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# Tracking Where Water Goes in a Changing Sacramento-San Joaquin Delta

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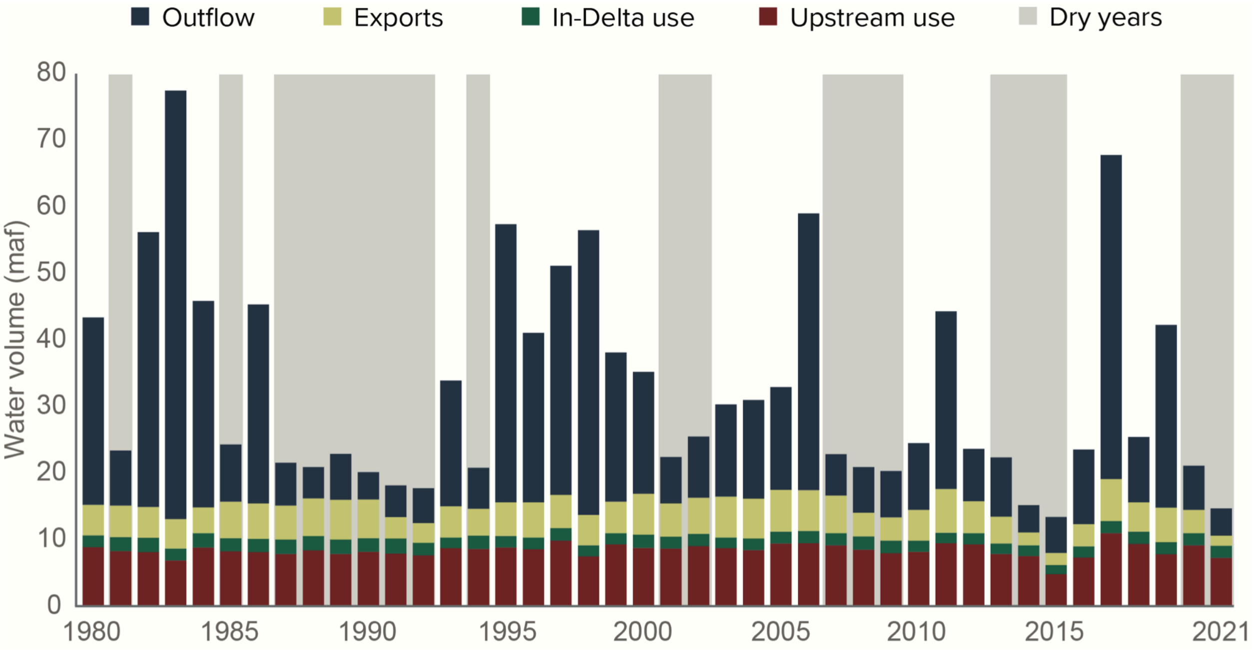
## The Delta is important to all Californians

The Sacramento–San Joaquin Delta lies at the confluence of two of the state's largest rivers and at the head of the San Francisco Estuary. Forty percent of California's runoff comes from the Delta watershed. It supplies water to roughly 30 million residents and more than 6 million acres of farmland upstream of and within the Delta, as well as in other watersheds including the Bay Area, the southern San Joaquin Valley, the Central Coast, and Southern California. The ecological health of the Delta and the reliability of its water supplies are in decline. Given the challenges facing the watershed and the competing uses for scarce supplies, Delta water management issues are a source of conflict and many misunderstandings about water use. Weak water accounting systems make this worse.

## Runoff in the Delta watershed has many destinations

Surface water available in the Delta watershed in any given year can be broken down into three broad categories:

**Water availability and uses in the Delta watershed have been changing**



*Sources: Uses and outflow: Technical Appendix to this report and PPIC Delta Water Accounting spreadsheets; dry years: Department of Water Resources.*

*Notes: Upstream and in-Delta uses (or "depletions") include net water diversions, water consumed by natural vegetation, channel evaporation, and net increases in groundwater storage. In-Delta uses include the legal Delta and diversions by the North Bay Aqueduct and the Contra Costa Canal. Exports are diversions by the Central Valley Project and the State Water Project. Upstream uses include out-of basin diverters in the Tulare Lake basin (Friant project) and the Bay Area (East Bay Municipal Utilities District and San Francisco Public Utilities Commission). Dry years are those classified as critical or dry in the Sacramento Valley based on the California Cooperative Snow Survey. Because this classification factors in the amount of runoff from the previous year, a single below-average year is often not classified as dry.*

