human society causes climate change. Climate change, through hazards, exposure and vulnerability generates impacts and risks that can surpass limits to adaptation and result in losses and damages. Human society can adapt to, maladapt and mitigate climate change, ecosystems can adapt and mitigate within limits. Ecosystems and their biodiversity provision livelihoods and ecosystem services. Human society impacts ecosystems and can restore and conserve them.

(b) 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. The recognition of climate risks can strengthen adaptation and mitigation actions and transitions that reduce risks. Taking action is enabled by governance, finance, knowledge and capacity building, technology and catalysing conditions. Transformation entails system transitions strengthening the resilience of ecosystems and society (Section D). In a) arrow colours represent principle human society interactions **(blue)**, ecosystem (including biodiversity) interactions **(green)** and the impacts of climate change and human activities, including losses and damages, under continued climate change **(red)**. In b) arrow colours represent human system interactions **(blue)**, ecosystem (including biodiversity) interactions **(green)** and reduced impacts from climate change and human activities **(grey)**. {1.2, Figure 1.2, Figure TS. 2} and/ or transformational. The latter changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts. Adaptation is subject to hard and soft limits[11].

Resilience[12] in the literature has a wide range of meanings. Adaptation is often organized around resilience as bouncing back and returning to a previous state after a disturbance. More broadly the term describes not just the ability to maintain essential function, identity and structure, but also the capacity for transformation.

This report recognises the value of diverse forms of knowledge such as scientific, as well as Indigenous knowledge and local knowledge in understanding and evaluating climate adaptation processes and actions to reduce risks from human-induced climate change. AR6 highlights adaptation solutions which are effective, feasible[13], and conform to principles of justice[14]. The term climate justice, while used in different ways in different contexts by different communities, generally includes three principles: *distributive justice* which refers to the allocation of burdens and benefits among individuals, nations and generations; *procedural justice* which refers to who decides and participates in decision-making; and *recognition* which entails basic respect and robust engagement with and fair consideration of diverse cultures and perspectives.

Effectiveness refers to the extent to which an action reduces vulnerability and climate-related risk, increases resilience, and avoids maladaptation[15].

This report has a particular focus on transformation[16] and system transitions in energy; land, ocean, coastal and freshwater ecosystems; urban, rural and infrastructure; and industry and society. These transitions make possible the adaptation required for high levels of human health and well-being, economic and social resilience, ecosystem health[17], and planetary health[18] (Figure SPM.1). These system transitions are also important for achieving the low global warming levels (Working Group III) that would avoid many limits to adaptation[11]. The report also assesses economic and non-economic losses and damages[19]. This report labels the process of implementing mitigation and adaptation together in support of sustainable development for all as climate resilient development[20].

Box SPM.1 | AR6 Common Climate Dimensions, Global Warming Levels and Reference Periods

Assessments of climate risks consider possible future climate change, societal development and responses. This report assesses literature including that based on climate model simulations that are part of the fifth and sixth Coupled Model Intercomparison Project Phase (CMIP5, CMIP6) of the World Climate Research Programme. Future projections are driven by emissions and/or concentrations from illustrative Representative Concentration Pathways (RCPs)[21] and Shared Socioeconomic Pathways (SSPs)[22] scenarios, respectively[23]. Climate impacts literature is based primarily on climate projections assessed in AR5 or earlier, or assumed global warming levels, though some recent impacts literature uses newer projections based on the CMIP6 exercise. Given differences in the impacts literature regarding

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11 Adaptation limits: The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions.
Hard adaptation limit—No adaptive actions are possible to avoid intolerable risks.
Soft adaptation limit—Options may exist but are currently not available to avoid intolerable risks through adaptive action.

12 Resilience in this report 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.

13 Feasibility refers to the potential for an adaptation option to be implemented.

14 Justice is concerned with setting out the moral or legal principles of fairness and equity in the way people are treated, often based on the ethics and values of society. *Social justice* comprises just or fair relations within society that seek to address the distribution of wealth, access to resources, opportunity and support according to principles of justice and fairness. *Climate justice* comprises justice that links development and human rights to achieve a rights-based approach to addressing climate change.

15 Maladaptation 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.

16 Transformation refers to a change in the fundamental attributes of natural and human systems.

17 Ecosystem health: a metaphor used to describe the condition of an ecosystem, by analogy with human health. Note that there is no universally accepted benchmark for a healthy ecosystem. Rather, the apparent health status of an ecosystem is judged on the ecosystem's resilience to change, with details depending upon which metrics (such as species richness and abundance) are employed in judging it and which societal aspirations are driving the assessment.

18 Planetary health: a concept based on the understanding that human health and human civilisation depend on ecosystem health and the wise stewardship of ecosystems.

19 In this report, the term 'losses and damages' refers to adverse observed impacts and/or projected risks and can be economic and/or non-economic.

20 In the WGII report, climate resilient development refers to the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development for all.

21 RCP-based scenarios are referred to as RCPy, where 'y' refers to the level of radiative forcing (in watts per square meter, or W m^{-2}) resulting from the scenario in the year 2100.

22 SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socioeconomic Pathway describing the socioeconomic trends underlying the scenarios, and 'y' refers to the level of radiative forcing (in watts per square meter, or W m^{-2}) resulting from the scenario in the year 2100.

23 IPCC is neutral with regard to the assumptions underlying the SSPs, which do not cover all possible scenarios. Alternative scenarios may be considered or developed.

Box SPM.1 (continued)

socioeconomic details and assumptions, WGII chapters contextualize impacts with respect to exposure, vulnerability and adaptation as appropriate for their literature, this includes assessments regarding sustainable development and climate resilient development. There are many emissions and socioeconomic pathways that are consistent with a given global warming outcome. These represent a broad range of possibilities as available in the literature assessed that affect future climate change exposure and vulnerability. Where available, WGII also assesses literature that is based on an integrative SSP-RCP framework where climate projections obtained under the RCP scenarios are analysed against the backdrop of various illustrative SSPs[22]. The WGII assessment combines multiple lines of evidence including impacts modelling driven by climate projections, observations, and process understanding. {1.2, 16.5, 18.2, CCB CLIMATE, WGI AR6 SPM.C, WGI AR6 Box SPM.1, WGI AR6 1.6, WGI AR6 12, AR5 WGI}

A common set of reference years and time periods are adopted for assessing climate change and its impacts and risks: the reference period 1850–1900 approximates pre-industrial global surface temperature, and three future reference periods cover the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2100). {CCB CLIMATE}

Common levels of global warming relative to 1850–1900 are used to contextualize and facilitate analysis, synthesis and communication of assessed past, present and future climate change impacts and risks considering multiple lines of evidence. Robust geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached. {16.5, CCB CLIMATE, WGI AR6 Box SPM.1, WGI AR6 4.2, WGI AR6 CCB11.1}

WGI assessed the increase in global surface temperature is 1.09 [0.95 to 1.20][24] °C in 2011–2020 above 1850–1900. The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22] °C).[25] Considering all five illustrative scenarios assessed by WGI, there is at least a greater than 50% likelihood that global warming will reach or exceed 1.5°C in the near-term, even for the very low greenhouse gas emissions scenario[26]. { WGI AR6 SPM A1.2, WGI AR6 SPM B1.3, WGI AR6 Table SPM.1, WGI AR6 CCB 2.3}

B: Observed and Projected Impacts and Risks

Since AR5, the knowledge base on observed and projected impacts and risks generated by climate hazards, exposure and vulnerability has increased with impacts attributed to climate change and key risks identified across the report. Impacts and risks are expressed in terms of their damages, harms, economic, and non-economic losses. Risks from observed vulnerabilities and responses to climate change are highlighted. Risks are projected for the near-term (2021–2040), the mid (2041–2060) and long term (2081–2100), at different global warming levels and for pathways that overshoot 1.5°C global warming level for multiple decades[27]. Complex risks result from multiple climate hazards occurring concurrently, and from multiple risks interacting, compounding overall risk and resulting in risks transmitting through interconnected systems and across regions.

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24 In the WGI report, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

25 Since AR5, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5.

26 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 (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the five illustrative scenarios, in the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high greenhouse gas emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high greenhouse gas emissions scenarios (SSP2-4.5 and SSP3-7.0), *more likely than not* to be exceeded under the low greenhouse gas emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low greenhouse gas emissions scenario (SSP1-1.9). Furthermore, for the very low greenhouse gas emissions scenario (SSP1-1.9), it is *more likely than not* that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.

27 Overshoot: In this report, pathways that first exceed a specified global warming level (usually 1.5°C, by more than 0.1°C), and then return to or below that level again before the end of a specified period of time (e.g., before 2100). Sometimes the magnitude and likelihood of the overshoot is also characterized. The overshoot duration can vary from at least one decade up to several decades.

Observed Impacts from Climate Change

B.1 Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability. Some development and adaptation efforts have reduced vulnerability. Across sectors and regions the most vulnerable people and systems are observed to be disproportionately affected. The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt. (*high confidence*) (Figure SPM.2) {TS B.1, Figure TS.5, 1.3, 2.3, 2.4, 2.6, 3.3, 3.4, 3.5, 4.2, 4.3, 5.2, 5.12, 6.2, 7.2, 8.2, 9.6, 9.8, 9.10, 9.11, 10.4, 11.3, 12.3, 12.4, 13.10, 14.4, 14.5, 15.3, 16.2, CCP1.2, CCP3.2, CCP4.1, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB DISASTER, CCB EXTREMES, CCB ILLNESS, CCB MIGRATE, CCB NATURAL, CCB SLR}

B.1.1 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[28] 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[19], 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[29] such as ocean acidification, sea level rise or regional decreases in precipitation have also been attributed to human induced climate change (*high confidence*). {1.3, 2.3, 2.4, 2.5, 3.2, 3.4, 3.5, 3.6, 4.2, 5.2, 5.4, 5.6, 5.12, 7.2, 9.6, 9.7, 9.8, 9.11, 11.3, Box 11.1, Box 11.2, Table 11.9, 12.3, 12.4, 13.3, 13.5, 13.10, 14.2, 14.5, 15.7, 15.8, 16.2, CCP1.2, CCP2.2, Box CCP5.1, CCP7.3, CCB DISASTER, CCB EXTREME, CCB ILLNESS, WGI AR6 SPM.3, WGI AR6 9, WGI AR6 11.3–11.8, SROCC Chapter 4}

B.1.2 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 climate change impacts are larger than estimated in previous assessments (*high confidence*). 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*). 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*). 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*). (Figure SPM.2a). { TS B.1, Figure TS.5, 2.3, 2.4, 3.4, 3.5, 4.2, 4.3, 4.5, 9.6, 10.4, 11.3, 12.3, 12.8, 13.3, 13.4, 13.10, 14.4, 14.5, 14.6, 15.3, 16.2, CCP1.2, CCP3.2, CCP4.1, CCP5.2, Figure CCP5.4, CCP6.1, CCP6.2, CCP7.2, CCP7.3, CCB EXTREMES, CCB ILLNESS, CCB MOVING PLATE, CCB NATURAL, CCB PALEO, CCB SLR, SROCC 2.3}

B.1.3 Climate change including increases in frequency and intensity of extremes have reduced food and water security, hindering efforts to meet Sustainable Development Goals (*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*). Ocean warming and ocean acidification have adversely affected food production from shellfish aquaculture and fisheries in some oceanic regions (*high confidence*). Increasing weather and climate extreme events have exposed millions of people to acute food insecurity[30] 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*). (Figure SPM.2b) {3.5, 4.3, 4.4, Box 4.1, 5.2, 5.4, 5.8, 5.9, 5.12, 7.1, 7.2, 9.8, 10.4, 11.3, 12.3, 13.5, 14.4, 14.5, 15.3, 16.2, CCP5.2, CCP6.2}

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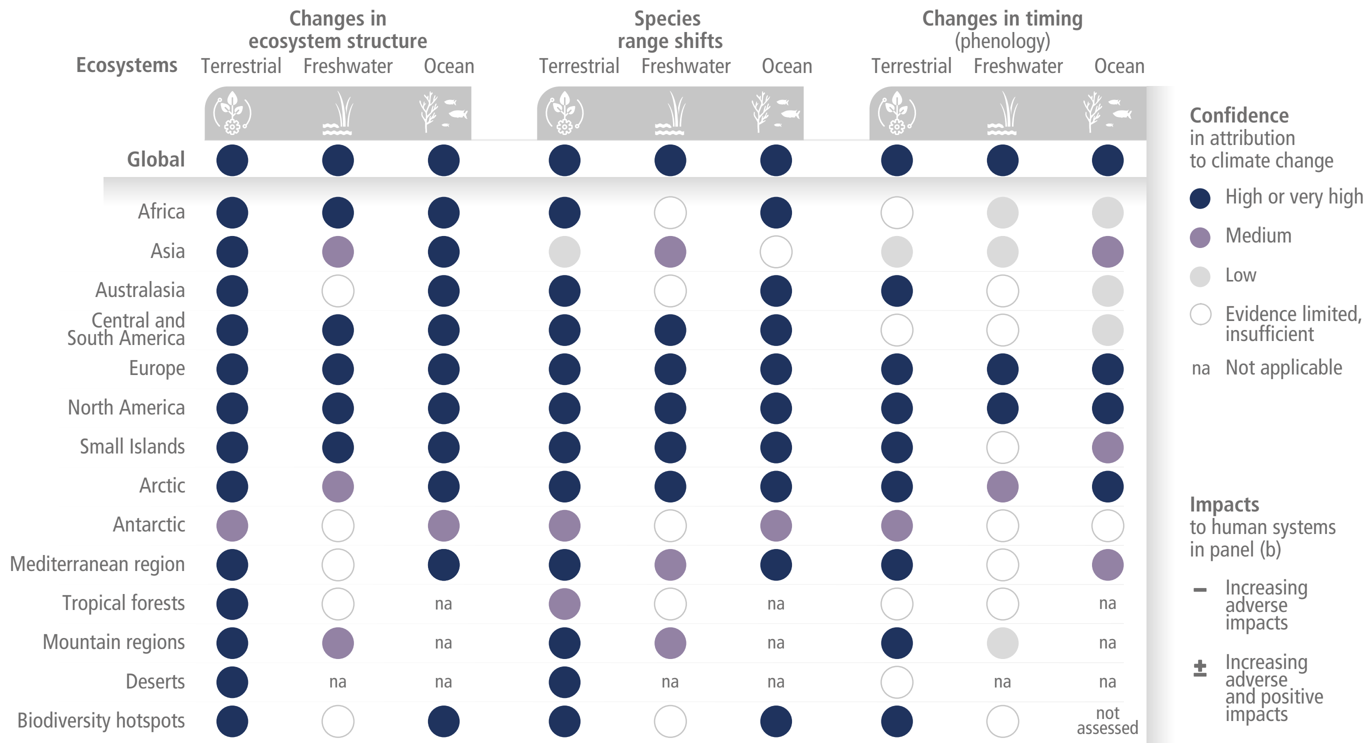
28 Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assessment of confidence. {Annex II Glossary, CWGB ATTRIB}

29 Impacts of climate change are caused by slow onset and extreme events. Slow onset events are described among the climatic-impact drivers of the WGI AR6 and refer to the risks and impacts associated with e.g., increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea level rise and salinization (https://interactive-atlas.ipcc.ch).

