

10

New Insights in Climate Science

2020

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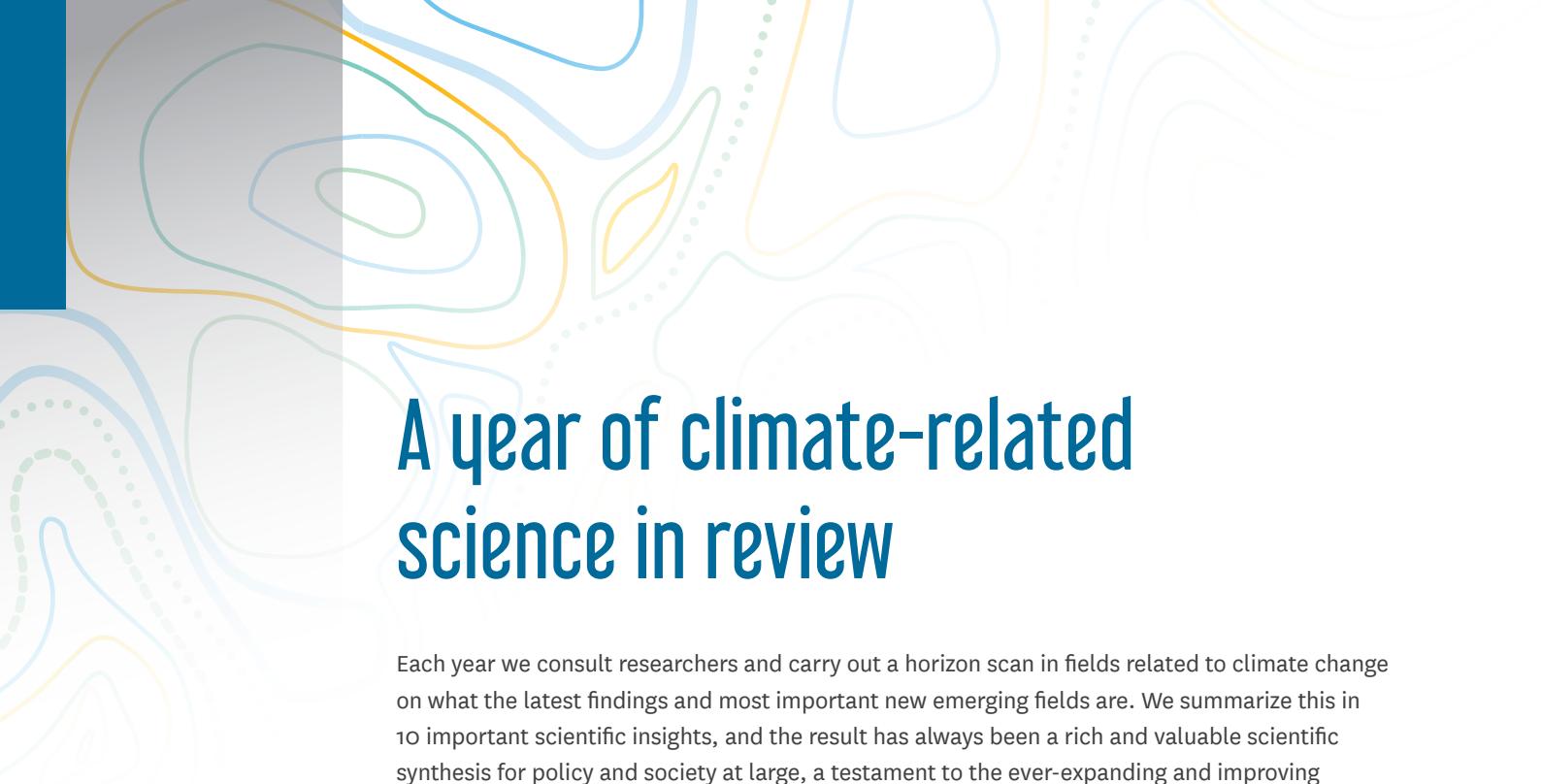
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A year of climate-related science in review

Each year we consult researchers and carry out a horizon scan in fields related to climate change on what the latest findings and most important new emerging fields are. We summarize this in 10 important scientific insights, and the result has always been a rich and valuable scientific synthesis for policy and society at large, a testament to the ever-expanding and improving knowledge of our planetary climate systems and the interactions with the human world.

This year has been no exception in terms of science advances, but an unusual one as the world was shaken by the COVID-19 pandemic. Researchers have scrambled to analyze and make sense of the rapid changes brought on by restrictions imposed by governments to control the pandemic. Several new methods for analyzing emissions of climate-affecting pollutants were developed at astonishing speed in order to track emissions at a higher temporal resolution than had previously been possible. As a result, it is estimated that global emissions of carbon dioxide fell by 8.8% for the first half of the year and by 17% at the day of maximum lockdown of our economies. The scale of these decreases is unprecedented. Interestingly, the scale of global emission reductions caused by the pandemic is on a par with the scientifically defined annual reduction requirements over the next 30 years (between 6–8% reduction in emissions per annum). This aligns with keeping within the global carbon budget for a chance of holding global warming at 1.5°C. And yet, the changes in emissions in 2020 have very little influence on humanity's total impact on climate systems, as greenhouse gases from human activities have been accumulating for centuries and continue to do so.

The past year has in many ways been unfortunate and tragic, but it's important that we use the experiences from the pandemic to deepen our understanding of how we can mitigate and prepare for global systemic threats. The pandemic has been a "stress test" that has spotlighted inadequacies of both governments and international institutions to cope with transboundary risks. The impacts of climate change have the potential to be as abrupt and far-reaching as the current pandemic. Recent research presented in this report shows that negative impacts can be expected on fundamental requirements for human well-being, such as access to clean water and conditions for good mental health.

Moving forward, the latest research calls for innovative, imaginative, and transformative approaches to building sustainable and resilient human societies. For instance, by strengthening global cooperative frameworks and building new governance arrangements that can include bottom-up community initiatives. In the short term, we have a one-off opportunity to get on the right path by directing post-pandemic recovery spending to green investments. If the focus is instead on economic growth, with sustainability as an afterthought, it would jeopardize our ability to deliver on the Paris Agreement. Alarmingly, governments do not yet seem to be seizing the opportunity to shift towards low-carbon, healthier, and more resilient societies.

While this report confirms the continued amplification of key environmental impacts, such as higher than expected emissions from permafrost thaw and possible weakening of the land sink, it also points to opportunities that arise from new insights in climate change economics and governance, and the possibility of using climate litigation. There is still a window of opportunity but 2021 will be a critical year to act if the world is to achieve the Paris Agreement targets.

This report is a summary of the article Pihl et al., (2021). 10 New Insights in Climate Science 2020 – a Horizon Scan, Global Sustainability, 4. <https://doi.org/10.1017/sus.2021.2>. All statements in this summary report are based on this article, except when referring to a specific source.

1

Improved models strengthen support for ambitious emission cuts to meet Paris Agreement

The climate's sensitivity to carbon dioxide – how much the temperature rises with a certain increase of emissions – is now better understood. This new knowledge indicates that moderate emission reductions are less likely to meet the Paris climate targets than previously anticipated.



Key new insights

- Earth's temperature response to doubling the levels of carbon dioxide in the atmosphere is now better understood. While previous IPCC assessments have used an estimated range of 1.5–4.5°C, recent research now suggests a narrower range of 2.3–4.5°C.
- This means that moderate emissions reduction scenarios are less likely to meet the Paris temperature targets than previously anticipated.
- Improved regional scale models provide better information about heavy rainfall events and hot and cold extremes, offering new opportunities for water resource management.
- Regional climate predictions can now be made up to a decade ahead with higher skill than previously thought possible.