- **Water sources.** Rain and snow in the headwaters, along with rainfall in the valley and the Delta, generate runoff. The volume of runoff varies dramatically between wet and dry years, with frequent droughts and occasional floods (see first figure). Upstream reservoirs change the runoff available in any given year by storing water in wet years and releasing it in dry years—such as 2021 (see second figure).
- **Water uses.** Most water use takes place upstream of the Delta, principally for farms, cities, wetlands, and groundwater recharge. Runoff that enters the Delta is used by farms, cities, and habitat within the Delta, and by farms, cities, and wetlands that receive exports from the Central Valley Project (CVP) and State Water Project (SWP). In-Delta water use does not vary much between wet and dry years; upstream use goes up some in wet years—such as 2017—when groundwater recharge is high. Exports vary the most: they are greatest during wet years and reach a low in very dry years—such as 2021 (see second figure).

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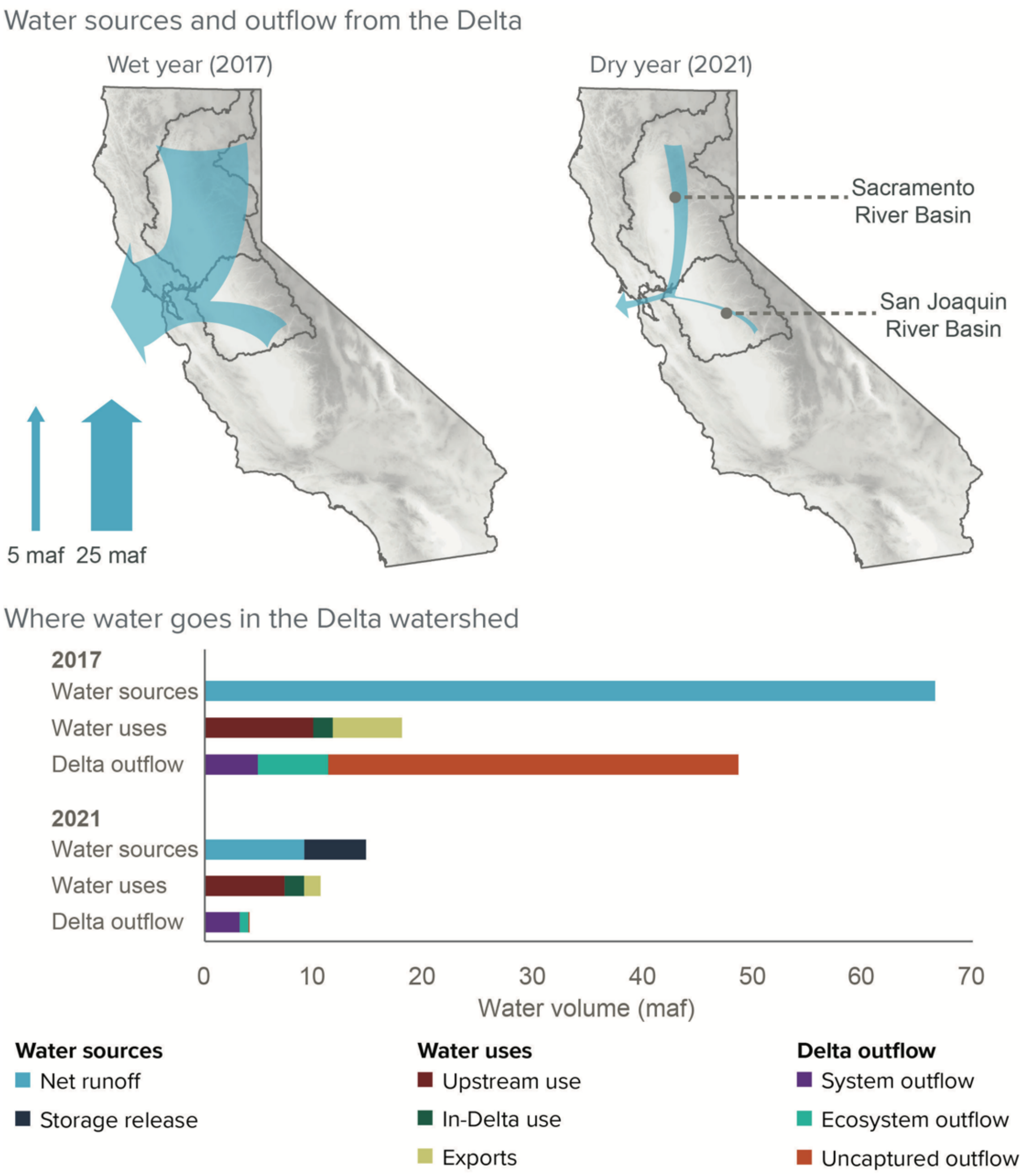
- **Delta outflow.** A significant portion of runoff in the watershed becomes outflow into San Francisco Bay:
  - Some outflow, referred to here as "system outflow," is needed to repel seawater from the Delta at all times. Without it, Delta water would be unusable by cities and farms. In dry periods, reservoir releases are needed to keep salinity low enough. System outflow also supports the Delta ecosystem, but this outflow would be needed to keep water usable, even if there were no ecosystem management objectives in the Delta.
  - Regulations ensure additional outflow to protect the ecosystem and several species of endangered fish. During dry periods, this "ecosystem outflow" is small compared to the outflow needed to maintain salinity, but during wetter years, outflow for the environment increases.
  - Finally, during most years, there are periods when runoff exceeds the capacity of infrastructure to divert and store it. This "uncaptured outflow" becomes quite large during wet years (see second figure).