30 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.

Impacts of climate change are observed in many ecosystems and human systems worldwide

(a) Observed impacts of climate change on ecosystems



(b) Observed impacts of climate change on human systems

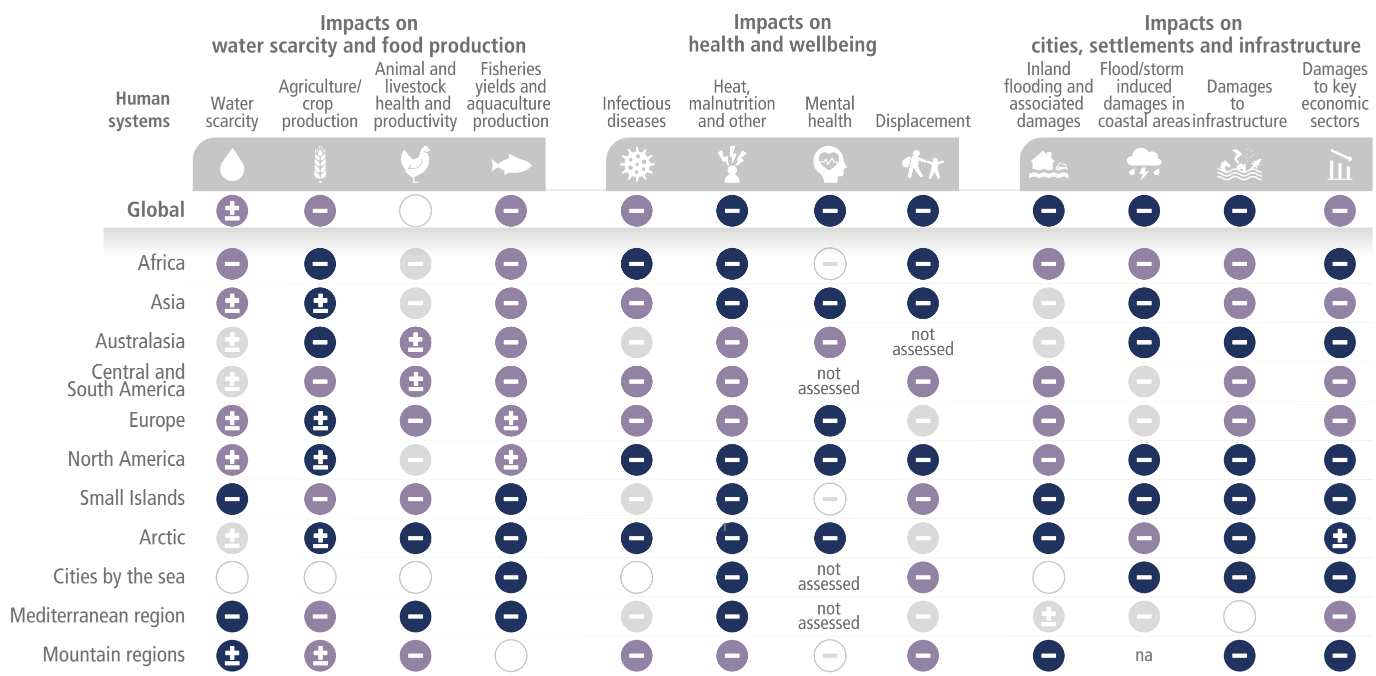


Figure SPM.2 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For that reason they can be assessed with higher confidence than regional studies, which may often rely on smaller studies that have more limited data. Regional assessments consider evidence on impacts across an entire region and do not focus on any country in particular.

(a) Climate change has already altered terrestrial, freshwater and ocean ecosystems at global scale, with multiple impacts evident at regional and local scales where there is sufficient literature to make an assessment. Impacts are evident on ecosystem structure, species geographic ranges and timing of seasonal life cycles (phenology) (for methodology and detailed references to chapters and cross-chapter papers see SMTS.1 and SMTS.1.1).

(b) Climate change has already had diverse adverse impacts on human systems, including on water security and food production, health and well-being, and cities, settlements and infrastructure. The + and – symbols indicate the direction of observed impacts, with a – denoting an increasing adverse impact and a ± denoting that, within a region or globally, both adverse and positive impacts have been observed (e.g., adverse impacts in one area or food item may occur with positive impacts in another area or food item). Globally, '–' denotes an overall adverse impact; 'Water scarcity' considers, e.g., water availability in general, groundwater, water quality, demand for water, drought in cities. Impacts on food production were assessed by excluding non-climatic drivers of production increases; Global assessment for agricultural production is based on the impacts on global aggregated production; 'Reduced animal and livestock health and productivity' considers, e.g., heat stress, diseases, productivity, mortality; 'Reduced fisheries yields and aquaculture production' includes marine and freshwater fisheries/production; 'Infectious diseases' include, e.g., water-borne and vector-borne diseases; 'Heat, malnutrition and other' considers, e.g., human heat-related morbidity and mortality, labour productivity, harm from wildfire, nutritional deficiencies; 'Mental health' includes impacts from extreme weather events, cumulative events, and vicarious or anticipatory events; 'Displacement' assessments refer to evidence of displacement attributable to climate and weather extremes; 'Inland flooding and associated damages' considers, e.g., river overflows, heavy rain, glacier outbursts, urban flooding; 'Flood/storm induced damages in coastal areas' include damages due to, e.g., cyclones, sea level rise, storm surges. Damages by key economic sectors are observed impacts related to an attributable mean or extreme climate hazard or directly attributed. Key economic sectors include standard classifications and sectors of importance to regions (for methodology and detailed references to chapters and cross-chapter papers see SMTS.1 and SMTS.1.2).

B.1.4 Climate change has adversely affected physical health of people globally (*very high confidence)* and mental health of people in the assessed regions (*very high confidence*). Climate change impacts on health are mediated through natural and human systems, including economic and social conditions and disruptions (*high confidence*). In all regions extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases has increased (*very high confidence*). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (*high confidence*). Animal and human diseases, including zoonoses, are emerging in new areas (*high confidence*). Water and food-borne disease risks have 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*). In assessed regions, some mental health challenges 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*). 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*). {4.3, 5.12, 7.2, Box 7.3, 8.2, 8.3, Box 8.6, Figure 8.10, 9.10, Figure 9.33, Figure 9.34, 10.4, 11.3, 12.3, 13.7, 14.4, 14.5, Figure 14.8, 15.3, 16.2, CCP5.2, Table CCP5.1, CCP6.2, Figure CCP6.3, Table CCB ILLNESS.1}

B.1.5 In urban settings, observed climate change has caused impacts on human health, livelihoods and key infrastructure (*high confidence*). Multiple climate and non-climate hazards impact cities, settlements and infrastructure and sometimes coincide, magnifying damage (*high confidence*). Hot extremes including heatwaves have intensified in cities (*high confidence*), where they have also aggravated air pollution events (*medium confidence*) and limited functioning of key infrastructure (*high confidence*). Observed impacts are concentrated amongst the economically and socially marginalized urban residents, e.g., in informal settlements (*high confidence*). Infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to well-being (*high confidence*). {4.3, 6.2, 7.1, 7.2, 9.9, 10.4, 11.3, 12.3, 13.6, 14.5, 15.3, CCP2.2, CCP4.2, CCP5.2}

B.1.6 Overall adverse economic impacts attributable to climate change, including slow-onset and extreme weather events, have been increasingly identified (*medium confidence*). Some positive economic effects have been identified in regions that have benefited from lower energy demand as well as comparative advantages in agricultural markets and tourism (*high confidence*). Economic damages from climate change have been detected in climate-exposed sectors, with regional effects to agriculture, forestry, fishery, energy, and tourism (*high confidence*), and through outdoor labour productivity (*high confidence*). Some extreme weather events, such as tropical cyclones, have reduced economic growth in the short-term (*high confidence*). Non-climatic factors including some patterns of settlement, and siting of infrastructure have contributed to the exposure of more assets to extreme climate hazards increasing the magnitude of the losses (*high confidence*). Individual livelihoods have been affected through changes in agricultural productivity, impacts on human health and food security, destruction of homes and infrastructure, and loss of property and income, with adverse effects on gender and social equity (*high confidence*). {3.5, 4.2, 5.12, 6.2, 7.2, 8.2, 9.6, 10.4, 13.10, 14.5, Box 14.6, 16.2, Table 16.5, 18.3, CCP6.2, CCB GENDER, CWGB ECONOMICS}

B.1.7 Climate change is contributing to humanitarian crises where climate hazards interact with high vulnerability (*high confidence*). Climate and weather extremes are increasingly driving displacement in all regions (*high confidence*), with Small Island States disproportionately affected (*high confidence*). Flood and drought-related acute food insecurity and malnutrition have increased in Africa (*high confidence*) and Central and South America (*high 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*). {4.2, 4.3, 5.4, 7.2, 9.8, Box 9.9, Box 10.4, 12.3, 12.5, 16.2, CCB DISASTER, CCB MIGRATE}

Vulnerability and Exposure of Ecosystems and People

B.2 Vulnerability of ecosystems and people to climate change differs substantially among and within regions (*very high confidence*), driven by patterns of intersecting socioeconomic development, unsustainable ocean and land use, inequity, marginalization, historical and ongoing patterns of inequity such as colonialism, and governance[31] (*high confidence*). Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change (*high confidence*). A high proportion of species is vulnerable to climate change (*high confidence*). Human and ecosystem vulnerability are interdependent (*high confidence*). Current unsustainable development patterns are increasing exposure of ecosystems and people to climate hazards (*high confidence*). {2.3, 2.4, 3.5, 4.3, 6.2, 8.2, 8.3, 9.4, 9.7, 10.4, 12.3, 14.5, 15.3, CCP5.2, CCP6.2, CCP7.3, CCP7.4, CCB GENDER}

B.2.1 Since 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*). {2.3, 2.5, 2.6, 3.5, 3.6, 4.2, 4.3, 4.6, 5.1, 5.4, 5.5, 5.7, 5.8, 7.2, 8.1, 8.2, 8.3, 8.4, 8.5, 9.6, 10.4, 11.3, 12.2, 12.5, 13.8, 14.4, 14.5, 15.3, CCP1.2, CCP1.3, CCP2.2, CCP3, CCP4.3, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCP7.4, CCB ILLNESS, CCB MOVING PLATE, CCB SLR}

B.2.2 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*). Globally, less than 15% of the land, 21% of the freshwater and 8% of the ocean are protected areas. In most protected areas, there is insufficient stewardship to contribute to reducing damage from, or increasing resilience to, climate change (*high confidence*). {2.4, 2.5, 2.6, 3.4, 3.6, 4.2, 4.3, 5.8, 9.6, 11.3, 12.3, 13.3, 13.4, 14.5, 15.3, CCP1.2, Figure CCP1.15, CCP2.1, CCP2.2, CCP4.2, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB NATURAL}

B.2.3 Future vulnerability of ecosystems to climate change will be strongly influenced by the past, present and future development of human society, including from overall unsustainable consumption and production, and increasing demographic pressures, as well as persistent unsustainable use and management of land, ocean, and water (*high confidence*). 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*). While agricultural development contributes to food security, unsustainable agricultural expansion, driven in part by unbalanced diets[32], increases ecosystem and human vulnerability and leads to competition for land and/or water resources (*high confidence*). {2.2, 2.3, 2.4, 2.6, 3.4, 3.5, 3.6, 4.3, 4.5, 5.6, 5.12, 5.13, 7.2, 12.3, 13.3, 13.4, 13.10, 14.5, CCP1.2, CCP2.2, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB HEALTH, CCB NATURAL}

B.2.4 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*). Present development challenges causing high vulnerability are influenced by historical and ongoing patterns of inequity such as colonialism, especially for many Indigenous Peoples and local communities (*high confidence*). {4.2, 5.12, 6.2, 6.4, 7.1, 7.2, Box 7.1, 8.2, 8.3, Box 8.4, Figure 8.6, Box 9.1, 9.4, 9.7, 9.9, 10.3, 10.4, 10.6, 12.3, 12.5, Box 13.2, 14.4, 15.3, 15.6, 16.2, CCP6.2, CCP7.4}

B.2.5 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*

31 Governance: The structures, processes and actions through which private and public actors interact to address societal goals. This includes formal and informal institutions and the associated norms, rules, laws and procedures for deciding, managing, implementing and monitoring policies and measures at any geographic or political scale, from global to local.

32 Balanced diets feature plant-based foods, such as those based on coarse grains, legumes fruits and vegetables, nuts and seeds, and animal-source foods produced in resilient, sustainable and low-greenhouse gas emissions systems, as described in SRCCL.

confidence). In rural areas vulnerability will be heightened by compounding processes including high emigration, reduced habitability and high reliance on climate-sensitive livelihoods (*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*). Future exposure to climatic hazards is also increasing globally due to socioeconomic development trends including migration, growing inequality and urbanization *(high confidence*). {4.5, 5.5, 6.2, 7.2, 8.3, 9.9, 9.11, 10.3, 10.4, 12.3, 12.5, 13.6, 14.5, 15.3, 15.4, 16.5, CCP2.3, CCP4.3, CCP5.2, CCP5.3, CCP5.4, CCP6.2, CCB MIGRATE}

Risks in the near term (2021–2040)

B.3 Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (*very high confidence*). The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development and adaptation (*high confidence*). 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*). (Figure SPM.3, Box SPM.1) {16.4, 16.5, 16.6, CCP1.2, CCP5.3, CCB SLR, WGI AR6 SPM B1.3, WGI AR6 Table SPM.1}

B.3.1 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). 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 warm-water 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*). Violent conflict and, separately, migration patterns, in the near-term will be driven by socioeconomic conditions and governance more than by climate change (*medium confidence*). (Figure SPM.3) {2.5, 3.4, 4.6, 6.2, 7.3, 8.7, 9.2, 9.9, 11.6, 12.5, 13.6, 13.10, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.1, CCP2.2, CCP5.3, CCP6.2, CCP6.3, CCB MIGRATE, CCB SLR}

B.3.2 In the near term, climate-associated risks to natural and human systems depend more strongly on changes in their vulnerability and exposure than on differences in climate hazards between emissions scenarios (*high confidence*). Regional differences exist, and risks are highest where species and people exist close to their upper thermal limits, along coastlines, in close association with ice or seasonal rivers (*high confidence*). Risks are also high where multiple non-climate drivers persist or where vulnerability is otherwise elevated (*high confidence*). Many of these risks are unavoidable in the near-term, irrespective of emissions scenario (*high confidence*). Several risks can be moderated with adaptation (*high confidence*). (Figure SPM.3, Section C) {2.5, 3.3, 3.4, 4.5, 6.2, 7.1, 7.3, 8.2, 11.6, 12.4, 13.6, 13.7, 13.10, 14.5, 16.4, 16.5, CCP2.2, CCP4.3, CCP5.3, CCB SLR, WGI AR6 Table SPM.1}

B.3.3 Levels of risk for all Reasons for Concern (RFC) are assessed to become high to very high at lower global warming levels than in AR5 (*high confidence*). Between 1.2°C and 4.5°C global warming level very high risks emerge in all five RFCs compared to just two RFCs in AR5 (*high confidence*). Two of these transitions from high to very high risk are associated with near-term warming: risks to unique and threatened systems at a median value of 1.5 [1.2 to 2.0] °C (*high confidence*) and risks associated with extreme weather events at a median value of 2.0 [1.8 to 2.5] °C (*medium confidence*). Some key risks contributing to the 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*). 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*). (Figure SPM.3b) {16.5, 16.6, CCB SLR}