At the center of international climate change negotiations is the concern about rising concentration of carbon dioxide in the atmosphere. Carbon dioxide (CO₂) is the most significant greenhouse gas anthropogenically emitted into the atmosphere, reducing terrestrial radiation to space and causing global temperatures to rise. Although this understanding pre-dates the 20th century, the quantitative relationship between CO₂ levels and global warming has remained uncertain for decades, hampering efforts to understand future risks and plan for change.

New likely range for equilibrium climate sensitivity

The climate effect of CO₂ is commonly expressed by the equilibrium climate sensitivity, which is the long-term global rise in air temperature expected as a result of doubling atmospheric CO₂ concentrations. The “likely range” (at least a 66% chance of being within this range) of equilibrium climate sensitivity was estimated to be 1.5–4.5°C by IPCC in its Fifth Assessment Report (AR5). These figures have remained unchanged since the Charney report of 1979.

A new comprehensive analysis of the broader evidence has now narrowed the likely range to 2.3–4.5°C. This analysis shows that a low climate sensitivity below 2.3°C is unlikely (less than 33% chance), which discounts the lower end of the IPCC AR5 range. This conclusion indicates that moderate emissions reduction scenarios are less likely to meet the Paris temperature targets than previously anticipated.

At the other end of the range, a larger climate sensitivity had been suggested by recent global-scale climate change experiments coordinated under the Coupled Model Intercomparison Project Phase 6, CMIP6 (which is set up to compare the models underpinning IPCC AR6). The Earth System models included there exhibit sensitivity values ranging from 1.8–5.6°C. The values for ten of these models exceeded 4.5°C. But many of these high-sensitivity models overestimated recent warming trends, suggesting their results should be treated with caution.

Evidence against the high sensitivities is provided from three sources: examining climate feedback processes, the historical record, and the paleoclimate (prehistoric climate) record, which counter the high model climate sensitivities. In particular, they found that sensitivities above 4.5°C are hard to reconcile with paleoclimate evidence.

Better predictions of regional climate change possible

On regional scales, climate models are now better at simulating temperature and hydrological extremes, including the intensity of heavy rainfall events and hot and cold extremes. Models can now simulate rainfall droughts well, particularly at the seasonal scale, and the projections of drought duration and frequency are becoming more consistent over many regions, even though regional changes in mean rainfall remain uncertain. The improvements provide new opportunities for national and regional water resource management.

In the near term, climate models are now better at predicting the observed evolution of regional climate

than previously thought possible, particularly around the Atlantic Basin. Decadal predictions of the atmospheric circulation and regional temperature and rainfall all now show encouraging levels of skill, offering great promise for the utility of regional climate predictions.

Where better regional climate predictions add value

- Energy sector planning, for understanding vulnerabilities under different energy mixes, planning future wind farm sites or developing resource management strategies.
- For water utilities, who have identified the need for improved climate information using decadal time scales for their planning. Decadal forecasts are particularly important in countries with an uneven distribution of water resources, such as India and China, that are facing increasing demands from the agriculture sector.

Climate sensitivity in models compared to the latest evidence based on multiple types of evidence

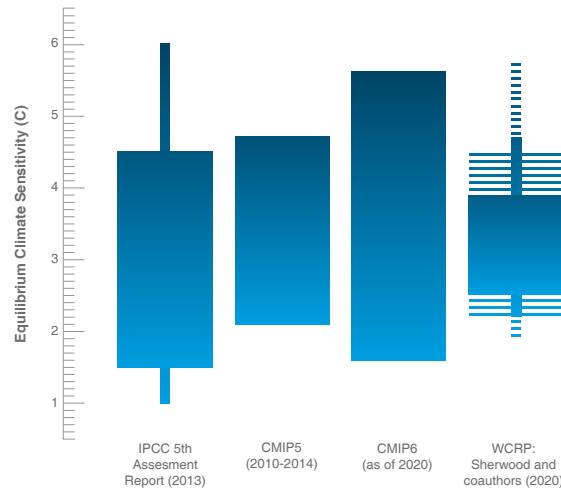


Figure 1. Climate sensitivity estimates have changed over time, as knowledge has developed. Here we see ranges from recent sources, from IPCC's 5th Assessment Report and onward. Thick and thin bars show 66% and 90% probability ranges, respectively. While the CMIP data is only from climate models, the other sources draw evidence from multiple types of evidence. Sherwood and coauthors (2020)¹ is a recent, extensive study compiling the latest known evidence including climate feedback processes, historic, and prehistoric data.

2

Emissions from thawing permafrost likely to be worse than expected

Climate models anticipate CO₂ and other greenhouse gases being released as permanently frozen ground – permafrost – thaws.

However, the calculations have not yet included processes where the ground collapses abruptly and exposes deep layers of permafrost, as these have previously been difficult to quantify. Recent advances make it possible to better understand the impact of these processes on emissions and they are significant enough to have an impact on climate negotiations.



Key new insights

- Emissions of greenhouse gases from permafrost will be larger than earlier projections because of abrupt thaw processes, which are not yet included in global climate models.
- These abrupt thaw effects could as much as double the emissions from permafrost thaw under moderate and high emissions scenarios.
- Emissions from permafrost thaw could be yet higher due to effects on plant root activity, which increases soil respiration.

Thawing permafrost in the Arctic is expected to release significant quantities of greenhouse gases over the coming decades, enough to merit consideration in climate negotiations. Recent research shows it will be larger than earlier projections due to abrupt permafrost thaw processes.

Permafrost is a perpetually frozen layer beneath the seasonally thawed surface layer of the ground, covering 18 million square kilometers in the northern hemisphere and storing



Thawing coastal permafrost in Arctic Canada with person for scale. Credit: G. Hugelius

1,460–1,600 petagrams of carbon (PgC) – one third of the world’s soil carbon. The Arctic is responding quickly to climate change, with air temperatures warming more than twice as fast as the global average. Unusually warm summers – such as the record-breaking 2020 heatwave in Siberia and Svalbard – are happening more often. This is causing Arctic permafrost to thaw in some northernmost regions almost a century earlier than some climate models projected.

Landscape-changing thaw on the up

Abrupt permafrost thaw happens when melting ground ice causes the ground surface above to collapse. This liberates previously frozen soil carbon, creating a so-called “thermokarst” landscape of slumps and gullies in upland areas and collapsed scar wetlands and lakes in less well-drained areas. Satellite observations of these landscape-scale changes have shown an acceleration in these processes over the past two decades; they are expected to substantially increase this century as climate warms. These processes increase thaw rates by exposing deeper regions of permafrost – which would otherwise be shielded by surface layers – to warm summer air.

While climate models do include gradual permafrost thaw, they do not include the more complex thermokarst-inducing processes. When thermokarst is included, by the year 2100 up to three times more carbon becomes exposed assuming moderate future warming at Representative Concentration Pathway (RCP) 4.5 and up to 12 times more carbon is exposed under a high warming scenario of RCP8.5.

Abrupt permafrost thaw also causes ecosystem shifts to conditions more conducive to producing strong

greenhouse gas emissions, notably methane. Accounting for these processes nearly doubles the annual projected 2100 greenhouse gas emissions from permafrost thaw (for a high warming RCP8.5 scenario).

Peatlands and increased soil respiration mean even higher emissions

Peatlands have year-round waterlogged conditions that slow plant decomposition, allowing peat to accumulate – one of the largest natural carbon stores on land. Nearly half of northern peatlands are underlain by permafrost. Abrupt thaw could shift the entire northern hemisphere peatland carbon sink into a net source of global warming, dominated by methane, lasting several centuries.