Tracking water sources, water uses, and Delta outflow in this watershed requires sophisticated water monitoring and accounting systems. Despite some recent improvements, information on some key measures—such as upstream use—is still very limited. This is important because our analysis indicates that water use upstream of the Delta is increasing.

**Comparing Delta flows in wet and dry years**



*Sources: Technical Appendix to this policy brief and PPIC Delta Water Accounting spreadsheets.*

*Notes: Maf is millions of acre-feet. The figures show Delta watershed flows in water years (October 1 through September 30). Map arrows show runoff from the Sacramento and San Joaquin River basins and outflow from the Delta, and are approximately to scale. Bars show the composition of sources, uses, and outflow. Net runoff is total runoff plus Delta precipitation minus net increases in surface storage (in 2017, 3.7 maf). Values for 2017 and 2021 (all in maf) are as follows: net runoff (66.6, 9.1); storage release (0, 5.6); upstream use (9.9, 7.3); in-Delta use (1.8, 1.8); exports (6.3, 1.5); system outflow (4.8, 3.2); ecosystem outflow (6.4, 0.8); uncaptured outflow (37.4, 0.1). Imports from the Trinity River (0.6 maf in both years) contributed to net changes in storage. See text and notes in the first figure for definitions of uses and outflow categories.*

## The watershed is experiencing important changes in runoff and water use

The climate of the Delta watershed is changing, with a significant rise in temperatures over the past few decades. California also has been in a relatively dry spell, following a spate of wet years in the late 1990s (first figure). Warming is increasing "evaporative demand"—or what can be thought of as the "thirst of the atmosphere"—making droughts more intense. Warming is also causing significant declines in snowpack, historically a key part of the watershed's seasonal water storage. These changes are impacting water sources, uses, and outflow—and posing major challenges for water supply managers, fish and wildlife managers, and state and federal regulators. Five key trends have emerged:

- **Upstream use is rising—and Delta inflow falling.** Upstream uses appear to be rising as a share of runoff in the Delta watershed in dry and critically dry years. In 2021, upstream uses accounted for a record 84 percent of runoff from the watershed. This shift is reducing inflows to the Delta, making it harder to meet other management objectives. While it is likely that increased evaporative demand is playing a role, it is not possible to determine the causes of increased upstream water use under the current monitoring system (e.g., drier and thirstier soils, more diversions, more reductions in river flows caused by higher groundwater pumping).
- **Maintaining salinity is requiring more outflow.** During the early 1990s, conditions seem to have changed in the Delta, requiring greater system outflow to meet salinity standards. The reasons are not well-documented, and research is underway to improve the understanding of trends, including estimates of in-Delta use and outflow and how they relate to salinity control. When system water needs increase, this puts increased pressure on upstream reservoirs, which must release more water to meet this higher outflow demand. Looking ahead, studies indicate that changes such as sea level rise, the creation of new tidal habitat in the western Delta, and other factors may lead to the need for more system outflow.
- **Environmental regulations have also increased Delta outflow.** During much of the last century, outflow was declining as water use grew. In the mid–1990s and 2000s, regulations on water flow and quality were expanded—and export pumping limits were set—to improve ecosystem health and protect endangered species. These changes have reduced exports in most years and increased outflow in dry years. In combination, increased outflow to meet salinity standards and protect the ecosystem has broken the long-term decline in the portion of runoff that becomes Delta outflow. Despite these changes, populations of many native species and the health of Delta ecosystems continue to decline.
- **Dry year management increasingly relies on emergency measures.** Eight of the last 10 years have been relatively dry; 2013–15 was the driest and hottest three-year period on record, and 2020–22 is on pace to equal or exceed that. In several of these years, the hot conditions and declining snowpack have significantly thrown off spring runoff forecasts—a crucial metric for managing supplies in dry years. Competing needs in the Delta include supplies for public health and safety and senior water right holders, cold water for salmon, and low salinity for water supply and species. Managing these competing needs has required gubernatorial drought emergency declarations, a relaxation of standards, and the installation of a temporary rock barrier in the Delta to reduce the amount of outflow needed to keep salinity low. Climate modeling suggests that wetter periods are likely to occur in the future, but hot conditions, increasing drought intensity, reduced snowpack, and changing patterns of runoff are here to stay.
- **Wet years are increasingly important for supply.** Even in extended dry periods, wet years still occur and are vital for supply. During very wet years, a large volume of water is uncapturable, and insufficient capacity to store water south of the Delta becomes a limitation on export pumping. Expanding above- and below-ground storage capacity could increase Delta exports without changing current regulations. In such years, more water could also be captured and stored upstream. Managers also need to adapt how they manage water storage in the watershed in a warming climate, where the snowpack is storing less water than it has historically.