Mid to Long-term Risks (2041–2100)

B.4 Beyond 2040 and depending on the level of global warming, climate change will lead to numerous risks to natural and human systems (*high confidence*). For 127 identified key risks, assessed mid- and long-term impacts are up to multiple times higher than currently observed (*high confidence*). The magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions, and projected adverse impacts and related losses and damages escalate with every increment of global warming (*very high confidence*). (Figure SPM.3) {2.5, 3.4, 4.4, 5.2, 6.2, 7.3, 8.4, 9.2, 10.2, 11.6, 12.4, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.2, CCP3.3, CCP4.3, CCP5.3, CCP6.3, CCP7.3}

B.4.1 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*). In terrestrial ecosystems, 3 to 14% of species assessed[33] will *likely* face very high risk of extinction[34] at global warming levels of 1.5°C, increasing up to 3 to 18% at 2°C, 3 to 29% at 3°C, 3 to 39% at 4°C, and 3 to 48% at 5°C. In ocean and coastal ecosystems, risk of biodiversity loss ranges between moderate and very high by 1.5°C global warming level and is moderate to very high by 2°C but with more ecosystems at high and very high risk (*high confidence*), and increases to high to very high across most ocean and coastal ecosystems by 3°C (*medium* to *high confidence*, depending on ecosystem). Very high extinction risk for endemic species in biodiversity hotspots is projected to at least double from 2% between 1.5°C and 2°C global warming levels and to increase at least tenfold if warming rises from 1.5°C to 3°C (*medium confidence*). (Figure SPM.3c, d, f) {2.4, 2.5, 3.4, 3.5,12.3, 12.5, Table 12.6, 13.4, 13.10, 16.4, 16.6, CCP1.2, Figure CCP1.6, Figure CCP1.7, CCP5.3, CCP6.3, CCB PALEO}

B.4.2 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*). 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*). {2.3, 4.4, 4.5, Box 4.2, Figure 4.20, 15.3, CCP5.3, CCB DISASTER, SROCC 2.3}

B.4.3 Climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition (*high confidence*). Increases in frequency, intensity and severity of droughts, floods and heatwaves, and continued sea level rise will 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*). At 2°C or higher global warming level in the mid-term, food security risks due to climate change will be more severe, leading to malnutrition and micro-nutrient deficiencies, concentrated in Sub-Saharan Africa, South Asia, Central and South America and Small Islands (*high 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*). At 3°C or higher global warming level in the long term, areas exposed to climate-related hazards will expand substantially compared with 2°C or lower global warming level (*high confidence*), exacerbating regional disparity in food security risks (*high confidence*). (Figure SPM.3) {1.1, 3.3, 4.5, 5.2, 5.4, 5.5, 5.8, 5.9, 5.12, 7.3, 8.3, 9.11, 13.5, 15.3, 16.5, 16.6, CCB MOVING PLATE, CCB SLR}

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33 Numbers of species assessed are in the tens of thousands globally.

34 The term 'very high risks of extinction' is used here consistently with the IUCN categories and criteria and equates with 'critically endangered'.

B.4.4 Climate change and related extreme events will significantly increase ill health and premature deaths from the near- to long-term (*high confidence*). Globally, population exposure to heatwaves will continue to increase with additional warming, with strong geographical differences in heat-related mortality without additional adaptation (*very high confidence*). Climate-sensitive food-borne, water-borne, and vector-borne disease risks are projected to increase under all levels of warming without additional adaptation (*high confidence*). In particular, dengue risk will increase with longer seasons and a wider geographic distribution in Asia, Europe, Central and South America and sub-Saharan Africa, potentially putting additional billions of people at risk by the end of the century (*high confidence*). Mental health challenges, including anxiety and stress, are expected to increase under further global warming in all assessed regions, particularly for children, adolescents, elderly, and those with underlying health conditions (*very high confidence*). {4.5, 5.12, Box 5.10, 7.3, Figure 7.9, 8.4, 9.10, Figure 9.32, Figure 9.35, 10.4, Figure 10.11, 11.3, 12.3, Figure 12.5, Figure 12.6, 13.7, Figure 13.23, Figure 13.24, 14.5, 15.3, CCP6.2}

B.4.5 Climate change risks to cities, settlements and key infrastructure will rise rapidly in the mid- and long-term with further global warming, especially in places already exposed to high temperatures, along coastlines, or with high vulnerabilities (*high 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*). Sea level rise poses an existential threat for some Small Islands and some low-lying coasts (*medium confidence*). By 2100 the value of global assets within the future 1-in-100 year coastal floodplains is projected to be between US$7.9 and US$12.7 trillion (2011 value) under RCP4.5, rising to between US$8.8 and US$14.2 trillion under RCP8.5 (*medium confidence*). Costs for maintenance and reconstruction of urban infrastructure, including building, transportation, and energy will increase with global warming level (*medium confidence*), the associated functional disruptions are projected to be substantial particularly for cities, settlements and infrastructure located on permafrost in cold regions and on coasts (*high confidence*). {6.2, 9.9, 10.4, 13.6, 13.10, 15.3, 16.5, CCP2.1, CCP2.2, CCP5.3, CCP6.2, CCB SLR, SROCC 2.3, SROCC CCB9}

B.4.6 Projected estimates of global aggregate net economic damages generally increase non-linearly with global warming levels (*high confidence*).[35] The wide range of global estimates, and the lack of comparability between methodologies, does not allow for identification of a robust range of estimates (*high confidence*). The existence of higher estimates than assessed in AR5 indicates that global aggregate economic impacts could be higher than previous estimates (*low confidence*).[36] Significant regional variation in aggregate economic damages from climate change is projected (*high confidence*) with estimated economic damages per capita for developing countries often higher as a fraction of income (*high confidence*). Economic damages, including both those represented and those not represented in economic markets, are projected to be lower at 1.5°C than at 3°C or higher global warming levels (*high confidence*). {4.4, 9.11, 11.5, 13.10, Box 14.6, 16.5, CWGB ECONOMIC}

B.4.7 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 socioeconomic 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*). {TS B.7.4, 7.3, 16.5, CCB MIGRATE }

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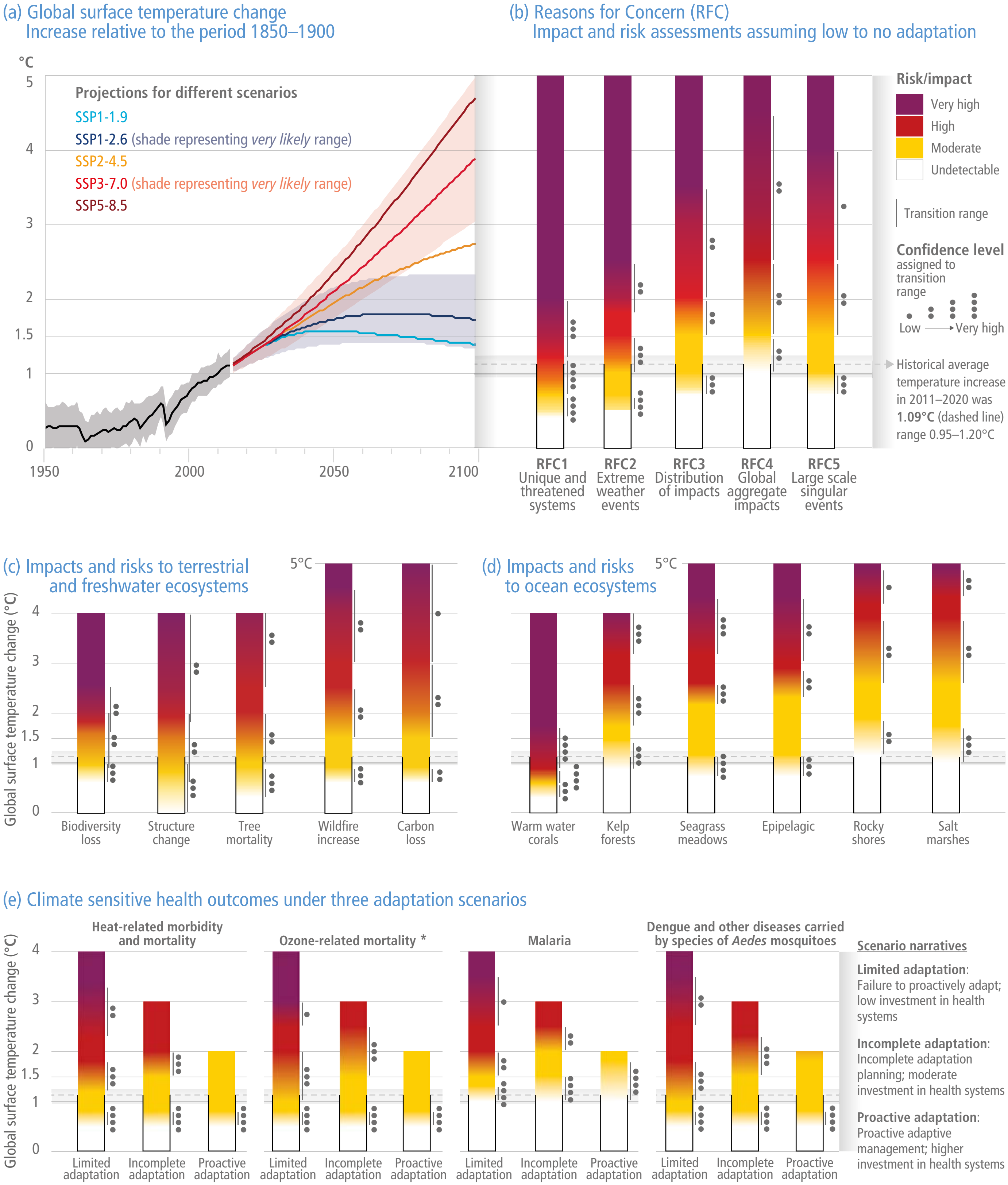
35 The assessment found estimated rates of increase in projected global economic damages that were both greater than linear and less than linear as global warming level increases. There is evidence that some regions could benefit from low levels of warming (*high confidence*). {CWGB ECONOMIC}

36 *Low confidence* assigned due to the assessed lack of comparability and robustness of global aggregate economic damage estimates. {CWGB ECONOMIC}

Global and regional risks for increasing levels of global warming



* Mortality projections include demographic trends but do not include future efforts to improve air quality that reduce ozone concentrations.

(f) Examples of regional key risks

Absence of risk diagrams does not imply absence of risks within a region. The development of synthetic diagrams for Small Islands, Asia and Central and South America was limited due to the paucity of adequately downscaled climate projections, with uncertainty in the direction of change, the diversity of climatologies and socioeconomic contexts across countries within a region, and the resulting few numbers of impact and risk projections for different warming levels.

The risks listed are of at least *medium confidence* level:

Small Islands
- Loss of terrestrial, marine and coastal biodiversity and ecosystem services
- Loss of lives and assets, risk to food security and economic disruption due to destruction of settlements and infrastructure
- Economic decline and livelihood failure of fisheries, agriculture, tourism and from biodiversity loss from traditional agroecosystems
- Reduced habitability of reef and non-reef islands leading to increased displacement
- Risk to water security in almost every small island

North America
- Climate-sensitive mental health outcomes, human mortality and morbidity due to increasing average temperature, weather and climate extremes, and compound climate hazards
- Risk of degradation of marine, coastal and terrestrial ecosystems, including loss of biodiversity, function, and protective services
- Risk to freshwater resources with consequences for ecosystems, reduced surface water availability for irrigated agriculture, other human uses, and degraded water quality
- Risk to food and nutritional security through changes in agriculture, livestock, hunting, fisheries, and aquaculture productivity and access
- Risks to well-being, livelihoods and economic activities from cascading and compounding climate hazards, including risks to coastal cities, settlements and infrastructure from sea level rise

Europe
- Risks to people, economies and infrastructures due to coastal and inland flooding
- Stress and mortality to people due to increasing temperatures and heat extremes
- Marine and terrestrial ecosystems disruptions
- Water scarcity to multiple interconnected sectors
- Losses in crop production, due to compound heat and dry conditions, and extreme weather

Central and South America
- Risk to water security
- Severe health effects due to increasing epidemics, in particular vector-borne diseases
- Coral reef ecosystems degradation due to coral bleaching
- Risk to food security due to frequent/extreme droughts
- Damages to life and infrastructure due to floods, landslides, sea level rise, storm surges and coastal erosion

Australasia
- Degradation of tropical shallow coral reefs and associated biodiversity and ecosystem service values
- Loss of human and natural systems in low-lying coastal areas due to sea level rise
- Impact on livelihoods and incomes due to decline in agricultural production
- Increase in heat-related mortality and morbidity for people and wildlife
- Loss of alpine biodiversity in Australia due to less snow

Asia
- Urban infrastructure damage and impacts on human well-being and health due to flooding, especially in coastal cities and settlements
- Biodiversity loss and habitat shifts as well as associated disruptions in dependent human systems across freshwater, land, and ocean ecosystems
- More frequent, extensive coral bleaching and subsequent coral mortality induced by ocean warming and acidification, sea level rise, marine heat waves and resource extraction
- Decline in coastal fishery resources due to sea level rise, decrease in precipitation in some parts and increase in temperature
- Risk to food and water security due to increased temperature extremes, rainfall variability and drought

Africa
- Species extinction and reduction or irreversible loss of ecosystems and their services, including freshwater, land and ocean ecosystems
- Risk to food security, risk of malnutrition (micronutrient deficiency), and loss of livelihood due to reduced food production from crops, livestock and fisheries
- Risks to marine ecosystem health and to livelihoods in coastal communities
- Increased human mortality and morbidity due to increased heat and infectious diseases (including vector-borne and diarrhoeal diseases)
- Reduced economic output and growth, and increased inequality and poverty rates
- Increased risk to water and energy security due to drought and heat

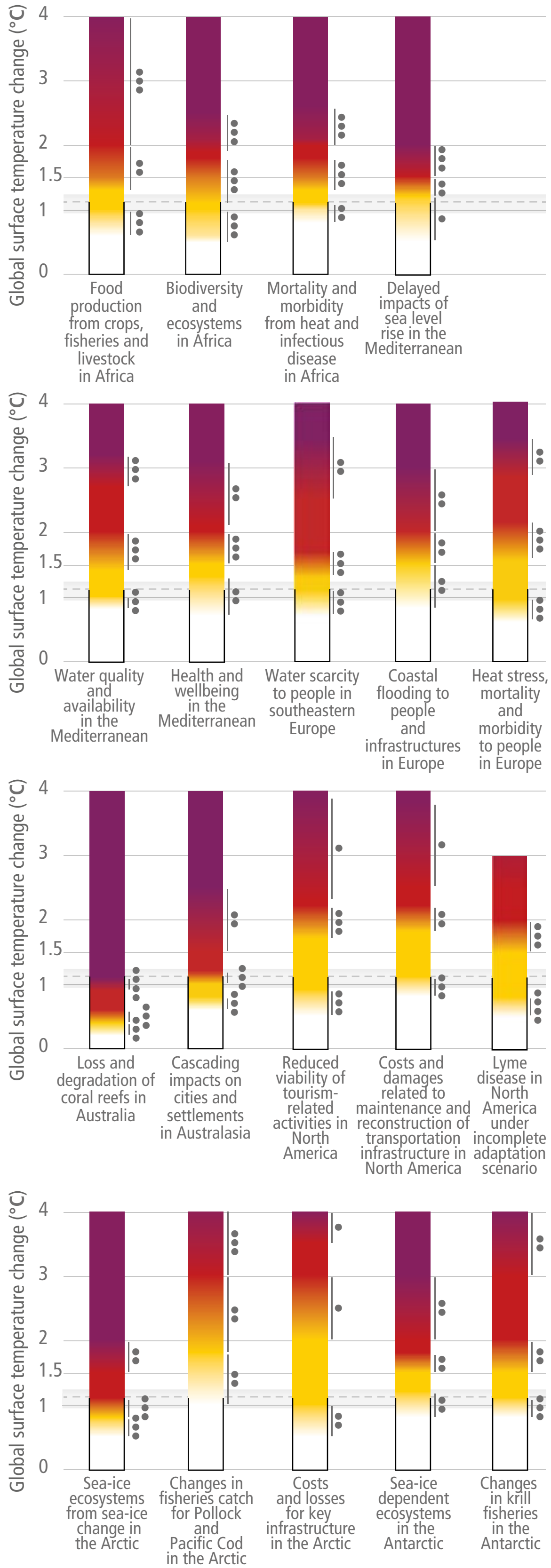


Figure SPM.3 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity (Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0 (WGI AR6 Figure SPM.8). Assessments were carried out at the global scale for (b), (c), (d) and (e).