An ecological feedback associated with permafrost thaw that is not yet included in global climate models is a priming effect on soil respiration, caused by an increase in root activity. This amplifies soil carbon loss, with an additional 40 Pg carbon loss (corresponding to 147 Gton CO₂) projected from Arctic permafrost by 2100 for RCP8.5.

In the Special Report on 1.5°C, the IPCC assumed that permafrost thaw will release 100 Gton of CO₂ equivalents cumulatively to year 2100. Abrupt thaw processes could, under moderate to high emissions scenarios, approximately double the cumulative carbon emissions compared to gradual thaw alone. This may also apply to emissions scenarios consistent with 1.5°C or 2°C warming targets, which would impose tighter restrictions on the remaining anthropogenic carbon emission budgets.

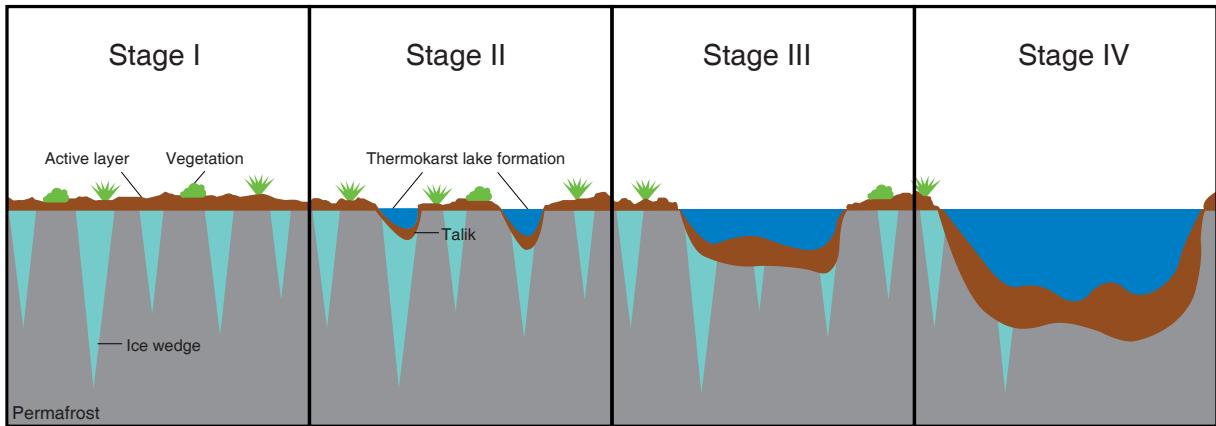


Figure 2. The thermokarst forming process proceeds in several stages. In the earliest stages, deeper layers are completely frozen and thawing proceeds top-down through gradual thaw. When thaw affects massive ice bodies in the ground, such as ice wedges, the loss of volume as the ice melts away causes the ground to collapse and thermokarst lakes, wetlands, or thaw slumps start to form. Once these thermokarst start growing, they enhance the thawing process by transporting heat to the thawing front through the movement of the water, causing it to thaw faster than surrounding permafrost at the same depth. Adapted from Zandt and coauthors, 2020.²

3

Deforestation is degrading the tropical carbon sink

The uptake of carbon by land ecosystems, the “land sink”, has grown as CO₂ in the atmosphere acts as fertilizer. This effect is increasingly being countered by human-driven land-use change, particularly in the tropics. Other factors, such as shortage of other nutrients, water stress, and permafrost thaw could further impede the land sink. The future for the land sink as a whole is uncertain.



Key new insights

- Land ecosystems currently draw down 30% of human CO₂ emissions due to a CO₂ fertilization effect on plants.
- Deforestation of the world’s tropical forests are causing these to level off as a carbon sink but this is balanced by greater recent carbon uptake in the northern hemisphere.
- Global plant biomass uptake of carbon due to CO₂ fertilization may be limited in the future by nitrogen and phosphorus.
- CO₂ emissions from land-use changes continue to be high in the 21st century and remain a large threat to the land sink.

Current atmospheric CO₂ levels would be significantly higher were it not for the uptake and storage of CO₂ by the Earth’s biosphere. Land ecosystems all over the globe provide important ecosystem services by removing about 30% of the CO₂ emitted through burning fossil fuels and human changes in land use and land cover (see Figure 1). Land-use change (LUC) refers to human activities carried out on land and the ways land is used, while land cover is the physical cover of the Earth’s surface. This ecosystem service, commonly referred to as the natural land sink, slows down the growth rate of atmospheric CO₂, hence reducing the rate of climate change. However, the natural land sink is not constant as it directly responds to environmental changes, both of natural and anthropogenic origins, which influence its capacity to absorb CO₂ from the atmosphere. The amount of CO₂ absorbed by the land has almost doubled since 1960, mainly

because of a phenomenon known as CO₂ fertilization. This is when the increase of CO₂ in the atmosphere enhances plant photosynthesis and resource-use efficiencies, resulting in plants taking up and storing more carbon.

Decreasing land sink in the tropics

The increased natural land sink has so far occurred despite increased large-scale human disruptions to ecosystems, such as deforestation and degradation of natural areas, but it cannot be taken for granted in the future. There is now evidence that some of the largest carbon sinks of the planet have already saturated, particularly in tropical ecosystems, due to different reasons. First, there are processes that could eventually limit the sink. In particular, low availability of certain nutrients such as nitrogen and phosphorus, reduce the ability of global ecosystems to translate the increased photosynthesis into increased biomass and thus carbon storage. Recent studies highlight how CO₂ fertilization effects on vegetation photosynthesis are globally declining as a result of these and other offsetting factors such as water limitations. Second, there are regionally specific processes that determine the net balance of the *natural land sink* and the *net land-use change flux*. While certain tropical regions appear to be at or near sink saturation, other regions such as boreal and temperate zones continue to see their sink capacity increasing. The decrease of the net sink in the tropics is mainly due to human LUC such as deforestation, while several factors drive increase in boreal forests, such as growing season extension and regrowth of forests from past disturbances. In some regions there is also an increase in forest mortality due to changes in the frequency of extreme weather events.

Wildfires and permafrost thaw add to emissions

Unprecedented carbon emissions have occurred due to wildfires in Australia, California, the Amazon, and the Arctic. Wildfires in 2020 are estimated to have caused global carbon losses of 244 megatonnes of

carbon (corresponding to 895 megatonnes of CO₂) and their impacts are predicted to worsen as a result of anthropogenic climate change. The ability of land to take up and store carbon is also negatively impacted by the warming of the soil (which increases decomposition rates) and thawing of permafrost. As was explained in Insight 2, the carbon release by thawing permafrost could be worse than previously expected. This “bad news” in cold regions is to some extent balanced by “good news” in warmer regions: recent studies suggest that previous models used to estimate long-term aridity changes have overestimated dryland aridification as they did not account for the water-saving effect of CO₂ on plants. This means that carbon losses in some dry areas may not be as bad as feared.

The future will depend on how we manage land

Several knowledge gaps exist regarding the future potential of the natural land sink and although it is now widely acknowledged that CO₂ affects the productivity of global ecosystems, it is still unclear exactly to what extent this occurs. Better quantification of land-use change fluxes is thus key for a better understanding of the natural land sink. Land management is still an important unknown, but it is clear that practices that focus on decarbonization and simultaneously address food security, land-degradation and desertification are urgently needed. Different climate strategies based on nature-based solutions – such as the protection and sustainable management of ecosystems, the application of ecosystem-based approaches and of soil carbon sequestration (SCS) – currently exist. If well implemented, these strategies could potentially contribute to the goal of staying well below 2°C. However, approaches based on global afforestation need to take into account the potential negative impacts and trade-offs of tree planting. Focused attention on these knowledge gaps can help narrow down projections of the expected trajectory of the land sink under various socio-economic pathways, to better inform effective policy design.