## Takeaways for water policy and management

The severe drought that California is now facing—coming so soon on the heels of the record-breaking 2012–16 drought—underscores the importance of adapting water management in the Delta watershed to the changing climate. Important progress has occurred, but more can be done.

- Continue to improve water accounting. Some significant advances in water accounting have been launched since the last drought, including better reporting of surface water diversions under Senate Bill 88 (2015) and better tracking of groundwater use under the Sustainable Groundwater Management Act (2014). Still needed are more frequent and accurate tracking of upstream and in-Delta diversions, along with explicit tracking of the water that returns to rivers and streams as discharges and irrigation runoff. These improvements are essential for tracking scarce supplies and responding effectively to drought in the Delta and its watershed. Technologies are available to help implement these improvements cost-effectively.
- Integrate planning for severe droughts into regular management practices. Within this watershed, water managers and regulators rely heavily on data from the historical hydrologic record to plan and forecast operations and to set regulations. But today's warmer, more intense droughts fall outside the bounds of historical conditions, and reliance on emergency measures to manage drought is now commonplace. To improve response capacity, the state should pivot toward more routine practices for managing severe drought. This includes adapting forecasting to better capture current drought conditions (an effort now underway); developing decision trees to help anticipate situations and prescribe possible actions as the season unfolds; improving the ability to curtail diversions with precision, including for senior water right holders; and considering installation of a permanent, operable barrier in the Delta to better manage salinity.
- Modernize and simplify regulations to provide water for the environment. The current mix of state and federal regulations is unnecessarily rigid, not well coordinated, and not always logical. Two efforts now underway—the State Water Board's comprehensive revision of its water quality control plan for the Delta, and endangered species consultations governing CVP and SWP operations (e.g., Biological Opinions, Incidental Take Permits)—provide an opportunity to coordinate and simplify regulations, and to increase flexibility to help both environmental water managers and water users respond to rapidly changing hydrologic conditions. One central change needed is to pivot from a system based on water year types—where regulatory requirements can change abruptly with subtle changes in conditions—to a system that operates on a continuum based on month-to-month hydrology.
- Prepare for wet years. Increasing the amount of water stored during wet periods—whether by taking more water out upstream of the Delta, or making the best use of export facilities—has to be done with care for the environment and other water users. But it is possible to do a better job of storing water during wet years—both above and below ground—without doing harm. Improving the management of wet-year supplies is a critical climate change adaptation strategy. This will require identifying cost- effective investment options and adapting operations and regulatory approaches to facilitate capturing more water in wet times.

## Fast Facts about Delta Watershed Accounts

- In very dry years, upstream and in-Delta uses consume most of the water in the watershed; in 2021, they used all available runoff, leaving water stored in reservoirs to meet export demands and water quality and flow standards.
- In very wet years, upstream and in-Delta uses consume less than 20% of runoff and exports account for 10%, leaving the remainder (70%) as outflow.
- The annual amount of outflow needed to keep the Delta fresh for in-Delta use and exports varies relatively little in volume (3.5–4.9 maf), but during severe droughts it is four times the amount of outflow needed to meet environmental standards.

- In very wet years, outflow to protect ecosystem health and endangered species accounts for about 10% of all water available, whereas during severe drought it averages 6%.
- The CVP and SWP are required to meet outflow requirements for salinity and ecosystem protection. But these requirements do not always result in corresponding declines in exports—especially in wet years when there is so much water in the system.
- Under current regulations, improving storage capacity south of the Delta would allow for 400,000 af or more of additional exports during wet years.