(b) The Reasons for Concern (RFC) framework communicates scientific understanding about accrual of risk for five broad categories. Diagrams are shown for each RFC, assuming low to no adaptation (i.e., adaptation is fragmented, localized and comprises incremental adjustments to existing practices). However, the transition to a very high risk level has an emphasis on irreversibility and adaptation limits. Undetectable risk level (white) indicates no associated impacts are detectable and attributable to climate change; moderate risk (yellow) indicates associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks; high risk (red) indicates severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks; and very high risk level (purple) indicates very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks. The horizontal line denotes the present global warming of 1.09°C which is used to separate the observed, past impacts below the line from the future projected risks above it. RFC1: Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its Indigenous Peoples, mountain glaciers and biodiversity hotspots. RFC2: Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heatwaves, heavy rain, drought and associated wildfires, and coastal flooding. RFC3: Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. RFC4: Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric, such as monetary damages, lives affected, species lost or ecosystem degradation at a global scale. RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet disintegration or thermohaline circulation slowing. Assessment methods are described in SM16.6 and are identical to AR5, but are enhanced by a structured approach to improve robustness and facilitate comparison between AR5 and AR6.

Risks for **(c)** terrestrial and freshwater ecosystems and **(d)** ocean ecosystems. For c) and d), diagrams shown for each risk assume low to no adaptation. The transition to a very high risk level has an emphasis on irreversibility and adaptation limits.

(e) Climate-sensitive human health outcomes under three scenarios of adaptation effectiveness. The assessed projections were based on a range of scenarios, including SRES, CMIP5, and ISIMIP, and, in some cases, demographic trends. The diagrams are truncated at the nearest whole °C within the range of temperature change in 2100 under three SSP scenarios in panel (a).

(f) Examples of regional key risks. Risks identified are of at least *medium confidence* level. Key risks are identified based on the magnitude of adverse consequences (pervasiveness of the consequences, degree of change, irreversibility of consequences, potential for impact thresholds or tipping points, potential for cascading effects beyond system boundaries); likelihood of adverse consequences; temporal characteristics of the risk; and ability to respond to the risk, e.g., by adaptation. The full set of 127 assessed global and regional key risks is given in SM16.7. Diagrams are provided for some risks. The development of synthetic diagrams for Small Islands, Asia and Central and South America were limited by the availability of adequately downscaled climate projections, with uncertainty in the direction of change, the diversity of climatologies and socioeconomic contexts across countries within a region, and the resulting low number of impact and risk projections for different warming levels. Absence of risks diagrams does not imply absence of risks within a region. (Box SPM.1) {Figure TS.4, Figure 2.11, Figure SM3.1, Figure 7.9, Figure 9.6, Figure 11.6, Figure 13.28, 16.5, 16.6, Figure 16.15, SM16.3, SM16.4, SM16.5, SM16.6 (methodologies), SM16.7, Figure CCP4.8, Figure CCP4.10, Figure CCP6.5, WGI AR6 2, WGI AR6 SPM A.1.2, WGI AR6 Figure SPM.8}

Complex, Compound and Cascading Risks

B.5 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*) {1.3, 2.4, Box 2.2, Box 9.5, 11.5, 13.5, 14.6, Box 15.1, CCP1.2, CCP2.2, CCB COVID, CCB DISASTER, CCB INTEREG, CCB SRM, }

B.5.1 Concurrent and repeated climate hazards occur in all regions, increasing impacts and risks to health, ecosystems, infrastructure, livelihoods and food (*high confidence*). Multiple risks interact, generating new sources of vulnerability to climate hazards, and compounding overall risk (*high confidence*). Increasing concurrence of heat and drought events are causing crop production losses and tree mortality (*high confidence*). Above 1.5°C global warming increasing concurrent climate extremes will increase risk of simultaneous crop losses of maize in major food-producing regions, with this risk increasing further with higher global warming levels (*medium confidence*). Future sea level rise combined with storm surge and heavy rainfall will increase compound flood risks (*high confidence*). Risks to health and food production will be made more severe from the interaction of sudden food production losses from heat and drought, exacerbated by heat-induced labour productivity losses (*high confidence*). These interacting impacts will increase food prices, reduce household incomes, and lead to health risks of malnutrition and climate-related mortality with no or low levels of adaptation, especially in tropical regions (*high confidence*). Risks to food safety from climate change will further compound the risks to health by increasing food contamination of crops from mycotoxins and contamination of seafood from harmful algal blooms, mycotoxins, and chemical contaminants (*high confidence*). {Figure TS.10c, 5.2, 5.4, 5.8, 5.9, 5.11, 5.12, 7.2, 7.3, 9.8, 9.11, 10.4, 11.3, 11.5, 12.3, 13.5, 14.5, 15.3, Box 15.1, 16.6, CCP1.2, CCP6.2, , WGI AR6 SPM A.3.1, WGI AR6 SPM A.3.2, WGI AR6 SPM C.2.7}

B.5.2 Adverse impacts from climate hazards and resulting risks are cascading across sectors and regions (*high confidence*), propagating impacts along coasts and urban centres (*medium confidence*) and in mountain regions (*high confidence*). These hazards and cascading risks also trigger tipping points in sensitive ecosystems and in significantly and rapidly changing social-ecological systems impacted by ice melt, permafrost thaw and changing hydrology in polar regions (*high confidence*). Wildfires, in many regions, have affected ecosystems and species, people and their built assets, economic activity, and health (*medium to high confidence*). In cities and settlements, climate impacts to key infrastructure are leading to losses and damages across water and food systems, and affect economic activity, with impacts extending beyond the area directly impacted by the climate hazard (*high confidence*). In Amazonia, and in some mountain regions, cascading impacts from climatic (e.g., heat) and non-climatic stressors (e.g., land use change) will result in irreversible and severe losses of ecosystem services and biodiversity at 2°C global warming level and beyond (*medium confidence*). Unavoidable sea level rise will bring cascading and compounding impacts resulting in losses of coastal ecosystems and ecosystem services, groundwater salinisation, flooding and damages to coastal infrastructure that cascade into risks to livelihoods, settlements, health, well-being, food and water security, and cultural values in the near to long-term (*high confidence*). (Figure SPM.3) {Figure TS.10, 2.5, 3.4, 3.5, Box 7.3, Box 8.7, Box 9.4, 11.5, Box 11.1, 12.3, 13.9, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.2, CCP5.2, CCP5.3, CCP6.2, CCP6.3, Box CCP6.1, Box CCP6.2, CCB EXTREMES, WGI AR6 Figure SPM.8d}

B.5.3 Weather and climate extremes are causing economic and societal impacts across national boundaries through supply-chains, markets, and natural resource flows, with increasing transboundary risks projected across the water, energy and food sectors (*high confidence*). Supply chains that rely on specialized commodities and key infrastructure can be disrupted by weather and climate extreme events. Climate change causes the redistribution of marine fish stocks, increasing risk of transboundary management conflicts among fisheries users, and negatively affecting equitable distribution of food provisioning services as fish stocks shift from lower to higher latitude regions, thereby increasing the need for climate-informed transboundary management and cooperation (*high confidence*). Precipitation and water availability changes increases the risk of planned infrastructure projects, such as hydropower in some regions, having reduced productivity for food and energy sectors including across countries that share river basins (*medium confidence*). {Figure TS.10e-f, 3.4, 3.5, 4.5, 5.8, 5.13, 6.2, 9.4, Box 9.5,14.5, Box 14.5, Box 14.6, CCP5.3, CCB DISASTER, CCB EXTREMES, CCB INTEREG, CCB MOVING PLATE}

B.5.4 Risks arise from some responses that are intended to reduce the risks of climate change, including risks from maladaptation and adverse side effects of some emissions reduction and carbon dioxide removal measures (*high confidence*). Deployment of afforestation of naturally unforested land, or poorly implemented bioenergy, with or without carbon capture and storage, can compound climate-related risks to biodiversity, water and food security, and livelihoods, especially if implemented at large scales, especially in regions with insecure land tenure (*high confidence*). {Box 2.2, 4.1, 4.7, 5.13, Table 5.18, Box 9.3, Box 13.2, CCB NATURAL, CWGB BIOECONOMY}

B.5.5 Solar radiation modification approaches, if they were to be implemented, introduce a widespread range of new risks to people and ecosystems, which are not well understood (*high confidence*). Solar radiation modification approaches have potential to offset warming and ameliorate some climate hazards, but substantial residual climate change or overcompensating change would occur at regional scales and seasonal timescales (*high confidence*). Large uncertainties and knowledge gaps are associated with the potential of solar radiation modification approaches to reduce climate change risks. Solar radiation modification would not stop atmospheric CO_2 concentrations from increasing or reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*). {CWGB SRM}

Impacts of Temporary Overshoot

B.6 If global warming transiently exceeds 1.5°C in the coming decades or later (overshoot)[37], then many human and natural systems will face additional severe risks, compared to remaining below 1.5°C (*high confidence*). Depending on the magnitude and duration of overshoot, some impacts will cause release of additional greenhouse gases (*medium confidence*) and some will be irreversible, even if global warming is reduced (*high confidence*). (Box SPM.1, Figure SPM.3) {2.5, 3.4, 12.3, 16.6, CCB DEEP, CCB SLR}

B.6.1 While model-based assessments of the impacts of overshoot pathways are limited, observations and current understanding of processes permit assessment of impacts from overshoot. Additional warming, e.g., above 1.5°C during an overshoot period this century, will result in irreversible impacts on certain ecosystems with low resilience, such as polar, mountain, and coastal ecosystems, impacted by ice-sheet, glacier melt, or by accelerating and higher committed sea level rise (*high confidence*).[38] Risks to human systems will increase, including those to infrastructure, low-lying coastal settlements, some ecosystem-based adaptation measures, and associated livelihoods (*high confidence*), cultural and spiritual values (*medium confidence*). Projected impacts are less severe with shorter duration and lower levels of overshoot (*medium confidence*). {2.5, 3.4, 12.3, 13.2, 16.5, 16.6, CCP1.2, CCP2.2, CCP5.3, CCP6.1, CCP6.2, CCB SLR, WGI AR6 SPM B.5, WGI AR6 SPM C.3, SROCC 2.3, SROCC 5.4}

37 In this report, overshoot pathways exceed 1.5°C global warming and then return to that level, or below, after several decades.

38 Despite limited evidence specifically on the impacts of a temporary overshoot of 1.5°C, a much broader evidence base from process understanding and the impacts of higher global warming levels allows a high confidence statement on the irreversibility of some impacts that would be incurred following such an overshoot.

B.6.2 Risk of severe impacts increase with every additional increment of global warming during overshoot (*high confidence*). In high-carbon ecosystems (currently storing 3,000 to 4,000 GtC)[39] such impacts are already observed and are projected to increase with every additional increment of global warming, such as increased wildfires, mass mortality of trees, drying of peatlands, and thawing of permafrost, weakening natural land carbon sinks and increasing releases of greenhouse gases (*medium confidence*). The resulting contribution to a potential amplification of global warming indicates that a return to a given global warming level or below would be more challenging (*medium confidence*). {2.4, 2.5, CCP4.2, WGI AR6 SPM B.4.3, SROCC 5.4}

C: Adaptation Measures and Enabling Conditions

Adaptation, in response to current climate change, is reducing climate risks and vulnerability mostly via adjustment of existing systems. Many adaptation options exist and are used to help manage projected climate change impacts, but their implementation depends upon the capacity and effectiveness of governance and decision-making processes. These and other enabling conditions can also support climate resilient development (Section D).

Current Adaptation and its Benefits

C.1 Progress in adaptation planning and implementation has been observed across all sectors and regions, generating multiple benefits (*very high confidence*). However, adaptation progress is unevenly distributed with observed adaptation gaps[40] (*high confidence*). Many initiatives prioritize immediate and near-term climate risk reduction which reduces the opportunity for transformational adaptation (*high confidence*). {2.6, 5.14, 7.4, 10.4, 12.5, 13.11, 14.7, 16.3, 17.3, CCP5.2, CCP5.4}

C.1.1 Adaptation planning and implementation have continued to increase across all regions (*very high confidence*). Growing public and political awareness of climate impacts and risks has resulted in at least 170 countries and many cities including adaptation in their climate policies and planning processes (*high confidence*). Decision support tools and climate services are increasingly being used (*very high confidence*). Pilot projects and local experiments are being implemented in different sectors (*high confidence*). Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and well-being, food security, livelihood, and biodiversity conservation as well as reduction of risks and damages (*very high confidence*). {1.4, 2.6, 3.5, 3.6, 4.7, 4.8, 5.4, 5.6, 5.10, 6.4, 7.4, 8.5, 9.3, 9.6, 10.4, 12.5, 13.11, 15.5, 16.3, 17.2, 17.3, 17.5, CCP5.4, CCB ADAPT, CCB NATURAL}

C.1.2 Despite progress, adaptation gaps exist between current levels of adaptation and levels needed to respond to impacts and reduce climate risks (*high confidence*). Most observed adaptation is fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near-term risks, and focused more on planning rather than implementation (*high confidence*). Observed adaptation is unequally distributed across regions *(high confidence)*, and gaps are partially driven by widening disparities between the estimated costs of adaptation and documented finance allocated to adaptation (*high confidence*). The largest adaptation gaps exist among lower income population groups (*high confidence*). At current rates of adaptation planning and implementation the adaptation gap will continue to grow (*high confidence*). As adaptation options often have long implementation times, long-term planning and accelerated implementation, particularly in the next decade, is important to close adaptation gaps, recognising that constraints remain for some regions (*high confidence*). {1.1, 1.4, 5.6, 6.3, Figure 6.4, 7.4, 8.3, 10.4, 11.3, 11.7, 13.11, Box 13.1, 15.2, 15.5, 16.3, 16.5, Box 16.1, Figure 16.4, Figure 16.5, 17.4, 18.2, CCP2.4, CCP5.4, CCB FINANCE, CCB SLR}

39 At the global scale, terrestrial ecosystems currently remove more carbon from the atmosphere (-3.4 ± 0.9 Gt yr^{-1}) than they emit ($+1.6 \pm 0.7$ Gt yr^{-1}), a net sink of -1.9 ± 1.1 Gt yr^{-1}. However, recent climate change has shifted some systems in some regions from being net carbon sinks to net carbon sources.