Historic emissions of carbon dioxide compared to uptake by the land sink

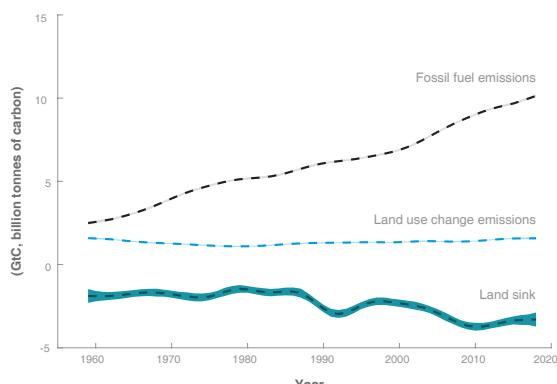


Figure 3. Long-term changes in the land carbon sink, along with the emissions from fossil fuel burning and land use. Data from Tharammal and coauthors, 2019.³

Causes of long-term changes to the land sink, relative contributions

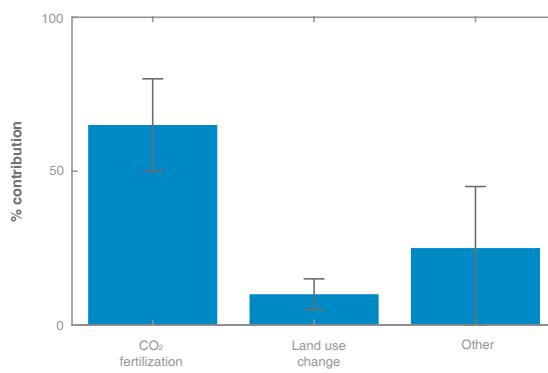


Figure 4. The relative contribution of CO₂ fertilization, land-use change and other factors (such as nitrogen deposition, ozone, phenology) to long-term changes in the land sink. Data from Tharammal and coauthors, 2019.³

4

climate change will severely exacerbate the water crisis

Crises of water quality and quantity are intimately linked with climate change. The impact mainly comes from extreme events of flooding and drought and is compounded by existing inequalities. Water extremes affected by climate already contribute to the migration and displacement of millions of people, and could further global migration crises.



Key new insights

- Crises of water quality and quantity are intimately linked with climate change and increasing extremes.
- New empirical studies show that climate change is already causing extreme precipitation events (floods and droughts), and these extreme settings in turn lead to water crises.
- The impact of these water crises is highly unequal, which is caused by and exacerbates gender, income, and sociopolitical inequality.
- Climate change coupled with socioeconomic drivers can impact access to water of good quality.
- Water-related climate extreme events are contributing to the migration and displacement of millions of people; migration is being treated as an adaptation strategy within the international policy community.

Climate change is already causing extreme events in many watersheds, impacting communities. The UNFCCC *Climate Action and Support Trends 2019* report pointed to water as one of the most vulnerable sectors, poised to impact the greatest number of countries relative to the other sectors identified. Changes in extreme precipitation are likely to be stronger than changes in mean precipitation. Extreme events will continue to increase in intensity and frequency. Extreme precipitation will increase over all climate regions, but with greater intensity in humid and semi-humid regions compared to semi-arid areas. This corresponds with a projected increase in the flood intensity for most areas.

Increase in seasonal variability of rainfall

Changes in precipitation impact the distribution and availability of water across geography and time. Specifically, this means that seasonally variable rainfall regimes are anticipated to become even more variable, whereas regimes with low seasonal variation will receive more rainfall in the monsoon. In terms of aridification, 72% of the global land area is likely to become drier (i.e., experience an increase in the aridity). Even when accounting for vegetation response to the increased CO₂ levels (higher CO₂ concentrations can help plants save water) the aridification is expected to have deleterious effects on ecosystems and the ability to sustain life. The aridification would especially affect the Middle East, North Africa, south Europe, and Australia. Urbanization is further altering rainfall, as part of shifts in regional climate patterns. For example, this is increasingly visible within large urban areas in China, where the magnitude and recurrence of extreme precipitation events is increasing. Increased droughts and floods will drive water scarcity due to physical shortage, or to the failure of institutions to ensure a regular supply, or because of a lack of adequate infrastructure.

Extreme rainfall events less studied

General Circulation Models (GCMs) are essential tools for decision-making related to climate. Yet, recent studies have suggested that current practices using them may underestimate the potential for significant changes in the hydrological cycle, including the risk of extreme events. In using these models, the focus on mean values and variance from that mean overshadows attention to extreme rainfall events. This is problematic since extreme climatic events are very important drivers of water crises, impacting water security in terms of degradation of quality and quantity. Global uncertainty in tropical and subtropical regions is high because of a combination of the difficulty in modeling convective rainstorms and the sparsity of weather observation networks for model validation and refinement. Extremes warrant greater attention in climate modeling and prediction research.

Inequity seen in water crisis impacts

Climate change can impact water quality, as well. For instance, shifts in monsoon timings can lead to dilution or concentration of nitrogen, phosphorus, and other pollutants. The impacts of water crises and climate risks are highly unequal, reflecting social inequality. Inadequate water, sanitation, and hygiene resources disproportionately affect women and girls, leading to negative health and social outcomes. Contamination also impairs the ability of sensitive ecosystems, such as coral reefs, to recover from extreme climate events.

Recent examinations of the 2018 Cape Town water crisis highlight how it is an important illustration of future water insecurity events spurred on in part and made worse by extreme climatic events. A multi-year drought provoked the severe water crisis in Cape Town in 2018, incurring complex political and social ramifications. While existing inequalities were reinforced and competition between water users increased, new opportunities for solidarity and collective action emerged. Water conservation efforts, particularly the city's creative campaign to reduce demand among residents and businesses, reduced the severity of water scarcity.

Water crises can drive migration

There is increasing policy recognition that water-related extreme events are also contributing to the migration and displacement of millions of people. *The United Nations World Water Development Report 2020: Water and Climate Change*, documents these cases and suggests that – rather than trying to prevent climate-driven migration and to support achievement of the Sustainable Development Goals – the international policy community should begin considering migration as a potential adaptation strategy. Migration, urban development pathways, and climate change are disruptors that can catalyze shifts in values toward water use and management. An approach to climate change that recognizes the importance of water can combat both the causes and impacts of climate change. Combining climate change adaptation and mitigation strategies based on water can benefit water resources management, including disaster risk reduction, and improve the provision of water supply.

5

Climate change can profoundly affect our mental health

Understanding and managing the mental health impacts from climate variability and change are growing fields of research, providing evidence of effects such as stress, trauma, depression, and suicide. Climate can negatively impact our mental health through catastrophic events, rising sea levels or high temperatures, or indirectly through distress about future changes. It can affect anyone, but particularly those in vulnerable conditions. These mental health impacts can be addressed by explicitly including them in health systems, city planning, ecosystem and biodiversity conservation and protection, and by promoting access to natural areas and addressing social and environmental justice.



Key new insights

- Climate change can directly and indirectly adversely affect mental health over short and longer time scales. Growing evidence suggests the overall burden of mental health impacts of climate variability is high and will increase with additional climate change.
- Cascading and compounding risks are contributing to anxiety and distress.
- The mental health consequences of climate variability and change can affect anyone but disproportionately affects those suffering from health inequities.
- The promotion and conservation of blue and green spaces within urban planning policies as well as the protection of ecosystems and biodiversity in natural environments have health co-benefits and provide resilience.

Climate change can directly and indirectly adversely affect mental health

Climate change is contributing directly to increased injuries, illnesses, and deaths from climate-sensitive health outcomes, with health risks projected to increase as temperatures, precipitation, and other variables continue to change. There is growing evidence that changing climatic conditions are adversely affecting mental health, including increased risk of stress, clinical disorders (trauma, anxiety, PTSD, or depression), and can even result in increased risk of suicide. Mental health impacts can last for years after an extreme event, and be transmitted to later generations.