*This article was originally published as a Policy Brief by the Public Policy Institute of California. The original article, along with the Technical Appendix upon which it is based, can be found on PPIC's website* ***here****.*

## California's Response to a Dry 2022

In the midst of extreme, multiyear drought conditions, early 2022 has been especially dry in California. The state normally relies on winter precipitation building up snow pack in the Sierra Nevada range, which melts later in the year to feed rivers and streams. However, this year, California endured the driest January, February, and March ever recorded, and warm temperatures have reduced snow pack to unusually low levels. California's two biggest reservoirs, Lake Oroville and Shasta Lake, are holding low amounts of water as well. At the beginning of May, Shasta was at only 40% of its total capacity, its lowest ever level at this time of year. Oroville is at 55% of its capacity, which is also well below its normal May level. California was also stricken with severe drought in 2021 – in August, Oroville was at only 24% of its capacity, low enough to force a hydroelectric plant to shut down for the first time in over 50 years of operation.

These reservoirs are critical to California's water supply and their low levels are a red flag for water availability in the state. Lake Oroville is the largest reservoir in the California State Water Project, a series of rivers, streams, reservoirs, and aqueducts that delivers water to about 27 million people and 750,000 acres of farmland. Shasta Lake, likewise, is the largest reservoir in the Central Valley Project, which sends most of its water supply to farms; it provides water to nearly 2.5 million residents and more than 3 million acres of farmland.

The hot and dry conditions that California is experiencing in 2022 have already prompted cutbacks to water deliveries from these two major water projects. In March, officials from the State Water Project announced that they would be curtailing water deliveries to only 5% of normal levels. At the beginning of the year, it was anticipated that deliveries would be at 15% their normal levels, but an exceptionally dry start to the year necessitated this further reduction. State officials noted that they would also provide enough water to meet all critical health and safety needs.

The Central Valley Project is also reducing its water deliveries, but the exact amount of the curtailment depends on the recipient. California's complex water rights system means that some senior agricultural water users could receive up to 75% of their normal allocations, while some farmers without senior rights will receive none of their allocated water. Cities will receive 25% of their normal allocation.

These restrictions to agricultural water supplies will be partially addressed by farmers pumping more groundwater and purchasing water from outside their water district. Groundwater sustainability is a critical issue in California, where wells frequently go dry in times of drought. These additional sources of water will not allow farmers to maintain their normal level of agricultural production. In 2021, also a severe drought year, farmers left almost 400,000 acres of land idle, ceasing to grow more water-intensive crops. A similar situation is expected in 2022.

In response to the drought and curtailments of water supply, the state government has begun taking actions to reduce municipal water use as well. In 2021, Governor Gavin Newsom asked residents to reduce their water use by 15%. This voluntary call to action has not been successful – in January of 2022, water use was actually slightly higher than it was in the same month in 2020. The State Water Board adopted regulations to prevent water waste in January, prohibiting certain wasteful practices like washing sidewalks and driveways with water. In March, Governor Newsom called on local water suppliers to move to Level 2 of their Water Shortage Contingency Plans.

Water Shortage Contingency Plans are locally defined plans to ensure continued water availability for residents during shortages. While these plans are individualized for local jurisdictions, the state provides guidance for effective measures. Typical approaches include public education about water conservation, augmenting local supplies, restricting outdoor watering, and in extreme cases, banning nonessential uses of water.

*RNRF Special Report:*

# Abating Methane Emissions from Oil and Gas

## Introduction

Methane emissions are a significant contributor to global warming, trapping 80 times more heat in the atmosphere than carbon dioxide over a 20-year timeframe. Over a longer period, the warming effect of methane lessens but is still significant – over a 100-year timeframe, methane traps between 27 and 30 times more heat than carbon dioxide according to the **EPA**. The **Intergovernmental Panel on Climate Change** reports that methane has caused about 30% of climate warming since the industrial revolution. These emissions come from several different sources, natural and human. One of the primary sources of methane emissions is the oil and gas industry. Mitigating these emissions has massive potential to make a significant contribution toward meeting climate goals. Because of methane's climate impact on a short timescale, benefits will be realized in the short-term.

Gas has often been touted as an energy source that is preferable to coal for the environment, especially since the hydraulic fracturing boom in the late 2000s and 2010s. In this period, gas became cheap enough to displace a significant amount of coal-fired electricity generation capacity in the United States. When burned, gas contributes significantly less carbon dioxide to the atmosphere than coal, hence the argument that gas is a superior fossil fuel for the climate. Proponents often describe it as a "bridge fuel," which can help slow climate warming and ease the transition to renewables. However, while burned gas contributes less to warming than other fossil fuels, unburned gas contributes to warming as well. At all stages of gas production, transmission, and use, climate-warming methane is leaked into the atmosphere. This puts the "bridge fuel" argument into question – the impact of gas on the climate depends on how much methane is being released.