40 Adaptation gaps are defined as the difference between actually implemented adaptation and a societally set goal, determined largely by preferences related to tolerated climate change impacts and reflecting resource limitations and competing priorities.

Future Adaptation Options and their Feasibility

C.2 There are feasible[41] and effective[42] adaptation options which can reduce risks to people and nature. The feasibility of implementing adaptation options in the near-term differs across sectors and regions (*very high confidence*). The effectiveness of adaptation to reduce climate risk is documented for specific contexts, sectors and regions (*high confidence*) and will decrease with increasing warming (*high confidence*). Integrated, multi-sectoral solutions that address social inequities, differentiate responses based on climate risk and cut across systems, increase the feasibility and effectiveness of adaptation in multiple sectors (*high confidence*). (Figure SPM.4) {Figure TS.6e, 1.4, 3.6, 4.7, 5.12, 6.3, 7.4, 11.3, 11.7, 13.2, 15.5, 17.6, CCP2.3, CCB FEASIB}

Land, Ocean and Ecosystems Transition

C.2.1 Adaptation to water-related risks and impacts make up the majority of all documented adaptation (*high confidence*). For inland flooding, combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives (*medium confidence*). Enhancing natural water retention such as by restoring wetlands and rivers, land use planning such as no build zones or upstream forest management, can further reduce flood risk (*medium confidence*). On-farm water management, water storage, soil moisture conservation and irrigation are some of the most common adaptation responses and provide economic, institutional or ecological benefits and reduce vulnerability (*high confidence*). Irrigation is effective in reducing drought risk and climate impacts in many regions and has several livelihood benefits, but needs appropriate management to avoid potential adverse outcomes, which can include accelerated depletion of groundwater and other water sources and increased soil salinization (*medium confidence*). Large scale irrigation can also alter local to regional temperature and precipitation patterns (*high confidence*), including both alleviating and exacerbating temperature extremes (*medium confidence*). The effectiveness of most water-related adaptation options to reduce projected risks declines with increasing warming (*high confidence*). {4.1, 4.6, 4.7, Box 4.3, Box 4.6, Box 4.7, Figure 4.22, Figure 4.28, Figure 4.29, Table 4.9, 9.3, 9.7, 11.3, 12.5, 13.1, 13.2, 16.3, CCP5.4}

C.2.2 Effective adaptation options, together with supportive public policies enhance food availability and stability and reduce climate risk for food systems while increasing their sustainability (*medium confidence*). Effective options include cultivar improvements, agroforestry, community-based adaptation, farm and landscape diversification, and urban agriculture (*high confidence*). Institutional feasibility, adaptation limits of crops and cost effectiveness also influence the effectiveness of the adaptation options (*limited evidence*, *medium agreement*). Agroecological principles and practices, ecosystem-based management in fisheries and aquaculture, and other approaches that work with natural processes support food security, nutrition, health and well-being, livelihoods and biodiversity, sustainability and ecosystem services (*high confidence*). These services include pest control, pollination, buffering of temperature extremes, and carbon sequestration and storage (*high confidence*). Trade-offs and barriers associated with such approaches include costs of establishment, access to inputs and viable markets, new knowledge and management (*high confidence*) and their potential effectiveness varies by socioeconomic context, ecosystem zone, species combinations and institutional support (*medium confidence*). Integrated, multi-sectoral solutions that address social inequities and differentiate responses based on climate risk and local situation will enhance food security and nutrition (*high confidence*). Adaptation strategies which reduce food loss and waste or support balanced diets[33] (as described in the IPCC Special Report on Climate Change and Land) contribute to nutrition, health, biodiversity and other environmental benefits (*high confidence*). {3.2, 4.7, 4.6, Box 4.3, 5.4, 5.5, 5.6, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, Box 5.10, Box 5.13, 6.3, 7.4, 10.4, 12.5, 13.5, 13.10, 14.5, CCP5.4, CCB FEASIB, CCB HEALTH, CCB MOVING PLATE, CCB NATURAL, CWGB BIOECONOMY}

C.2.3 Adaptation for natural forests[43] includes conservation, protection and restoration measures. In managed forests[43], adaptation options include sustainable forest management, diversifying and adjusting tree species compositions to build resilience, and managing increased risks from pests and diseases and wildfires. Restoring natural forests and drained peatlands and improving sustainability of managed forests, generally enhances the resilience of carbon stocks and sinks. Cooperation, and inclusive decision making, with local communities and Indigenous Peoples, as well as recognition of inherent rights of Indigenous Peoples, is integral to successful forest adaptation in many areas. (*high confidence*) {2.6, Box 2.2, 5.6, 5.13, Table 5.23, 11.4, 12.5, 13.5, Box 14.1, Box 14.2, CCP7.5, Box CCP7.1, CCB FEASIB, CCB INDIG, CCB NATURAL}

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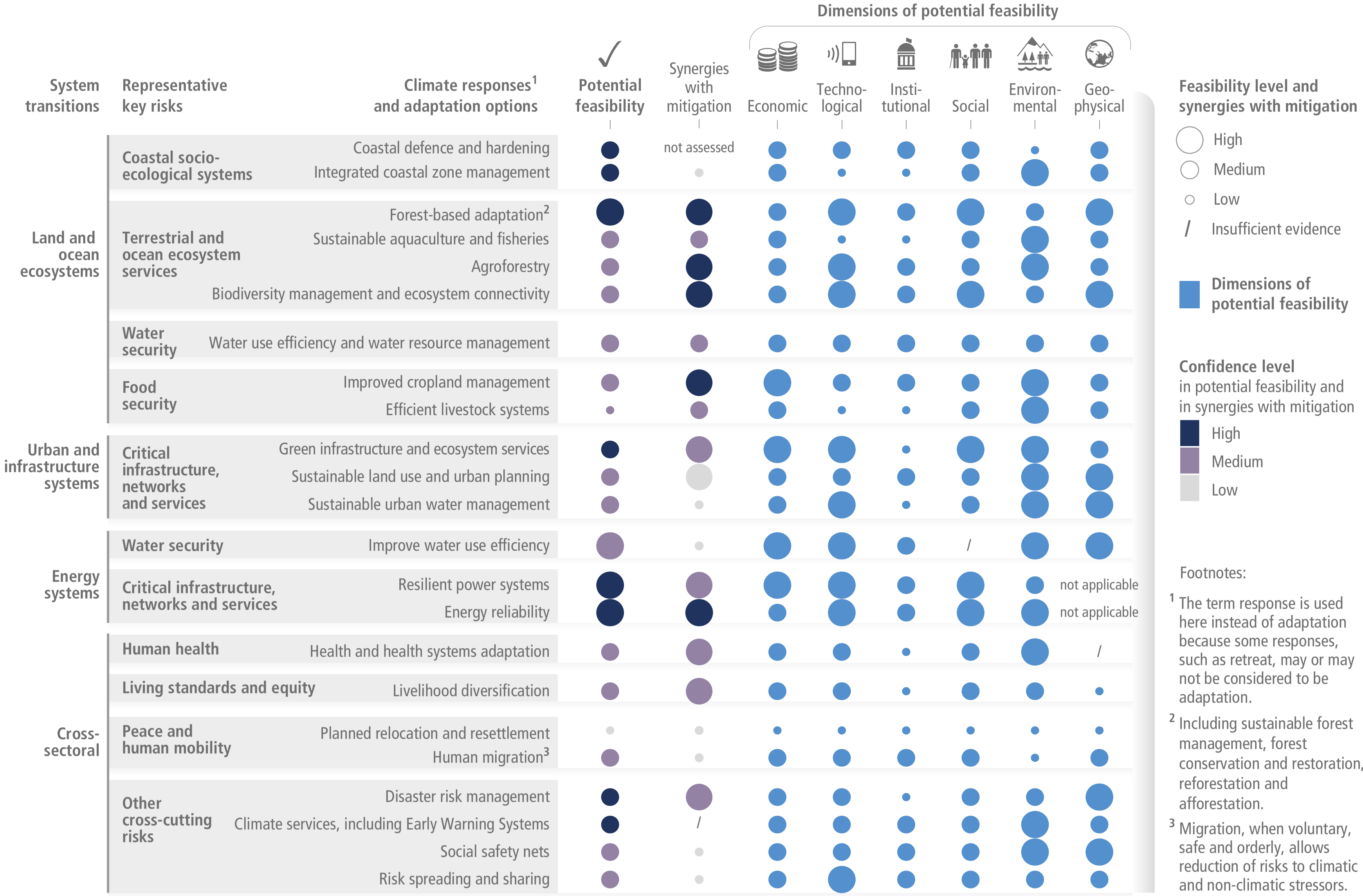
41 In this report, feasibility refers to the potential for a mitigation or adaptation option to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic, and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined and increase when enabling conditions are strengthened.

42 Effectiveness refers to the extent to which an adaptation option is anticipated or observed to reduce climate-related risk.

43 In this report, the term natural forests describes those which are subject to little or no direct human intervention, whereas the term managed forests describes those where planting or other management activities take place, including those managed for commodity production.

(a) Diverse feasible climate responses and adaptation options exist to respond to Representative Key Risks of climate change, with varying synergies with mitigation

Multidimensional feasibility and synergies with mitigation of climate responses and adaptation options relevant in the near-term, at global scale and up to 1.5°C of global warming



Footnotes:

[1] The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation.

[2] Including sustainable forest management, forest conservation and restoration, reforestation and afforestation.

[3] Migration, when voluntary, safe and orderly, allows reduction of risks to climatic and non-climatic stressors.

Figure SPM.4 | (a) Climate responses and adaptation options, organized by System Transitions and Representative Key Risks (RKRs), are assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at higher levels of warming may change, which is currently not possible to assess robustly. Climate responses and adaptation options at global scale are drawn from a set of options assessed in AR6 that have robust evidence across the feasibility dimensions. This figure shows the six feasibility dimensions (economic, technological, institutional, social, environmental and geophysical) that are used to calculate the potential feasibility of climate responses and adaptation options, along with their synergies with mitigation. For potential feasibility and feasibility dimensions, the figure shows high, medium, or low feasibility. Synergies with mitigation are identified as high, medium, and low. Insufficient evidence is denoted by a dash. {CCB FEASIB, Table SMCCB FEASIB.1.1, SR1.5 4.SM.4.3}

(b) Climate responses and adaptation options have benefits for ecosystems, ethnic groups, gender equity, low-income groups and the Sustainable Development Goals

Relations of sectors and groups at risk (as observed) and the SDGs (relevant in the near-term, at global scale and up to 1.5°C of global warming) with climate responses and adaptation options

Footnotes: [1] The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. [2] Including sustainable forest management, forest conservation and restoration, reforestation and afforestation. [3] Migration, when voluntary, safe and orderly, allows reduction of risks to climatic and non-climatic stressors. [4] The Sustainable Development Goals (SDGs) are integrated and indivisible, and efforts to achieve any goal in isolation may trigger synergies or trade-offs with other SDGs. [5] Relevant in the near-term, at global scale and up to 1.5°C of global warming.

Figure SPM.4 | (b) Climate responses and adaptation options, organized by System Transitions and Representative Key Risks, are assessed at global scale for their likely ability to reduce risks for ecosystems and social groups at risk, as well as their relation with the 17 Sustainable Development Goals (SDGs). Climate responses and adaptation options are assessed for observed benefits (+) to ecosystems and their services, ethnic groups, gender equity, and low-income groups, or observed dis-benefits (-) for these systems and groups. Where there is highly diverging evidence of benefits/ dis-benefits across the scientific literature, e.g., based on differences between regions, it is shown as not clear or mixed (•). Insufficient evidence is shown by a dash. The relation with the SDGs is assessed as having benefits (+), dis-benefits (-) or not clear or mixed (•) based on the impacts of the climate response and adaptation option on each SDG. Areas not coloured indicate there is no evidence of a relation or no interaction with the respective SDG. The climate responses and adaptation options are drawn from two assessments. For comparability of climate responses and adaptation options see Table SM17.5. {17.2, 17.5, CCB FEASIB}

C.2.4 Conservation, protection and restoration of terrestrial, freshwater, coastal and ocean ecosystems, together with targeted management to adapt to unavoidable impacts of climate change, reduces the vulnerability of biodiversity to climate change (*high confidence*). The resilience of species, biological communities and ecosystem processes increases with size of natural area, by restoration of degraded areas and by reducing non-climatic stressors (*high confidence*). To be effective, conservation and restoration actions will increasingly need to be responsive, as appropriate, to ongoing changes at various scales, and plan for future changes in ecosystem structure, community composition and species' distributions, especially as 1.5°C global warming is approached and even more so if it is exceeded (*high confidence*). Adaptation options, where circumstances allow, include facilitating the movement of species to new ecologically appropriate locations, particularly through increasing connectivity between conserved or protected areas, targeted intensive management for vulnerable species and protecting refugial areas where species can survive locally (*medium confidence*). {2.3, 2,6, Figure 2.1, Table 2.6, 3.3, 3.6, Box 3.4, 4.6, Box 4.6, Box 11.2, 12.3, 12.5, 13.4, 14.7, CCP5.4, CCB FEASIB}

C.2.5 Effective Ecosystem-based Adaptation[44] reduces a range of climate change risks to people, biodiversity and ecosystem services with multiple co-benefits (*high confidence*). Ecosystem-based Adaptation is vulnerable to climate change impacts, with effectiveness declining with increasing global warming (*high confidence*). Urban greening using trees and other vegetation can provide local cooling (*very high confidence*). Natural river systems, wetlands and upstream forest ecosystems reduce flood risk by storing water and slowing water flow, in most circumstances (*high confidence*). Coastal wetlands protect against coastal erosion and flooding associated with storms and sea level rise where sufficient space and adequate habitats are available until rates of sea level rise exceeds natural adaptive capacity to build sediment (*very high confidence*). {2.4, 2.5, 2.6, Table 2.7, 3.4, 3.5, 3.6, Figure 3.26, 4.6, Box 4.6, Box 4.7, 5.5, 5.14, Box 5.11, 6.3, 6.4, Figure 6.6, 7.4, 8.5, 8.6, 9.6, 9.8, 9.9, 10.2, 11.3, 12.5, 13.3, 13.4, 13.5, 14.5, Box 14.7, 16.3, 18.3, CCP5.4, CCB FEASIB.3, CCB HEALTH, CCB MOVING PLATE, CCB NATURAL, CWGB BIOECONOMY}