Mental disorders and substance-use disorders account for 5–10% of national disease burdens, with women nearly twice as likely as men to suffer from mental illness. Mental and addictive disorders affect more than 1 billion people globally. Growing public awareness of the current impacts and future risks of changing climate and weather patterns could undermine mental health also for those not directly affected by climate-related disaster, especially among youth concerned about the future. Indirect mental health impacts include eco-anxiety, ecological grief, biospheric concern, and solastalgia (distress caused by the experience of environmental change).

Cascading and compounding risks are contributing to anxiety and distress

Cascading and compounding risks across spatial and temporal scales are amplifying the impacts of these events and adversely affecting mental health. Wildfires, rising sea levels, coastal erosion, deforestation, and thawing permafrost will contribute to relocation, displacement, and migration away from vulnerable sites. Population displacement heightens psychosocial risks as community networks, livelihoods, and place attachment are disrupted.

There is growing governmental acknowledgment of the magnitude of the burden of mental health impacts. In Pacific Island countries, climate-sensitive health risks of high priority include trauma from extreme weather events and psychosocial impacts linked to emerging and anticipated climate change impacts. For example, a study of climate change and distress in the country of Tuvalu

found that climate change and the threat it portends for the future is a determinant of distress among residents of Funafuti atoll. In Canada, the 2013 Southern Alberta flood resulted in long-term mental health impacts.

A proactive approach to mental health would increase health and climate resilience

Health systems need to proactively plan to include mental health support for people affected by climate-related disasters. This can be achieved by implementing international agreements around mental health support for affected populations, people on the move, as well as those “left behind.” Further, climate mental health specialists can be trained to provide trauma-informed care for mental distress. One example is supporting those staying in temporary shelters for prolonged periods of time – if shelters are even available – when living spaces are damaged or destroyed.

Further research is required to advance understanding of the causal associations and attributions between climate change – including disasters – and mental health consequences, and what the most effective solutions are. Social and environmental justice concerns need to be addressed as well: to improve communication and outreach; increase mental health literacy; and develop culturally relevant resources. Mental health and well-being and emotional resiliency can be improved when there is an extreme event or disaster, especially by focusing interventions on disproportionately affected groups.

The promotion and conservation of ecosystems and biodiversity, and blue and green spaces have health co-benefits

Measures to protect and strengthen blue and green spaces (accessible open-water surfaces or green spaces), not least those with rich ecosystems and high biodiversity, are important as these are associated with short- and longer term positive mental health and well-being outcomes. These spaces can reduce risk factors for climate-related disasters and extreme events and enhance people’s quality of life. Such measures are fundamental components of climate-resilient development and have multiple benefits, for human health and the health of our natural environment.

6

Governments are not yet seizing the opportunity for a green recovery from COVID-19

Worldwide responses to the coronavirus pandemic have, as a side-effect, led to unprecedented reductions in emissions of greenhouse gases and pollutants. CO₂ emissions dropped by almost 9% for the first half of 2020, with a 17% reduction during peak restrictions. While it may seem encouraging from a climate perspective, the long-term impact will depend on the content of the economic recovery packages. Governments have announced trillions of dollars in stimulus packages but are not yet directing sufficient amounts to low-carbon investments while continuing to fund activities that may lock-in emissions-intense pathways.



Key new insights

- Temporary COVID-19 lockdowns resulted in a large and unprecedented global reduction in GHG emissions and visible improvements in urban air quality.
- The substantial drops in GHG emissions during COVID-19-induced lockdowns are unlikely to have any significant long-term impact on global emission trajectories.
- Governments all over the world have committed to mobilizing more than US\$12 trillion for COVID-19 pandemic recovery. As a comparison, annual investments needed for a Paris-compatible emissions pathway are estimated to be US\$1.4 trillion.
- Stimulus packages allocated by leading economies for agriculture, industry, waste, energy, and transport, amounting to US\$3.7 trillion, have the potential to reduce emissions from these sectors significantly but governments do not seem to be seizing this opportunity.
- Governments' economic stimulus packages will shape GHG emissions trajectories for decades to come – for better or worse. If invested in climate-compatible activities, they could be a turning point for climate protection.

Temporary but sharp emissions reductions in 2020

In order to limit the spread of COVID-19, governments all over the world imposed unprecedented restrictions on human mobility, leading to drastic changes in energy use, transportation, and non-essential consumption activities. As businesses closed, economic activity halted, and many people worked from home, GHG emissions associated with these activities plummeted. Researchers estimate that carbon emissions dropped by 8.8% in the first six months of 2020 compared to the same period in 2019. During the maximum confinement that took place in most parts of the world in April 2020, a 17% decline in carbon emissions was estimated, with emissions in some countries dropping even more. In addition, air pollution was reduced significantly especially in urban areas, attributable to cutting back on automobile use, factory production, and construction activities. However, these drops have been temporary and when restrictions have eased and economic activities resumed, transport emissions have risen towards 2019 levels, except for air-travel emissions, which are still down by almost half. All of these numbers show that long-term climate goals cannot be reached by response strategies adopted during pandemics and temporary economic downturns of even ~3–5% decline in global GDP.

Opportunity for green stimulus spending

To make 2020 a turning point, there is a need for structural changes in production and consumption. An opportunity exists as countries are making plans for injection of money through stimulus packages for economic recovery. Governments are currently mobilizing vast amounts of financial resources for a COVID-19 pandemic recovery effort. Funding of low-carbon (“green”) activities such as renewable energy, energy efficiency, electrification of transport, active mobility, clean R&D, and building efficiency retrofits will accelerate the transition to a low-carbon society. This would bring multiple co-benefits and have synergies with 2030 Sustainable Development Goals such as health improvement and reduction in air pollution.

Clean energy investment has been acknowledged as a major driver of employment and innovation, and offers an attractive risk profile for investors by reducing the possibility of stranded assets.

Brown investments still dominate recovery packages

At the time of writing, more than US\$12 trillion in funding is being allocated by governments globally to stimulate economies. Researchers have estimated that roughly half of this sum is needed over 5 years to reach long-term goals – about US\$1.4 trillion per year for the period 2020–2024 in global investments are projected in order to achieve net-zero emissions by mid-century. In fact, as of October 2020, around US\$3.7 trillion in stimulus funds is being allocated for sectors like agriculture, industry, waste, energy, and transport, which have long-lasting impacts on carbon emissions and nature. However the potential for greening these sectors is not being seized by governments. Furthermore, what is worrying is that fossil fuel-based (“brown”) activities continue to dominate spending from economic recovery efforts, with G20 governments committing US\$233 billion to fossil fuel production and consumption compared to only US\$146 billion to clean alternatives as of November 2020. This type of spending will lock-in such carbon-intensive activities for years or decades, entrenching fossil fuel companies’ role in the global economic system. Meanwhile, green stimulus is falling short of the required investment for a Paris Agreement-compatible pathway.

Responses to the COVID-19 pandemic show that government policies and human behaviour can change dramatically and abruptly when there is urgency, enough impetus to do so, and when decision-makers have no alternative options. The choices that governments and investors make now to rebuild economies – and especially in the coming months when they come out of rescue and crisis mode – will determine the emissions trajectory for decades to come.