Methane leakage from the oil and gas industry is in many cases, by its very nature, difficult to detect. Gas leaks from active and inactive wells, pipelines, smaller transmission lines, power plants, and even home appliances add up to have a serious impact on the climate. Often, smaller-scale fugitive emissions go unnoticed. Larger leaks, often dubbed "ultra-emitters" or "super emitters," can release massive amounts of methane over a short period. In recent years, new satellite detection technology **has allowed the detection of these leaks** from space. Despite this new innovation, it is still very difficult to quantify how much methane is leaking from gas infrastructure.

## Comparing Gas to Coal

Because gas has largely replaced coal as the primary fuel used for electricity generation in the United States, the climate impacts of these two fossil fuels are often compared. **Research dating back to 2011** has suggested that, due to methane leakage, gas can actually be worse for climate warming than coal. While that research indicated that warming caused by gas could be 20% higher than that of coal, the authors acknowledged that a lack of accurate monitoring data on leakage makes it difficult to accurately verify this. While this information gap is steadily being closed, lack of data is still a problem today. In reality, the coal-vs.-gas comparison is nuanced and its outcome can be different on a case-to-case basis.

The Proceedings of the National Academies of Science, Engineering, and Medicine released a **study** in 2012 which found that, if more than about 3% of total gas leaks into the atmosphere, the warming effect of that gas is likely worse than that of coal. While the **EPA estimates** that, on average, 1.4% of methane is leaked into the atmosphere through gas operations, multiple studies have indicated that this is a considerable underestimate. For example, a **2018 study published in Science** found that supply chain emissions were 60% higher than the EPA estimate; a 2021 study published in the American Geophysical Union's *Journal of Geophysical Research: Atmospheres* found emissions to be 48%-76% higher. Even some companies that are conscientious about leakage are finding that they had underestimated how much of their methane was escaping. An oil and gas company based in the Permian Basin in Texas **recently found** that they were leaking 4% of their gas after an EPA formula had estimated their leakage at 0.2%, a 20-fold underestimate. Other studies have discovered even more leakage – a **March 2022 Stanford study** estimated that Permian Basin oil and gas operations in New Mexico leak 9% of the gas they extract, making the gas from that region drastically worse for the climate than coal. While leakage should be evaluated on a case-by-case basis, it is clearly evident that, in many circumstances, the transition to gas from coal has had a negative impact on the climate. As data and monitoring on methane emissions improve, understanding of the extent and impact of leakage will become clearer.

### Tracking Methane Emissions and a Roadmap for Reducing Emissions

As the climate impact of methane leakage has become more apparent, it has become an issue of heightened public concern, prompting preliminary action from some policymakers to address it. A prominent voice supporting this action has been the International Energy Agency (IEA). The IEA, a research institution that provides information and statistics about the energy industry, has expanded its mandate in recent years to examine the industry's impacts on the climate and provide support for the clean energy transition. The centerpiece of this effort is their **roadmap to net zero by 2050 for the global energy sector**, which provides support for countries to achieve their climate goals. Alongside this effort, in early 2021, they began releasing tools and guides related to the monitoring and mitigation of methane emissions from the gas industry. These include their **Methane Tracker**, a tool which aims to collect and present the best available data on methane emissions. They also released a report titled "**Driving Down Methane Leaks from the Oil and Gas Industry: A Regulatory Roadmap and Toolkit**," which provides guidance for governments looking to reduce their nation's methane emissions from oil and gas.

These products were launched and summarized at an **official event** hosted in January of 2021. The event was introduced by Dr. Fatih Birol, executive director of the IEA, followed by a presentation by Tim Gould, head of the IEA Division for Energy Supply and Investment Outlooks. They emphasized that there is still uncertainty about the extent of methane emissions around the world, but that the IEA Methane Tracker was an attempt to collect the best available data and improve estimates. The tracker shows that in 2020, methane emissions decreased slightly, but this did not indicate improved abatement action; it was a result of decreased oil and gas production during the pandemic. There is still much work to be done to reduce methane emissions from oil and gas. In 2021, emissions rose again, and the global energy industry released about 135 million tons of methane into the atmosphere. Although several countries contribute to these emissions, Russia and the United States have much higher oil and gas sector emissions than any other country due to their massive gas industries.