Urban, Rural and Infrastructure Transition

C.2.6 Considering climate change impacts and risks in the design and planning of urban and rural settlements and infrastructure is critical for resilience and enhancing human well-being (*high confidence*). The urgent provision of basic services, infrastructure, livelihood diversification and employment, strengthening of local and regional food systems and community-based adaptation enhance lives and livelihoods, particularly of low-income and marginalised groups (*high confidence*). Inclusive, integrated and long-term planning at local, municipal, sub-national and national scales, together with effective regulation and monitoring systems and financial and technological resources and capabilities foster urban and rural system transition (*high confidence*). Effective partnerships between governments, civil society, and private sector organizations, across scales provide infrastructure and services in ways that enhance the adaptive capacity of vulnerable people (*medium* to *high confidence*). {5.12, 5.13, 5.14, 6.3, 6.4, Box 6.3, Box 6.6, Table 6.6, 7.4, 12.5, 13.6, 14.5, Box 14.4, Box 17.4, CCP2.3, CCP2.4, CCP5.4, CCB FEASIB}

C.2.7 An increasing number of adaptation responses exist for urban systems, but their feasibility and effectiveness is constrained by institutional, financial, and technological access and capacity, and depends on coordinated and contextually appropriate responses across physical, natural and social infrastructure (*high confidence*). Globally, more financing is directed at physical infrastructure than natural and social infrastructure (*medium confidence*) and there is *limited evidence* of investment in the informal settlements hosting the most vulnerable urban residents (*medium* to *high confidence*). Ecosystem-based adaptation (e.g., urban agriculture and forestry, river restoration) has increasingly been applied in urban areas (*high confidence*). Combined ecosystem-based and structural adaptation responses are being developed, and there is growing evidence of their potential to reduce adaptation costs and contribute to flood control, sanitation, water resources management, landslide prevention and coastal protection (*medium confidence*). {3.6, Box 4.6, 5.12, 6.3, 6.4, Table 6.8, 7.4, 9.7, 9.9, 10.4, Table 10.3, 11.3, 11.7, Box 11.6, 12.5, 13.2, 13.3, 13.6, 14.5, 15.5, 17.2, Box 17.4, CCP2.3, CCP 3.2, CCP5.4, CCB FEASIB, CCB SLR, SROCC SPM}

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44 Ecosystem based Adaptation (EbA) is recognised internationally under the Convention on Biological Diversity (CBD14/5). A related concept is Nature-based Solutions (NbS), which includes a broader range of approaches with safeguards, including those that contribute to adaptation and mitigation. The term 'Nature-based Solutions' is widely but not universally used in the scientific literature. The term is the subject of ongoing debate, with concerns that it may lead to the misunderstanding that NbS on its own can provide a global solution to climate change.

C.2.8 Sea level rise poses a distinctive and severe adaptation challenge as it implies dealing with slow onset changes and increased frequency and magnitude of extreme sea level events which will escalate in the coming decades (*high confidence*). Such adaptation challenges would occur much earlier under high rates of sea level rise, in particular if low-likelihood, high impact outcomes associated with collapsing ice sheets occur (*high confidence*). Responses to ongoing sea level rise and land subsidence in low-lying coastal cities and settlements and small islands include protection, accommodation, advance and planned relocation (*high confidence*)[45]. These responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and development priorities, and underpinned by inclusive community engagement processes (*high confidence*). { 6.2, 10.4, 11.7, Box 11.6, 13.2, 14.5, 15.5, CCP2.3, CCB SLR, WGI AR6 SPM B.5, WGI AR6 SPM C.3, SROCC SPM C3.2}

C.2.9 Approximately 3.4 billion people globally live in rural areas around the world, and many are highly vulnerable to climate change. Integrating climate adaptation into social protection programs, including cash transfers and public works programmes, is highly feasible and increases resilience to climate change, especially when supported by basic services and infrastructure. Social safety nets are increasingly being reconfigured to build adaptive capacities of the most vulnerable in rural and also urban communities. Social safety nets that support climate change adaptation have strong co-benefits with development goals such as education, poverty alleviation, gender inclusion and food security. (*high confidence*) {5.14, 9.4, 9.10, 9.11, 12.5, 14.5, CCP5.4, CCB FEASIB, CCB GENDER}

Energy System Transition

C.2.10 Within energy system transitions, the most feasible adaptation options support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems (*very high confidence*). Energy generation diversification, including with renewable energy resources and generation that can be decentralised depending on context (e.g., wind, solar, small scale hydroelectric) and demand side management (e.g., storage, and energy efficiency improvements) can reduce vulnerabilities to climate change, especially in rural populations (*high confidence*). Adaptations for hydropower and thermo-electric power generation are effective in most regions up to 1.5°C to 2°C, with decreasing effectiveness at higher levels of warming (*medium confidence*). Climate responsive energy markets, updated design standards on energy assets according to current and projected climate change, smart-grid technologies, robust transmission systems and improved capacity to respond to supply deficits have high feasibility in the medium- to long-term, with mitigation co-benefits (*very high confidence*). {4.6, 4.7, Figure 4.28, Figure 4.29, 10.4, Table 11.8, 13.6, Figure 13.16, Figure 13.19, 18.3,CCP5.2, CCP5.4, CCB FEASIB, CWGB BIOECONOMY}

Cross-cutting Options

C.2.11 Strengthening the climate resiliency of health systems will protect and promote human health and well-being (*high confidence*). There are multiple opportunities for targeted investments and finance to protect against exposure to climate hazards, particularly for those at highest risk. Heat Health Action Plans that include early warning and response systems are effective adaptation options for extreme heat (*high confidence*). Effective adaptation options for water-borne and food-borne diseases include improving access to potable water, reducing exposure of water and sanitation systems to flooding and extreme weather events, and improved early warning systems (*very high confidence*). For vector-borne diseases, effective adaptation options include surveillance, early warning systems, and vaccine development (*very high confidence*). Effective adaptation options for reducing mental health risks under climate change include improving surveillance, access to mental health care, and monitoring of psychosocial impacts from extreme weather events (*high confidence*). Health and well-being would benefit from integrated adaptation approaches that mainstream health into food, livelihoods, social protection, infrastructure, water and sanitation policies requiring collaboration and coordination at all scales of governance (*very high confidence*). {5.12, 6.3, 7.4, 9.10, Box 9.7, 11.3, 12.5, 13.7, 14.5, CCB COVID, CCB FEASIB, CCB ILLNESS }

C.2.12 Increasing adaptive capacities minimises the negative impacts of climate-related displacement and involuntary migration for migrants and sending and receiving areas (*high confidence*). This improves the degree of choice under which migration decisions are made, ensuring safe and orderly movements of people within and between countries (*high confidence*). Some development reduces underlying vulnerabilities associated with conflict, and adaptation contributes by reducing the impacts of climate change on climate sensitive drivers of conflict (*high confidence*). Risks to peace are reduced, for example, by supporting people in climate-sensitive economic activities (*medium confidence*) and advancing women's empowerment (*high confidence*). {7.4, Box 9.8, Box 10.2, 12.5, CCB FEASIB, CCB MIGRATE}

45 The term 'response' is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation.

C.2.13 There are a range of adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing that have broad applicability across sectors and provide greater benefits to other adaptation options when combined (*high confidence*). For example, climate services that are inclusive of different users and providers can improve agricultural practices, inform better water use and efficiency, and enable resilient infrastructure planning (*high confidence*). {2.6, 3.6, 4.7, 5.4, 5.5, 5.6, 5.8, 5.9, 5.12, 5.14, 9.4, 9.8, 10.4, 12.5, 13.11, CCP5.4, CCB FEASIB, CCB MOVING PLATE}

Limits to Adaptation

C.3 Soft limits to some human adaptation have been reached, but can be overcome by addressing a range of constraints, primarily financial, governance, institutional and policy constraints (*high confidence*). Hard limits to adaptation have been reached in some ecosystems (*high confidence*). With increasing global warming, losses and damages will increase and additional human and natural systems will reach adaptation limits (*high confidence*). {Figure TS.7, 1.4, 2.4, 2.5, 2.6, 3.4, 3.6, 4.7, Figure 4.30, 5.5, Table 8.6, Box 10.7, 11.7, Table 11.16, 12.5, 13.2, 13.5, 13.6, 13.10, 13.11, Figure 13.21, 14.5, 15.6, 16.4, Figure 16.8, Table 16.3, Table 16.4, CCP1.2, CCP1.3, CCP2.3, CCP3.3, CCP5.2, CCP5.4, CCP6.3, CCP7.3, CCB SLR}

C.3.1 Soft limits to some human adaptation have been reached, but can be overcome by addressing a range of constraints, which primarily consist of financial, governance, institutional and policy constraints (*high confidence*). For example, individuals and households in low-lying coastal areas in Australasia and Small Islands and smallholder farmers in Central and South America, Africa, Europe and Asia have reached soft limits (*medium confidence*). Inequity and poverty also constrain adaptation, leading to soft limits and resulting in disproportionate exposure and impacts for most vulnerable groups (*high confidence*). Lack of climate literacy[46] at all levels and limited availability of information and data pose further constraints to adaptation planning and implementation (*medium confidence*). {1.4, 4.7, 5.4, 8.4, Table 8.6, 9.1, 9.4, 9.5, 9.8, 11.7, 12.5 13.5, 15.3, 15.5, 15.6, 16.4, Box 16.1, Figure 16.8, CCP5.2, CCP5.4, CCP6.3}

C.3.2 Financial constraints are important determinants of soft limits to adaptation across sectors and all regions (*high confidence*). Although global tracked climate finance has shown an upward trend since AR5, current global financial flows for adaptation, including from public and private finance sources, are insufficient for and constrain implementation of adaptation options especially in developing countries (*high confidence*). The overwhelming majority of global tracked climate finance was targeted to mitigation while a small proportion was targeted to adaptation (*very high confidence*). Adaptation finance has come predominantly from public sources (*very high confidence*). Adverse climate impacts can reduce the availability of financial resources by incurring losses and damages and through impeding national economic growth, thereby further increasing financial constraints for adaptation, particularly for developing and least developed countries (*medium confidence*). {Figure TS.7, 1.4, 2.6, 3.6, 4.7, Figure 4.30, 5.14, 7.4, 8.4, Table 8.6, 9.4, 9.9, 9.11, 10.5, 12.5, 13.3, 13.11, Box 14.4, 15.6, 16.2, 16.4, Figure 16.8, Table 16.4, 17.4, 18.1, CCP2.4, CCP5.4, CCP6.3, CCB FINANCE}

C.3.3 Many natural systems are near the hard limits of their natural adaptation capacity and additional systems will reach limits with increasing global warming (*high confidence*). Ecosystems already reaching or surpassing hard adaptation limits include some warm-water coral reefs, some coastal wetlands, some rainforests, and some polar and mountain ecosystems (*high confidence*). Above 1.5°C global warming level, some Ecosystem-based Adaptation measures will lose their effectiveness in providing benefits to people as these ecosystems will reach hard adaptation limits (*high confidence*). (Figure SPM.4) {1.4, 2.4, 2.6, 3.4, 3.6, 9.6, Box 11.2, 13.4, 14.5, 15.5, 16.4, 16.6, 17.2, CCP1.2, CCP5.2, CCP6.3, CCP7.3, CCB SLR}

C.3.4 In human systems, some coastal settlements face soft adaptation limits due to technical and financial difficulties of implementing coastal protection (*high confidence*). Above 1.5°C global warming level, limited freshwater resources pose potential hard limits for Small Islands and for regions dependent on glacier and snow-melt (*medium confidence*). By 2°C global warming level, soft limits are projected for multiple staple crops in many growing areas, particularly in tropical regions (*high confidence*). By 3°C global warming level, soft limits are projected for some water management measures for many regions, with hard limits projected for parts of Europe (*medium confidence*). Transitioning from incremental to transformational adaptation can help overcome soft adaptation limits (*high confidence*). {1.4, 4.7, 5.4, 5.8, 7.2, 7.3, 8.4, Table 8.6, 9.8, 10.4, 12.5, 13.2, 13.6, 16.4, 17.2, CCP1.3. Box CCP1.1, CCP2.3, CCP3.3, CCP4.4, CCP5.3, CCB SLR}

C.3.5 Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits. Losses and damages are unequally distributed across systems, regions and sectors and are not comprehensively addressed by current financial, governance and institutional arrangements, particularly in vulnerable developing countries. With increasing global warming, losses and damages increase and become increasingly difficult to avoid, while strongly concentrated among the poorest vulnerable populations. (*high confidence*) {1.4, 2.6, 3.4, 3.6, 6.3, Figure 6.4, 8.4, 13.2, 13.7, 13.10, 17.2, CCP2.3, CCP4.4, CCB LOSS, CCB SLR, CWGB ECONOMIC}

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46 Climate literacy encompasses being aware of climate change, its anthropogenic causes and implications.

Avoiding Maladaptation

C.4 There is increased evidence of maladaptation[15] across many sectors and regions since the AR5. Maladaptive responses to climate change can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities. Maladaptation can be avoided by flexible, multi-sectoral, inclusive and long-term planning and implementation of adaptation actions with benefits to many sectors and systems. (*high confidence*) {1.3, 1.4, 2.6, Box 2.2, 3.2, 3.6, 4.6, 4.7, Box 4.3, Box 4.5, Figure 4.29, 5.6, 5.13, 8.2, 8.3, 8.4, 8.6, 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, Box 9.5, Box 9.8, Box 9.9, Box 11.6, 13.11, 13.3, 13.4, 13.5, 14.5, 15.5, 15.6, 16.3, 17.2, 17.3, 17.4, 17.5, 17.6, CCP2.3, CCP2.3, CCP5.4, CCB DEEP, CCB NATURAL, CCB SLR, CWGB BIOECONOMY}

C.4.1 Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation if long-term impacts of the adaptation option and long-term adaptation commitment are not taken into account (*high confidence*). The implementation of these maladaptive actions can result in infrastructure and institutions that are inflexible and/or expensive to change (*high confidence*). For example, seawalls effectively reduce impacts to people and assets in the short-term but can also result in lock-ins and increase exposure to climate risks in the long-term unless they are integrated into a long-term adaptive plan (*high confidence*). Adaptation integrated with development reduces lock-ins and creates opportunities (e.g., infrastructure upgrading) (*medium confidence*). {1.4, 3.4, 3.6, 10.4, 11.7, Box 11.6, 13.2, 17.2, 17.5, 17.6, CCP 2.3, CCB DEEP, CCB SLR}

C.4.2 Biodiversity and ecosystem resilience to climate change are decreased by maladaptive actions, which also constrain ecosystem services. Examples of these maladaptive actions for ecosystems include fire suppression in naturally fire-adapted ecosystems or hard defences against flooding. These actions reduce space for natural processes and represent a severe form of maladaptation for the ecosystems they degrade, replace or fragment, thereby reducing their resilience to climate change and the ability to provide ecosystem services for adaptation. Considering biodiversity and autonomous adaptation in long-term planning processes reduces the risk of maladaptation. (*high confidence*) {2.4, 2.6, Table 2.7, 3.4, 3.6, 4.7, 5.6, 5.13, Table 5.21, Table 5.23, Box 11.2, 13.2, Box 13.2, 17.2, 17.5, CCP5.4}