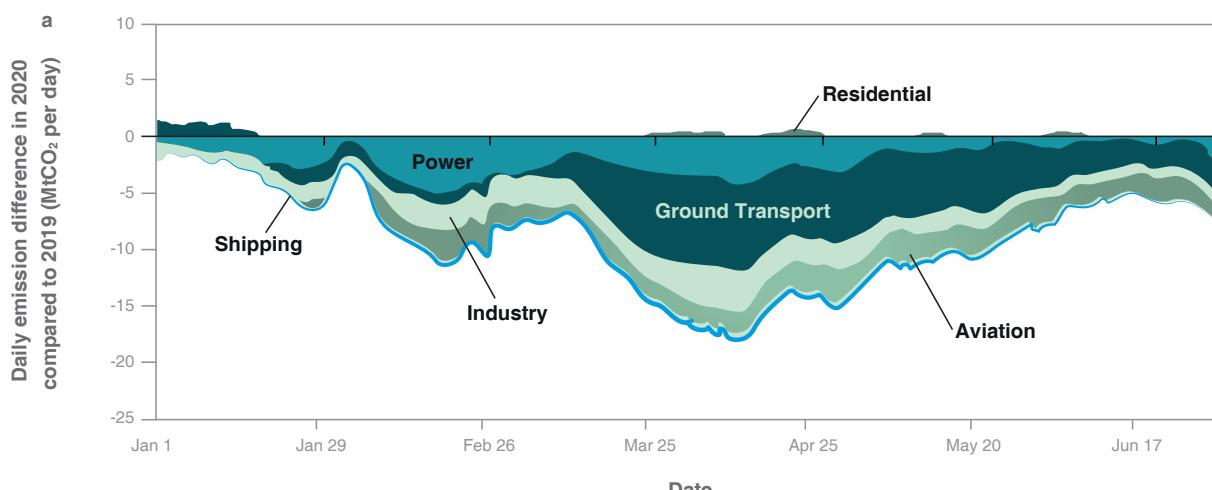
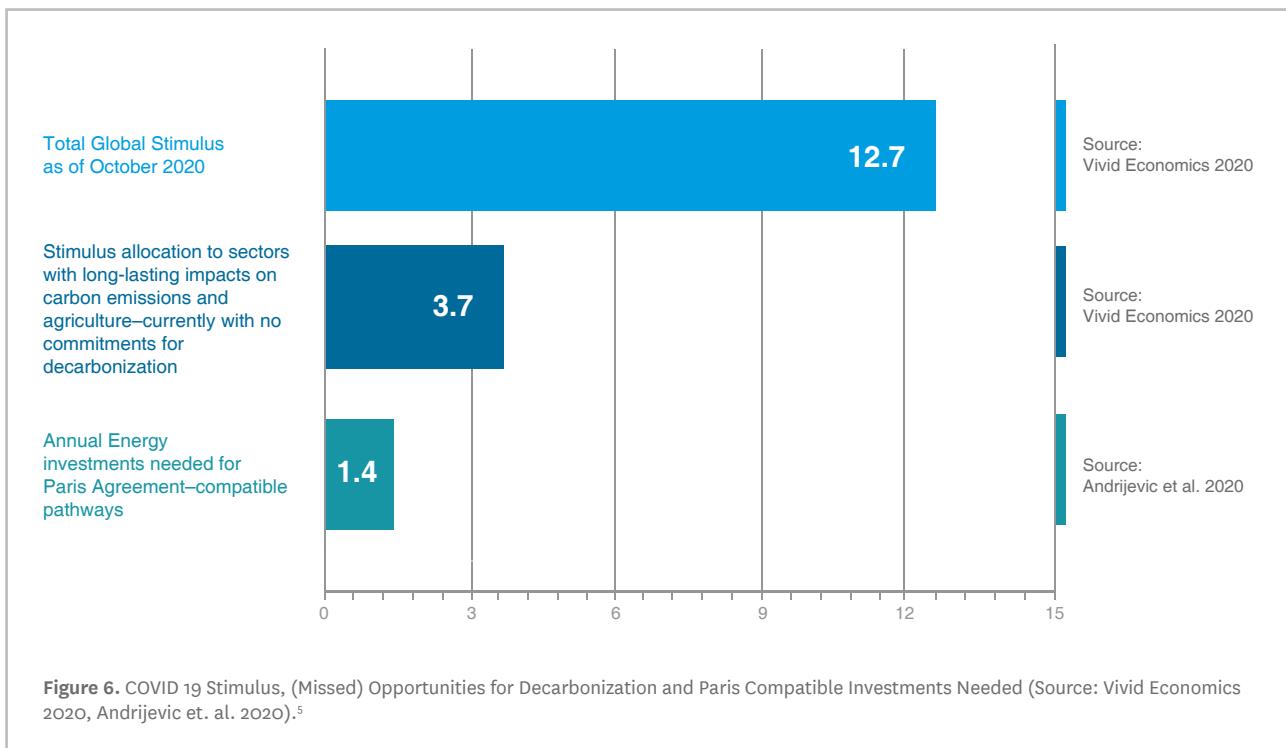


Figure 5. Effect of restrictions to control COVID-19 on global CO₂ emissions in 2020, per sector. Adapted from Liu and coauthors, 2020.⁴



7

COVID-19 and climate change demonstrate the need for a new social contract

The coronavirus pandemic has exposed our societies' vulnerability to systemic crises. Climate change has the potential to be at least as disruptive and we cannot take for granted that current societal systems can gradually adapt as impacts worsen. Instead, new kinds of governance arrangements and global agreements are urgently required to strengthen both the capacity for cross-national collaboration and public support for rapid action.



Key new insights

- COVID-19 and climate change exemplify transboundary risks that erode human well-being and economic security, particularly affecting the most vulnerable.
- The pandemic has spotlighted inadequacies of both governments and international institutions to cope with transboundary risks.
- Accelerating climate risks require innovative approaches to governance.
- Some communities and governments have demonstrated that COVID-19 risks can be addressed with innovative local, national, and international responses, and stronger global responses are needed.
- NGOs, community groups, youth movements, and many other social actors have shown that transboundary responses to global risks of climate change are also possible and there is mounting pressure on governments to act decisively. A new social compact would strengthen the prospects for a humane and just world with a stable climate.

The world urgently needs innovative, imaginative, and transformative approaches to building sustainable and resilient human societies. Across the globe, responses to COVID-19 at local, national, and global scales have revealed the inadequacy of existing capabilities to navigate systemic crises like climate-related disasters and global pandemics. COVID-19 and climate change together not only threaten to disrupt human health and the environment, but also increase racial and social inequality and, without decisive action by governments, exacerbate intra- and intergenerational injustice.

Scientists anticipate that, like COVID-19, the impacts of climate change have the potential to be abrupt and far-reaching, creating a disruptive new normal. The events of the past year challenge myths that systemic risks will occur gradually and that societies and ecosystems will be able to adjust and cope with global environmental changes. Pandemics, extreme weather events, growing inequalities, financial crises, and other global and systemic shocks stem from and profoundly threaten the foundations of our 21st-century societies, including our food, water, energy, data, commodities, manufacturing, and transport systems. The disruptive human and ecological footprints of these systems, as well as their inherent instability, are obstacles to just and equitable societal relations – and they demand a global response.

Heightened awareness of risks and fragile governance

Fortunately, the global tragedy of COVID-19 has heightened awareness and consciousness across many societies of the deficiencies and fragility of global governance, and of the need for cooperative frameworks that would enable the world to respond collectively to shared global risks. While devastating, COVID-19 and the rising impacts felt from climate change are also important opportunities for transformation away from existing economic and social systems that produce and reinforce climate fragility, social inequality, and systemic risks.

Recognizing the challenges that they pose, the world is now in a position to build new kinds of governance arrangements that can navigate global risks and shocks like pandemics and climate change. Innovation can occur

locally, such as with bottom-up community initiatives in Taiwan, in which the online civic and tech community coordinated their activities to leverage government data to develop online maps and tools to successfully combat COVID-19. It can also occur nationally, as in the case of New Zealand, where the government was able to successfully eliminate COVID-19. And innovation can occur internationally, as seen in the ways countries have begun to prepare to coordinate equitable access to and distribution of emerging COVID-19 vaccines although the situation to date remains far from fair.