Gould noted that the methane tracker compiles original data from the IEA alongside data from other sources to give a complete picture of methane emissions data. Data on sources of methane emissions are still flawed, incomplete, and often conflicting; this tool is a step forward in compiling available information from disparate sources into coherent and consistent estimates. The IEA is working to improve it with new estimates, and in early 2022 updated the tracker with new information and analysis. The tool also includes information on abatement, including different actions that can be taken and their cost-effectiveness. The IEA emphasizes that improvement is possible and realistic, and effective methane abatement has been accomplished in some countries. If all countries around the world performed as well as Norway, methane emissions from the oil and gas industry would fall by 90%. The magnitude of emissions between the highest and least-emitting countries and companies can differ by a factor of 100. Gould said that this could be considered a hopeful message, proving that huge and rapid improvements in performance should be possible in many countries.

Among the IEA's set of tools is satellite data. In 2020, satellites were able to detect 5.5 million tons of methane emissions from oil and gas operations. This a small fraction of the total estimated emissions from the industry worldwide since only super emitter events are detectable from space. In practice, super emitter leaks may not last very long but can allow massive amounts of methane to escape into the atmosphere. A typical leakage rate for these events is about 20 tons of methane per hour. This is equivalent to the emissions from a 600 MW coal-fired power plant. While there are limitations to current satellite technology, it is a big step forward to be able to detect super emitters, and the technology is expected to improve in the years to come to provide higher-quality data.

In his presentation, Gould emphasized that, although current data is still flawed, more than enough information is now available to motivate strong action on methane. Increasingly, governments around the world are motivated to address this issue but lack the tools to do so effectively.

Through the other report described by Birol and Gould, “Driving Down Methane Leaks from the Oil and Gas Industry: A Regulatory Roadmap and Toolkit,” the IEA aims to address this lack of resources. The first recommendation made by Birol was, very simply, that governments include methane targets in their climate commitments. He also noted that, according to the IEA’s analysis of energy markets, the reason to take action on methane is not only environmental or reputational; it has become increasingly evident that consumers are carefully examining emissions profiles when deciding from whom to purchase gas. This makes methane leakage a commercial issue as well.

Abating methane is one of the most cost-effective methods of mitigating carbon emissions. Leak detection and repair is especially cost-effective since methane that is saved from leakage can be sold. Depending on the price of gas, preventing gas leakage can actually be a revenue-positive endeavor for gas companies. Currently, high energy prices are creating an opportunity to abate methane emissions cheaply. However, markets cannot be relied upon as the only incentive to reducing methane emissions. Regulatory action is also important to prevent the implementation of abatement measures from being subject to the notoriously unstable gas markets around the world.

The roadmap and toolkit include a database of mitigation actions that have been taken in various countries. These include a variety of approaches, all of which are prescriptive, performance-based, economic, or information-based. Many jurisdictions already have measures in place. Gould outlined a ten-step guide for policymakers:

1) Understand the legal and political context;
2) Characterize the nature of your industry;
3) Develop an emissions profile;
4) Build regulatory capacity;
5) Engage stakeholders;
6) Define regulatory objectives;
7) Select the appropriate policy design;
8) Draft the policy;
9) Enable and enforce compliance;
10) Periodically review and refine your policy.

Gould emphasized that, in practice, these steps may take place in a different order, and that policymakers may opt to return to past steps at various stages in the process. He ended his presentation by listing key takeaways for designing effective policy and regulation to stop methane leakage from oil and gas operations. He emphasized that policymakers must tailor their approaches to local circumstances, including the local political and regulatory context, the nature of the local industry, the size and locations of emissions sources, and emissions goals. For example, a market dominated by one national oil and gas company would warrant a different approach than a country with several independent companies.

He also emphasized that while improving monitoring and measurement of methane emissions is important, there are policy tools available to reduce emissions even without a strong measurement regime. Leak detection and repair mandates can be effective first steps. These can be developed immediately alongside national measurement and reporting regimes, with the intention to add additional measures over time. Overall, sound policies for the abatement of methane emissions should incentivize early action, drive performance improvements, facilitate proper enforcement, and support flexibility and innovation.

### U.S. Action Under the Biden Administration

In the United States, the Biden administration has expressed its intent to address the issue of methane emissions. In November of 2021, the White House Office of Domestic Climate Policy released the "**U.S. Methane Emissions Reduction Action Plan**," which articulates actions for the U.S. to meet its methane emissions reduction goals. While the action plan covers several different sectors, including agriculture, waste, coal, industry, and buildings, the oil and gas industry is a large focus.

30% of the U.S.'s methane emissions come from natural gas and petroleum systems, more than any other individual sector. The Biden administration has already taken some action to address this, having issued an **executive order** in January of 2021 that directed the EPA to issue regulations under the Clean Air Act to reduce methane emissions from the oil and gas industry. The resultant EPA policy proposal includes three elements:

- Updating and strengthening existing requirements for new sources of pollution, broadening the types of sources covered, and encouraging the deployment of cost-effective abatement technologies.
- Defining guidelines for states to follow in their programs to reduce emissions from pre-existing oil and gas infrastructure. These guidelines include rigorous leak detection and repair, among other measures. This would be the first rule to regulate methane emissions in existing oil and gas infrastructure.
- Seeking further information to help the agency identify cost-effective abatement methods, which will be addressed in a subsequent proposal in 2022.