C.4.3 Maladaptation especially affects marginalised and vulnerable groups adversely (e.g., Indigenous Peoples, ethnic minorities, low-income households, informal settlements), reinforcing and entrenching existing inequities. Adaptation planning and implementation that do not consider adverse outcomes for different groups can lead to maladaptation, increasing exposure to risks, marginalising people from certain socioeconomic or livelihood groups, and exacerbating inequity. Inclusive planning initiatives informed by cultural values, Indigenous knowledge, local knowledge, and scientific knowledge can help prevent maladaptation. (*high confidence*) (Figure SPM.4) {2.6, 3.6, 4.3, 4.6, 4.8, 5.12, 5.13, 5.14, 6.1, Box 7.1, 8.4, 11.4, 12.5, Box 13.2, 14.4, Box 14.1, 17.2, 17.5, 18.2, 17.2, CCP2.4}

C.4.4 To minimize maladaptation, multi-sectoral, multi-actor and inclusive planning with flexible pathways encourages low-regret[47] and timely actions that keep options open, ensure benefits in multiple sectors and systems and indicate the available solution space for adapting to long-term climate change (*very high confidence*). Maladaptation is also minimized by planning that accounts for the time it takes to adapt (*high confidence*), the uncertainty about the rate and magnitude of climate risk (*medium confidence*) and a wide range of potentially adverse consequences of adaptation actions (*high confidence*). {1.4, 3.6, 5.12, 5.13, 5.14, 11.6, 11.7, 17.3, 17.6, CCP2.3, CCP2.4, CCP5.4, CCB DEEP, CCB SLR}

Enabling Conditions

C.5 Enabling conditions are key for implementing, accelerating and sustaining adaptation in human systems and ecosystems. These include political commitment and follow-through, institutional frameworks, policies and instruments with clear goals and priorities, enhanced knowledge on impacts and solutions, mobilization of and access to adequate financial resources, monitoring and evaluation, and inclusive governance processes. (*high confidence*) {1.4, 2.6, 3.6, 4.8, 6.4, 7.4, 8.5, 9.4, 10.5, 11.4, 11.7, 12.5, 13.11, 14.7, 15.6, 17.4, 18.4, CCP2.4, CCP5.4, CCB FINANCE, CCB INDIG}

C.5.1 Political commitment and follow-through across all levels of government accelerate the implementation of adaptation actions (*high confidence*). Implementing actions can require large upfront investments of human, financial and technological resources (*high confidence*), whilst some benefits could only become visible in the next decade or beyond (*medium confidence*). Accelerating commitment and follow-through is promoted by rising public awareness, building business cases for adaptation, accountability and transparency mechanisms, monitoring and evaluation of adaptation progress, social movements, and climate-related litigation in some regions (*medium confidence*). {3.6, 4.8, 5.8, 6.4, 8.5, 9.4, 11.7, 12.5, 13.11, 17.4, 17.5, 18.4, CCP2.4, CCB COVID}

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47 From AR5, an option *that would generate net social and/or economic benefits under current climate change and a range of future climate change scenarios*, and represent one example of robust strategies.

C.5.2 Institutional frameworks, policies and instruments that set clear adaptation goals and define responsibilities and commitments and that are coordinated amongst actors and governance levels, strengthen and sustain adaptation actions (*very high confidence*). Sustained adaptation actions are strengthened by mainstreaming adaptation into institutional budget and policy planning cycles, statutory planning, monitoring and evaluation frameworks and into recovery efforts from disaster events (*high confidence*). Instruments that incorporate adaptation such as policy and legal frameworks, behavioural incentives, and economic instruments that address market failures, such as climate risk disclosure, inclusive and deliberative processes strengthen adaptation actions by public and private actors (*medium confidence*). {1.4, 3.6, 4.8, 5.14, 6.3, 6.4, 7.4, 9.4, 10.4, 11.7, Box 11.6, Table 11.17, 13.10, 13.11, 14.7, 15.6, 17.3, 17.4, 17.5, 17.6, 18.4, CCP2.4, CCP5.4, CCP6.3, CCB DEEP}

C.5.3 Enhancing knowledge on risks, impacts, and their consequences, and available adaptation options promotes societal and policy responses (*high confidence*). A wide range of top-down, bottom-up and co-produced processes and sources can deepen climate knowledge and sharing, including capacity building at all scales, educational and information programmes, using the arts, participatory modelling and climate services, Indigenous knowledge and local knowledge and citizen science (*high confidence*). These measures can facilitate awareness, heighten risk perception and influence behaviours (*high confidence*). {1.3, 3.6, 4.8, 5.9, 5.14, 6.4, Table 6.8, 7.4, 9.4, 10.5, 11.1, 11.7, 12.5, 13.9, 13.11, 14.3, 15.6, 15.6, 17.4, 18.4, CCP2.4.1, CCB INDIG}

C.5.4 With adaptation finance needs estimated to be higher than those presented in AR5, enhanced mobilization of and access to financial resources are essential for implementation of adaptation and to reduce adaptation gaps (*high confidence*). Building capacity and removing some barriers to accessing finance is fundamental to accelerate adaptation, especially for vulnerable groups, regions and sectors (*high confidence*). Public and private finance instruments include inter alia grants, guarantee, equity, concessional debt, market debt, and internal budget allocation as well as savings in households and insurance. Public finance is an important enabler of adaptation (*high confidence*). Public mechanisms and finance can leverage private sector finance for adaptation by addressing real and perceived regulatory, cost and market barriers, for example via public-private partnerships (*high confidence*). Financial and technological resources enable effective and ongoing implementation of adaptation, especially when supported by institutions with a strong understanding of adaptation needs and capacity (*high confidence*). {4.8, 5.14, 6.4, Table 6.10, 7.4, 9.4, Table 11.17, 12.5, 13.11, 15.6, 17.4, 18.4, Box 18.9, CCP5.4, CCB FINANCE}

C.5.5 Monitoring and evaluation (M&E) of adaptation are critical for tracking progress and enabling effective adaptation (*high confidence*). M&E implementation is currently limited (*high confidence*) but has increased since AR5 at local and national levels. Although most of the monitoring of adaptation is focused towards planning and implementation, the monitoring of outcomes is critical for tracking the effectiveness and progress of adaptation *(high confidence).* M&E facilitates learning on successful and effective adaptation measures, and signals when and where additional action may be needed. M&E systems are most effective when supported by capacities and resources and embedded in enabling governance systems (*high confidence*). {1.4, 2.6, 6.4, 7.4, 11.7, 11.8, 13.2, 13.11, 17.5, 18.4, CCP2.4, CCB DEEP, CCB ILLNESS, CCB NATURAL, CCB PROGRESS}

C.5.6 Inclusive governance that prioritises equity and justice in adaptation planning and implementation leads to more effective and sustainable adaptation outcomes (*high confidence*). Vulnerabilities and climate risks are often reduced through carefully designed and implemented laws, policies, processes, and interventions that address context specific inequities such as based on gender, ethnicity, disability, age, location and income (*high confidence*). These approaches, which include multi-stakeholder co-learning platforms, transboundary collaborations, community-based adaptation and participatory scenario planning, focus on capacity-building, and meaningful participation of the most vulnerable and marginalised groups, and their access to key resources to adapt (*high confidence*). {1.4, 2.6, 3.6, 4.8, 5.4, 5.8, 5.9, 5.13, 6.4, 7.4, 8.5, 11.8, 12.5, 13.11, 14.7, 15.5, 15.7, 17.3, 17.5, 18.4, CCP2.4, CCP5.4, CCP6.4, CCB GENDER, CCB HEALTH, CCB INDIG}

D: Climate Resilient Development

Climate resilient development integrates adaptation measures and their enabling conditions (Section C) with mitigation to advance sustainable development for all. Climate resilient development involves questions of equity and system transitions in land, ocean and ecosystems; urban and infrastructure; energy; industry; and society and includes adaptations for human, ecosystem and planetary health. Pursuing climate resilient development focuses on both where people and ecosystems are co-located as well as the protection and maintenance of ecosystem function at the planetary scale. Pathways for advancing climate resilient development are development trajectories that successfully integrate mitigation and adaptation actions to advance sustainable development. Climate resilient development pathways may be temporarily coincident with any RCP and SSP scenario used throughout AR6, but do not follow any particular scenario in all places and over all time.

Conditions for Climate Resilient Development

D.1 Evidence of observed impacts, projected risks, levels and trends in vulnerability, and adaptation limits, demonstrate that worldwide climate resilient development action is more urgent than previously assessed in AR5. Comprehensive, effective, and innovative responses can harness synergies and reduce trade-offs between adaptation and mitigation to advance sustainable development. (*very high confidence*) {2.6, 3.4, 3.6, 4.2, 4.6, 7.2, 7.4, 8.3, 8.4, 9.3, 10.6, 13.3, 13.8, 13.10, 14.7, 17.2, 18.3, Box 18.1, Figure 18.1, Table 18.5}

D.1.1 There is a rapidly narrowing window of opportunity to enable climate resilient development. Multiple climate resilient development pathways are still possible by which communities, the private sector, governments, nations and the world can pursue climate resilient development – each involving and resulting from different societal choices influenced by different contexts and opportunities and constraints on system transitions. Climate resilient development pathways are progressively constrained by every increment of warming, in particular beyond 1.5°C, social and economic inequalities, the balance between adaptation and mitigation varying by national, regional and local circumstances and geographies, according to capabilities including resources, vulnerability, culture and values, past development choices leading to past emissions and future warming scenarios, bounding the climate resilient development pathways remaining, and the ways in which development trajectories are shaped by equity, and social and climate justice. (*very high confidence*) {Figure TS.14d, 2.6, 4.7, 4.8, 5.14, 6.4, 7.4, 8.3, 9.4, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 14.7, 15.3, 18.5, CCP2.3, CCP3.4, CCP4.4, CCP5.3, CCP5.4, Table CCP5.2, CCP6.3, CCP7.5}

D.1.2 Opportunities for climate resilient development are not equitably distributed around the world (*very high confidence*). Climate impacts and risks exacerbate vulnerability and social and economic inequities and consequently increase persistent and acute development challenges, especially in developing regions and sub-regions, and in particularly exposed sites, including coasts, small islands, deserts, mountains and polar regions. This in turn undermines efforts to achieve sustainable development, particularly for vulnerable and marginalized communities (*very high confidence*). {2.5, 4.4, 4.7, 6.3, Box 6.4, Figure 6.5, 9.4, Table 18.5, CCP2.2, CCP3.2, CCP3.3, CCP5.4, CCP6.2, CCB HEALTH, CWGB URBAN}

D.1.3 Embedding effective and equitable adaptation and mitigation in development planning can reduce vulnerability, conserve and restore ecosystems, and enable climate resilient development. This is especially challenging in localities with persistent development gaps and limited resources (*high confidence*). Dynamic trade-offs and competing priorities exist between mitigation, adaptation, and development. Integrated and inclusive system-oriented solutions based on equity and social and climate justice reduce risks and enable climate resilient development (*high confidence*). {1.4, 2.6, Box 2.2, 3.6, 4.7, 4.8, Box 4.5, Box 4.8, 5.13, 7.4, 8.5, 9.4, Box 9.3, 10.6, 12.5, 12.6, 13.3, 13.4, 13.10, 13.11, 14.7, 18.4, CCB DEEP, CCP2, CCP5.4, CCB HEALTH, SRCCL}

Enabling Climate Resilient Development

D.2 Climate resilient development is enabled when governments, civil society and the private sector make inclusive development choices that prioritise risk reduction, equity and justice, and when decision-making processes, finance and actions are integrated across governance levels, sectors and timeframes (*very high confidence*). Climate resilient development is facilitated by international cooperation and by governments at all levels working with communities, civil society, educational bodies, scientific and other institutions, media, investors and businesses; and by developing partnerships with traditionally marginalised groups, including women, youth, Indigenous Peoples, local communities and ethnic minorities (*high confidence*). These partnerships are most effective when supported by enabling political leadership, institutions, resources, including finance, as well as climate services, information and decision support tools (*high confidence*). (Figure SPM.5) {1.3, 1.4, 1.5, 2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.4, 17.6, 18.4, 18.5, CCP2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB GENDER, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.2.1 Climate resilient development is advanced when actors work in equitable, just and enabling ways to reconcile divergent interests, values and worldviews, toward equitable and just outcomes (*high confidence*). These practices build on diverse knowledges about climate risk and chosen development pathways account for local, regional and global climate impacts, risks, barriers and opportunities (*high confidence*). Structural vulnerabilities to climate change can be reduced through carefully designed and implemented legal, policy, and process interventions from the local to global that address inequities based on gender, ethnicity, disability, age, location and income (*very high confidence*). This includes rights-based approaches that focus on capacity-building, meaningful participation of the most vulnerable groups, and their access to key resources, including financing, to reduce risk and adapt (*high confidence*). Evidence shows that climate resilient development processes link scientific, Indigenous, local, practitioner and other forms of knowledge, and are more effective and sustainable because they are locally appropriate and lead to more legitimate, relevant and effective actions (*high confidence*).

There is a rapidly narrowing window of opportunity to enable climate resilient development

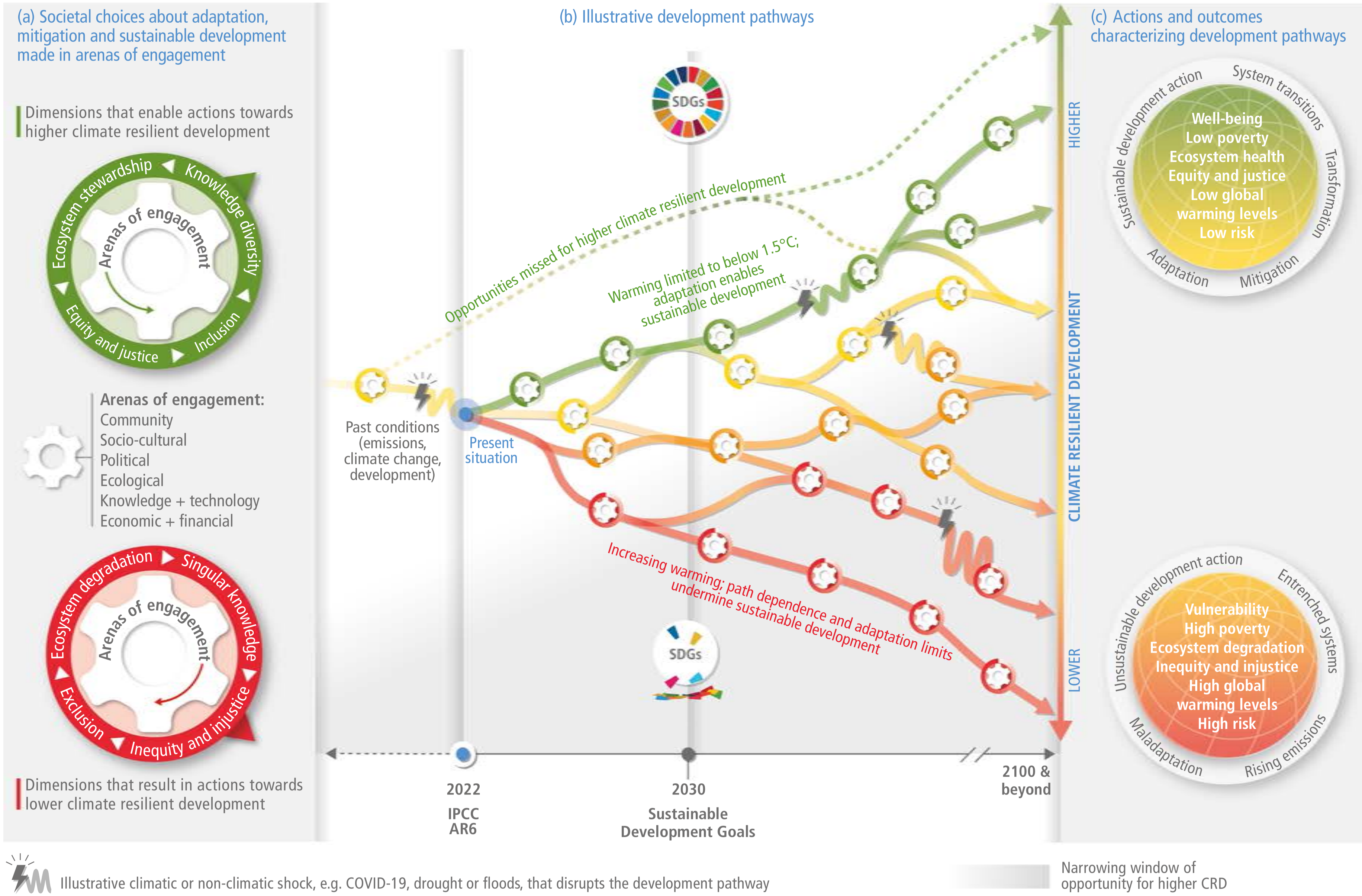

Figure SPM.5 | Climate resilient development (CRD) is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. This figure builds on Figure SPM.9 in AR5 WGII (depicting climate resilient pathways) by describing how CRD pathways are the result of cumulative societal choices and actions within multiple arenas.