A new social contract

What is needed now is a new social compact, or global agreement to act,⁶ to tackle global risks systematically. Such a compact will need to include new narratives and moral reasoning on climate justice, fair access and allocation of the planet's resources, and equity in human rights to health and well-being.⁷ New imaginations of a sustainable future and a circular economy with sustainable lifestyles that depart from current consumption and production models will need to guide new policies at all levels of government. Importantly, this project of imagining and creating new, livable, sustainable, and resilient futures must deeply engage the world's youth.

Humanity has the opportunity to develop a renewed focus and commitment between countries to reform institutions and drive just, systemic transitions. There is already evidence of momentum toward climate-friendly global action: the Green New Deal, which has gained traction in the European Union; C40 collaborations between 94 cities; accelerating movements among youth and indigenous climate activists; and the commitments to net-zero carbon emissions by 2050 by a growing array of governmental and business organizations, including the global alliance of 73 parties to the United Nations Framework Convention on Climate Change, with 14 regions, 398 cities, 786 businesses, and 16 investors.

The recent systemic disruptions to global society are perhaps a last chance to create the social foundations for global collaboration to envision and build more humane and sustainable socio-ecological systems on scales from the local to the global.⁸



Youth wearing goggles at the Fridays For Future protest on 27 September 2020 in Taipei, to emphasize the increasing disaster risk due to rising sea levels. Image from Taiwan Youth Climate Coalition

8

Economic stimulus focused primarily on growth would jeopardize the Paris Agreement

An increasing number of studies provide solid evidence that there are substantial co-benefits of climate action and that it is economically optimal to pursue a 2°C or lower warming. This is due to significant cost decreases in low-carbon technologies, while models have been updated to fully capture the societal costs of climate impacts and pollution. Time is running out, however, meaning that green investments and societal changes are required immediately. Economic stimulus focused primarily on growth would jeopardize the Paris Agreement and thereby also threaten long-term social and economic prosperity.

Key new insights



- A growing number of studies highlight the economic benefits of strategies that stay well below 2°C or even 1.5°C.
- The costs of renewable energy, battery-electric vehicles, and other low-carbon solutions have fallen dramatically.
- A COVID-19 recovery strategy based on growth first and sustainability second is likely to fail the Paris Agreement.
- Investments are needed for a system transition but all must contribute to net energy or CO₂ savings in line with the Paris Agreement.

There is no trade-off between sustainability and economic development. A prosperous economy is dependent on productive ecosystems. The suggested economic stimuli in response to the

COVID-19 pandemic provide a unique opportunity to accelerate the investments needed to reach the Paris Agreement and transition to a sustainable economy.

Increasing economic benefits on green transition

An increasing number of studies provide solid evidence that there are substantial economic benefits of climate action in the short as well as long term. Some integrated climate-economic models have previously found that strong mitigation to limit global warming to below 2°C would not be economically beneficial, but when updated with the latest data, these models instead suggest the Paris Agreement targets of 1.5°C or well below 2°C to be cost-optimal. Indeed, a recent study is suggesting that phasing out coal has enough co-benefits to health, local environment, and other direct societal effects that it would be cost-beneficial even when the future damage from a changing climate is not included.

One reason for the shifting economic assessments is that the technology development of renewable energy and electrification options has been much faster than assumed in most scenarios, giving rapid cost reductions. For instance, the global average cost of electricity from solar panels has fallen by 82% between 2010–2019. Of all the newly commissioned utility-scale renewable power generation projects, 56% had a cost lower than the cheapest new source of fossil fuel-fired power. Battery costs have also fallen by almost an order of magnitude in a decade. As a result, in many sectors, a decarbonization strategy will be easier to implement.

“Green growth” not as good as it seems

While the prospects for climate mitigation improve as the economics shift, the time to meet the Paris Agreement’s goals is decreasing and the carbon budget shrinks. Simultaneously, there is an immediate need to stimulate the economy in the wake of the effects of the coronavirus pandemic. This may seem like a perfect time for policies advocating “green growth,” i.e. economic growth decoupled from climate and environmental impacts.

In the short term, there is scientific support for a combination of investments in low-carbon technology that can simultaneously reduce emissions within the remaining carbon budget while stimulating the current economy. Scientific evidence, however, establishes that there is a lack of support for a strategy relying on decoupling of GDP

growth and emissions as a safe method for achieving the goals of the Paris Agreement and long-term sustainability. While technological advances increase resource efficiency and reduce emission intensities, they have historically been outpaced by increases in economic growth and consumption. A recent body of research shows poor evidence for absolute and global decoupling of emissions from economic throughput. In general, high-income countries are also high-emissions countries. There are some examples of countries that have managed absolute decoupling and decreased their emissions, also when weighing in emissions of goods and services from abroad. However, these countries have started from high levels of emissions, had low economic growth, and targeted policy measures.

New economic strategies are required

The lacking historical evidence for decoupling climate from economic growth indicate that different and/or complementary strategies are required. There are models showing possible pathways where modest growth can be achieved while global temperatures are kept in line with the Paris Agreement. They do, however, require drastic behavioural change in addition to technology improvements in order to avoid rebound effects. The issue is that the time available is minimal, so measures need to be taken very rapidly, involving technical and behavioural change at unprecedented levels.

Weighing in the critical time factor, recent scientific evidence shows that if the economic recovery after COVID-19 has a primary focus on economic growth, with sustainability and climate mitigation as a secondary goal, it would jeopardize our last chance of achieving the Paris Agreement and safeguarding people’s health, well-being, and prosperous economic development. A primary focus on greening the economy through sustainable investments will, on the other hand, stimulate economic activity and give other co-benefits. Caution should be taken to avoid adverse environmental or social impacts in attempts to decouple climate change and economic development through, for instance, potential large-scale production of biofuels, geoengineering options, or conflict minerals. As the remaining carbon budget is limited, it is essential to use it on investments that lead to high net CO₂ savings, i.e. have a high return on investment in terms of CO₂-emission reductions. While this is a universal necessity, it particularly applies to high-income countries that have the resources to invest in greener solutions.



9

Electrification in cities is pivotal for just sustainability transitions

Electrification is a key enabler of decarbonization, but the role of urban areas as an accelerator of these processes is only just emerging. Urban electrification can be understood as a sustainable way to reduce poverty by providing over a billion people with modern types of energy, but also as a way to substitute clean energy for existing services that drive climate change and harmful local pollution. Commercial actors such as utilities and investors are increasingly seeing electrification as markets for growth. The current transitions are an opportunity for increased self-sufficiency, decreasing inequalities, and better conditions for small- and medium-sized enterprises. They require a rethinking of energy systems, design thinking, and democratized decision-making.



Key new insights

- Urban electrification is a powerful pathway to an equitable energy transition.
- Over a billion people who currently lack access to electricity will benefit from stronger electrification efforts.
- Reductions in local air pollution and improvements to health and quality of life are tangible co-benefits of urban electrification.
- An actor-oriented, equity-based approach to the transition will maximize the benefits and mitigate the risks of urban electrification, such as generating a new electrical divide.
- Key aspects for a successful transition include considering the constraints of the built environment, equity, governance, and how electricity-powered technologies interact with building design, urban, and mobility planning, and people's use of urban space.

Urban electrification is a strong strategy to leapfrog toward efficient and low-carbon sustainable energy systems and facilitate broad, just changes in the urban environment. The approach aligns adaptation and mitigation with the Sustainable Development Goals, in part due to the tangible co-benefits of improved air quality and associated improvements in health. Urban electrification has a dual meaning. On the one hand it refers to gaining access to electricity in urban areas, particularly those urban areas that are growing rapidly. On the other hand, urban electrification refers to the increased use of electricity as an alternative fuel in urban areas, and the coupling of built environment designs with the development of clean electricity provision systems.