Panel (a) Societal choices towards higher CRD **(green cog)** or lower CRD **(red cog)** result from interacting decisions and actions by diverse government, private sector and civil society actors, in the context of climate risks, adaptation limits and development gaps. These actors engage with adaptation, mitigation and development actions in political, economic and financial, ecological, socio-cultural, knowledge and technology, and community arenas from local to international levels. Opportunities for climate resilient development are not equitably distributed around the world.

Panel (b) Cumulatively, societal choices, which are made continuously, shift global development pathways towards higher **(green)** or lower **(red)** climate resilient development. Past conditions (past emissions, climate change and development) have already eliminated some development pathways towards higher CRD **(dashed green line)**.

Panel (c) Higher CRD is characterised by outcomes that advance sustainable development for all. Climate resilient development is progressively harder to achieve with global warming levels beyond 1.5°C. Inadequate progress towards the Sustainable Development Goals (SDGs) by 2030 reduces climate resilient development prospects. There is a narrowing window of opportunity to shift pathways towards more climate resilient development futures as reflected by the adaptation limits and increasing climate risks, considering the remaining carbon budgets. (Figure SPM.2, Figure SPM.3) {Figure TS.14b, 2.6, 3.6, 7.2, 7.3, 7.4, 8.3, 8.4, 8.5, 16.4, 16.5, 17.3, 17.4, 17.5, 18.1, 18.2, 18.3, 18.4, Box 18.1, Figure 18.1, Figure 18.2, Figure 18.3, CCB COVID, CCB GENDER, CCB HEALTH, CCB INDIG, CCB SLR, WGI AR6 Table SPM.1, WGI AR6 Table SPM.2, SR1.5 Figure SPM.1}

Pathways towards climate resilient development overcome jurisdictional and organizational barriers, and are founded on societal choices that accelerate and deepen key system transitions (*very high confidence*). Planning processes and decision analysis tools can help identify 'low regrets' options[47] that enable mitigation and adaptation in the face of change, complexity, deep uncertainty and divergent views (*medium confidence*). {1.3, 1.4, 1.5, 2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, Box 8.7, 9.4, Box 9.2, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2–18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.2.2 Inclusive governance contributes to more effective and enduring adaptation outcomes and enables climate resilient development (*high confidence*). Inclusive processes strengthen the ability of governments and other stakeholders to jointly consider factors such as the rate and magnitude of change and uncertainties, associated impacts, and timescales of different climate resilient development pathways given past development choices leading to past emissions and scenarios of future global warming (*high confidence*). Associated societal choices are made continuously through interactions in arenas of engagement from local to international levels. The quality and outcome of these interactions helps determine whether development pathways shift towards or away from climate resilient development (*medium confidence*). (Figure SPM.5) {2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2, 18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB GENDER, CCB HEALTH, CCB INDIG}

D.2.3 Governance for climate resilient development is most effective when supported by formal and informal institutions and practices that are well-aligned across scales, sectors, policy domains and timeframes. Governance efforts that advance climate resilient development account for the dynamic, uncertain and context-specific nature of climate-related risk, and its interconnections with non-climate risks. Institutions[48] that enable climate resilient development are flexible and responsive to emergent risks and facilitate sustained and timely action. Governance for climate resilient development is enabled by adequate and appropriate human and technological resources, information, capacities and finance. (*high confidence*) {2.7, 3.6, 4.8, 5.14, 6.3, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2-17.6, 18.2, 18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB GENDER, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

Climate Resilient Development for Natural and Human Systems

D.3 **Interactions between changing urban form, exposure and vulnerability can create climate change-induced risks and losses for cities and settlements. However, the global trend of urbanisation also offers a critical opportunity in the near-term, to advance climate resilient development (*high confidence*). Integrated, inclusive planning and investment in everyday decision-making about urban infrastructure, including social, ecological and grey/physical infrastructures, can significantly increase the adaptive capacity of urban and rural settlements. Equitable outcomes contributes to multiple benefits for health and well-being and ecosystem services, including for Indigenous Peoples, marginalised and vulnerable communities (*high confidence*). Climate resilient development in urban areas also supports adaptive capacity in more rural places through maintaining peri-urban supply chains of goods and services and financial flows (*medium confidence*). Coastal cities and settlements play an especially important role in advancing climate resilient development (*high confidence*). {6.2, 6.3, Table 6.6, 7.4, 8.6, Box 9.8, 18.3, CCP2.1. CCP2.2, CCP6.2, CWGB URBAN}**

48 Institutions: Rules, norms and conventions that guide, constrain or enable human behaviours and practices. Institutions can be formally established, for instance through laws and regulations, or informally established, for instance by traditions or customs. Institutions may spur, hinder, strengthen, weaken or distort the emergence, adoption and implementation of climate action and climate governance.

D.3.1 Taking integrated action for climate resilience to avoid climate risk requires urgent decision making for the new built environment and retrofitting existing urban design, infrastructure and land use. Based on socioeconomic circumstances, adaptation and sustainable development actions will provide multiple benefits including for health and well-being, particularly when supported by national governments, non-governmental organisations and international agencies that work across sectors in partnerships with local communities. Equitable partnerships between local and municipal governments, the private sector, Indigenous Peoples, local communities, and civil society can, including through international cooperation, advance climate resilient development by addressing structural inequalities, insufficient financial resources, cross-city risks and the integration of Indigenous knowledge and local knowledge. (*high confidence*) {6.2, 6.3, 6.4, Table 6.6, 7.4, 8.5, 9.4, 10.5. 12.5, 17.4, Table 17.8, 18.2, Box 18.1, CCP2.4, CCB FINANCE, CCB GENDER, CCB INDIG, CWGB URBAN}

D.3.2 Rapid global urbanisation offers opportunities for climate resilient development in diverse contexts from rural and informal settlements to large metropolitan areas (*high confidence*). Dominant models of energy intensive and market-led urbanisation, insufficient and misaligned finance and a predominant focus on grey infrastructure in the absence of integration with ecological and social approaches, risks missing opportunities for adaptation and locking in maladaptation (*high confidence*). Poor land use planning and siloed approaches to health, ecological and social planning also exacerbates, vulnerability in already marginalised communities (*medium confidence*). Urban climate resilient development is observed to be more effective if it is responsive to regional and local land use development and adaptation gaps, and addresses the underlying drivers of vulnerability (*high confidence*). The greatest gains in well-being can be achieved by prioritizing finance to reduce climate risk for low-income and marginalized residents including people living in informal settlements (*high confidence*). {5.14, 6.1, 6.2, 6.3, 6.4, 6.5, Figure 6.5, Table 6.6, 7.4, 8.5, 8.6, 9.8, 9.9, 10.4, Table 17.8, 18.2, CCP2.2, CCP5.4, CCB HEALTH, CWGB URBAN}

D.3.3 Urban systems are critical, interconnected sites for enabling climate resilient development, especially at the coast. Coastal cities and settlements play a key role in moving toward higher climate resilient development given firstly, almost 11% of the global population – 896 million people – lived within the Low Elevation Coastal Zone[49] in 2020, potentially increasing to beyond 1 billion people by 2050, and these people, and associated development and coastal ecosystems, face escalating climate compounded risks, including sea level rise. Secondly, these coastal cities and settlements make key contributions to climate resilient development through their vital role in national economies and inland communities, global trade supply chains, cultural exchange, and centres of innovation. (*high confidence*) {6.1, 6.2, 6.4, Table 6.6, Box 15.2, SMCCP Table 2.1, CCP2.2, CCP2.4, CCB SLR, XWGB URBAN, SROCC Chapter 4}

D.4 **Safeguarding biodiversity and ecosystems is fundamental to climate resilient development, in light of the threats climate change poses to them and their roles in adaptation and mitigation (*very high confidence*). Recent analyses, drawing on a range of lines of evidence, suggest that maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems (*high confidence*). {2.4, 2.5, 2.6, 3.4, 3.5, 3.6, Box 3.4, 12.5, 13.3, 13.4, 13.5, 13.10, CCB INDIG, CCB NATURAL}**

D.4.1 Building the resilience of biodiversity and supporting ecosystem integrity[50] can maintain benefits for people, including livelihoods, human health and well-being and the provision of food, fibre and water, as well as contributing to disaster risk reduction and climate change adaptation and mitigation. {2.2, 2.5, 2.6, Table 2.6, Table 2.7, 3.5, 3.6, 5.8, 5.13, 5.14, Box 5.11, 12.5, CCP5.4, CCB COVID, CCB GENDER, CCB ILLNESS, CCB INDIG, CCB MIGRATE, CCB NATURAL}

D.4.2 Protecting and restoring ecosystems is essential for maintaining and enhancing the resilience of the biosphere (*very high confidence*). Degradation and loss of ecosystems is also a cause of greenhouse gas emissions and is at increasing risk of being exacerbated by climate change impacts, including droughts and wildfire *(high confidence).* Climate resilient development avoids adaptation and mitigation measures that damage ecosystems (*high confidence*). Documented examples of adverse impacts of land-based measures intended as mitigation, when poorly implemented, include afforestation of grasslands, savannas and peatlands, and risks from bioenergy crops at large scale to water supply, food security and biodiversity (*high confidence*). {2.4, 2.5, Box 2.2, 3.4, 3.5, Box 3.4, Box 9.3, CCP7.3, CCB NATURAL, CWGB BIOECONOMY}

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49 LECZ, coastal areas below 10 m of elevation above sea level that are hydrologically connected to the sea.

50 Ecosystem integrity refers to the ability of ecosystems to maintain key ecological processes, recover from disturbance, and adapt to new conditions.

D.4.3 Biodiversity and ecosystem services have limited capacity to adapt to increasing global warming levels, which will make climate resilient development progressively harder to achieve beyond 1.5°C warming (*very high confidence*). Consequences of current and future global warming for climate resilient development include reduced effectiveness of Ecosystem-based Adaptation and approaches to climate change mitigation based on ecosystems and amplifying feedbacks to the climate system (*high confidence*). {Figure TS.14d, 2.4, 2.5, 2.6, 3.4, Box 3.4, 3.5, 3.6, Table 5.2, 12.5, 13.2, 13.3, 13.10, 14.5, 14.5, Box 14.3, 15.3, 17.3, 17.6, CCP5.3, CCP5.4, CCB EXTREMES, CCB ILLNESS, CCB NATURAL, CCB SLR, SR1.5, SRCCL, SROCC}

Achieving Climate Resilient Development

D.5 It is unequivocal that climate change has already disrupted human and natural systems. Past and current development trends (past emissions, development and climate change) have not advanced global climate resilient development (*very high confidence*). Societal choices and actions implemented in the next decade determine the extent to which medium- and long-term pathways will deliver higher or lower climate resilient development (*high confidence*). Importantly climate resilient development prospects are increasingly limited if current greenhouse gas emissions do not rapidly decline, especially if 1.5°C global warming is exceeded in the near-term (*high confidence*). These prospects are constrained by past development, emissions and climate change, and enabled by inclusive governance, adequate and appropriate human and technological resources, information, capacities and finance (*high confidence*). {Figure TS.14d, 1.2, 1.4, 1.5, 2.6, 2.7, 3.6, 4.7, 4.8, 5.14, 6.4, 7.4, 8.3, 8.5, 8.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 13.11, 14.7, 15.3, 15.6, 15.7, 16.2, 16.4, 16.5, 16.6, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.3, CCP5.4, Table CCP5.2, CCP6.3, CCP6.4, CCP7.5, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.5.1 Climate resilient development is already challenging at current global warming levels (*high confidence*). The prospects for climate resilient development will be further limited if global warming levels exceeds 1.5°C (*high confidence*) and not be possible in some regions and sub-regions if the global warming level exceeds 2°C (*medium confidence*). Climate resilient development is most constrained in regions/subregions in which climate impacts and risks are already advanced, including low-lying coastal cities and settlements, small islands, deserts, mountains and polar regions (*high confidence*). Regions and subregions with high levels of poverty, water, food and energy insecurity, vulnerable urban environments, degraded ecosystems and rural environments, and/or few enabling conditions, face many non-climate challenges that inhibit climate resilient development which are further exacerbated by climate change (*high confidence*). {Figure TS.14d, 1.2, Box 6.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 14.7, 15.3, CCP2.3, CCP3.4, CCP4.4, CCP5.3, Table CCP5.2, CCP6.3, CCP7.5}

D.5.2 Inclusive governance, investment aligned with climate resilient development, access to appropriate technology and rapidly scaled-up finance, and capacity building of governments at all levels, the private sector and civil society enable climate resilient development. Experience shows that climate resilient development processes are timely, anticipatory, integrative, flexible and action focused. Common goals and social learning build adaptive capacity for climate resilient development. When implementing adaptation and mitigation together, and taking trade-offs into account, multiple benefits and synergies for human well-being as well as ecosystem and planetary health can be realised. Prospects for climate resilient development are increased by inclusive processes involving local knowledge and Indigenous Knowledge as well as processes that coordinate across risks and institutions. Climate resilient development is enabled by increased international cooperation including mobilising and enhancing access to finance, particularly for vulnerable regions, sectors and groups. (*high confidence*) (Figure SPM.5) {2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.5.3 The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (*very high confidence*) {1.2, 1.4, 1.5, 16.2, Table SM16.24, 16.4, 16.5, 16.6, 17.4, 17.5, 17.6, 18.3, 18.4, 18.5, CCB DEEP, CWGB URBAN, WGI AR6 SPM, SROCC SPM, SRCCL SPM}