Cities at the forefront

Cities, including government, community, and private actors, are at the forefront of innovation. Cities can become hubs of accelerated and equitable energy transitions. Adaptation may increase energy demand, on account of the population density as well as accounting for informal settlements, environmental inequalities, and energy poverty. Urban electrification opens up opportunities to provide access to clean and affordable energy from renewable sources to adapt. Urban electrification initiatives will benefit over a billion people in the world who lack access to electricity, many of whom live in rapidly urbanizing areas or urbanized areas where access to electricity is highly uneven. In rural areas the potential for mini-grids to deliver income generation and poverty alleviation benefits is limited because electricity demand remains low but the energy poverty impacts of electrification in urban areas are not thoroughly understood.

Electrification as a new source of market growth

Currently, urban electrification is driven by urban buildings and on-road transportation, especially battery electric vehicles, heat pumps, and cookstoves. Utilities and investors see these changes as new sources of growth, as can be seen from the global trends in investment in electricity networks. Rates of decline in carbon intensity are forecast to be faster in cities and with municipally-owned

utilities due to their renewable targets, unique regulatory structures, and prominent roles in regional, state, and national economies.

Urban electrification's full potential lies in fundamentally rethinking electricity provisions from a systems perspective that recognizes the multifaceted value proposition of decentralized energy systems, disrupting powerful centralized high-carbon electricity systems. Urban electrification entails risks because there are significant inequalities of access to decision-making on investments and technologies. Unmitigated, it could deepen the divide between those who benefit and can afford low-carbon systems and those who do not, or who bear the negative impacts. An equity, justice-oriented approach that involves a diverse stakeholder base through the transition is essential to ensure fair innovation processes and that electrification projects do not have unintended negative impacts on vulnerable populations. Leveraging the benefit of urban electrification involves considering the constraints of governance, the built environment, how electricity-powered technologies interact with building design, urban, and mobility planning, and people's use of urban space.

Bottom-up transitions

Many actions can help realize the potential of urban electrification. Communities, local officials, and utilities are introducing decentralized power systems such as distributed energy generation, micro-grids and smart grids. City officials are promoting the use of renewables in their government-owned facilities, integrating them into their building codes, and fostering renewables in the electricity, building, and transport sectors. Grassroots movements such as youth climate activists, community actors and transnational networks are in many cases driving transitions. Their efforts include working on urban planning, green transport, and grid integration, as well as challenging existing power relationships around current energy regimes and the actors and political authorities who maintain them. Addressing the demands of the built environment, institutional constraints, and the carbon intensity of energy sources with an equity approach to a systems transition will enable the benefits of urban electrification to be realized.

10

Going to court to defend human rights can be an essential climate action

Courtrooms have become one of the frontlines for those seeking to limit climate change. The cases that have been fought with climate change as a primary concern have meant an expansion of who and what has legal standing in courts and as a matter of law, and who may represent interests such as those of future generations. The novelty of these cases has meant that the courts learn from each other across jurisdictions, for instance, an international tribunal being influenced by how a national court has dealt with a case or vice versa. The urgency to address climate change has also meant that courts may take on roles as “lawmakers” and enforce action.



Key new insights

- Rights-based litigation is emerging as a tool to address climate change.
- Through such climate litigation, legal understandings of who or what is a rights-holder are expanding to include future, unborn generations, and elements of nature, as well as who can represent them in court.
- Climate litigation shows cross-fertilization between outcomes in different courts and tribunals, such as national case law influencing responses of international tribunals.
- Climate-related court cases address harm to people also across national boundaries.
- Courts come in as “lawmakers” to address climate change, given the absence of adequate climate action in other contexts.

Litigation is an essential tool to urge action to prevent dangerous climate change and support the goals of the Paris Agreement. Most climate cases are public interest litigation against a government, such as the Urgenda Foundation filing a case against the State of the Netherlands in 2015. Claims are also brought against private actors such as oil companies (e.g., a group of environmental NGOs, including Friends of the Earth Netherlands, sued Royal Dutch Shell in 2019). Such cases can be initiated before domestic and international courts, tribunals or human rights treaty bodies or non-compliance mechanisms. Human rights violation claims have served as the primary premise of climate litigation, around which cases in less-developed countries, particularly in Latin America, are growing in number and impact substantively, and we have seen examples earlier in Europe and the United States.

Applying human rights to the context of climate change

Climate litigation is clarifying the content and scope of existing human rights in light of climate change impacts, such as the right to life and of a human right to a clean and healthy environment. The rights-based prism has led to a more focused debate on climate change and improved outcomes on states' obligation of conduct (i.e., due diligence), specifically by refining the requirement of states' climate plans, policies, and laws to reflect on their highest possible ambition. Through these developments we see a critical interplay between scientific evidence and adjudication.

Courts take role as “lawmakers”

Given the urgency to act and the absence of adequate climate action or enforcement, the courts in some cases come in as lawmakers. This challenges conventional interpretations of the balance of power, since developing climate policy is typically the domain of the legislative branch of the state.

Litigation addresses cross-boundary issues

The cross-boundary nature of climate change, both in terms of impacts and cause, makes litigation a critical tool in addressing human rights complaints related to climate change internationally. One contentious issue that climate litigation is useful in determining is whether states are responsible for “imported emissions” (which are produced elsewhere and cause emissions during those processes but are consumed at home) or “exported emissions” (the result of exported oil and gas products that are refined and burned abroad). This is referred to as extraterritoriality. Also, courts, compliance procedures, and human rights treaty bodies are starting to be asked to recognize the standing and rights of those who leave their

country because it no longer sustains their life – climate migrants – like the case of Ioane Teitiota v. New Zealand. Decided by the UN Human Rights Committee in January 2020, this case was the first ruling to determine that for a government to force someone to return somewhere where the adverse effects of climate change could put their life at risk would be a violation of the right to life (on the basis of Article 6, the International Covenant on Civil and Political Rights).

Expanding legal standing and representation

Several recent, and in some instances high-profile, international claims alleging climate change-related harm could provide new conceptions of who or what has legal standing in the eyes of the court and who or what is eligible to represent the rights and interests of future generations to a healthy environment. The range of actors who can represent climate-related cases has widened, to include an NGO, ombudsperson, trustee, institution, governmental agency or a select group of individuals. Children, uncommonly situated as legal actors in the international arena, have initiated cases or similar proceedings as representatives of themselves and, to a certain extent, future generations. Plaintiffs strive to establish victimhood involving future harm or harm to future generations. For example, 16 children – representing 12 nationalities – filed a complaint against 5 countries before the United Nations Committee on the Rights of the Child in 2019 and a group of 6 Portuguese youth lodged an application in 2020 at the European Court of Human Rights against 33 states to provoke more ambitious climate action.

Legal rights of nature

Another pivotal innovation of climate litigation is the development of legal rights of nature. For example, the environmental organization *Asociación Civil por la Justicia Ambiental* filed a case in Argentina in 2020 to recognize a wetland ecosystem as a “Subject of Rights”; and, in 2018 the Colombian Supreme Court found the Amazon to be a legal subject with the right to protection in large part for climate change mitigation.

Cross-fertilization across levels and scales

International courts and tribunals are increasingly recognized as a potentially powerful venue for adjudication and advisory opinions on climate change. States in recent decades have considered international courts and tribunals to be appropriate fora for the settlement of international environmental legal disputes. The demonstrated influence and cross-fertilization among judges, courts, and tribunals at domestic, regional, and international levels further points to their emerging impact on climate litigation more generally.



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