The White House report claims that this proposal would reduce methane emissions by 75% from the pollution sources it covers. This equates to 41 million cumulative tons of methane abated between 2023 and 2035.

The report also details actions to be taken by the Bureau of Land Management (BLM) and the Bureau of Ocean Energy Management (BOEM) under the Department of the Interior. These bureaus have the responsibility to regulate the oil and gas operations that are located on federal land and in federal offshore waters. Measures that they are planning include requiring oil and gas companies to pay royalties for flared gas, which releases methane into the atmosphere. They are also planning to strengthen regulations on properly plugging retired wells to ensure that they do not keep leaking methane once they are no longer in use.

The issue of plugging inactive oil and gas wells was also addressed in the **Infrastructure Investment and Jobs Act**, passed in November of 2021. The act includes a $4.7 billion program to plug inactive oil and gas wells, many of which are "orphaned," meaning they have been abandoned by the oil and gas industry and often had been the responsibility of companies that are no longer operating. The program gives priority to the wells leaking the most methane. It is estimated that there are 1.6 million unplugged oil wells and 380,000 unplugged gas wells in the United States, creating a significant climate hazard. Unplugged wells are also a threat to the health and safety of the millions of people living in close proximity to them, who disproportionately tend to be people of color and low-income people.

The White House plan also addresses methane leakage from oil and gas transmission and storage facilities. New regulations, implemented under the Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA), will impose new safety rules on previously unregulated pipelines, which will reduce methane emissions. They will also strengthen regulations on LNG facilities. The PHMSA will also propose new rules to expand monitoring and repair of methane leaks on smaller distribution lines, which bring gas to homes and businesses.

These new measures are being proposed and implemented in addition to pre-existing rules on methane first implemented in 2016 under the Obama administration. Those rules were reversed in 2017 during the Trump presidency, only to be **reinstated in April of 2021**. The Obama-era regulations only apply to new oil and gas infrastructure; these new regulations apply to existing infrastructure as well.

## International Action: The Global Methane Pledge

These new domestic methane policies were announced in November of 2021, coinciding with COP26 in Glasgow, Scotland. One of the most significant outcomes of that global climate change conference was a new international agreement on reducing methane emissions, titled the **Global Methane Pledge**. The goal of the pledge is to reduce methane emissions by 30% globally by 2030. This would have the same climate impact by mid-century as shifting the entire global transportation sector to zero emissions. However, while it is a global goal, not every country has signed on to the pledge. 100 countries have signed, including the U.S. and European Union. Signatories only represent an estimated 50% of global methane emissions. Russia, Iran, and Qatar, which are three of the five biggest gas producers in the world, are notably absent. Of the world's five largest methane-emitting countries (from all sources, not only oil and gas) – China, India, the United States, Russia, and Brazil – only the U.S. and Brazil have signed the pledge. Realistically, each of the countries that have signed the pledge will have to reduce their emissions by much more than 30%, assuming that the states that have not signed on will not significantly reduce their emissions.

## Conclusion

Discussions about methane emissions from the oil and gas industry occur against the backdrop of the climate crisis and the imperative to cease burning fossil fuels altogether. Reducing methane emissions from oil and gas is the "low-hanging fruit" of climate action due to its cost-effectiveness. However, the combustion of gas still contributes to the climate crisis. According to the **IPCC's 6th Assessment report**, gas supply and demand will likely have to decline 45% by 2050 (compared to 2019 levels) for warming to remain below 1.5° C. Ultimately, the abatement of methane emissions from the oil and gas industry is a necessary short-term goal that, while realistic, will require considerable regulatory oversight and international cooperation to accomplish. However, it should not distract from the simultaneous goal of reducing the use of oil and gas overall.

# The Costs of Climate Change in India

## A review of the climate-related risks facing India, and their economic and social costs

Angela Picciarello, Sarah Colenbrander, Amir Bazaz, and Rathin Roy

### 1. Introduction

Over the last three decades, India has made rapid progress in boosting incomes and living standards. Before the pandemic struck, the median annual income in India was $2,100 – just shy of eight dollars a day (World Bank, 2021). This is almost a sixfold increase since 1990, yet most Indians still live close to the poverty line.

In that same period, slightly over half of all cumulative global carbon dioxide (CO2) emissions have been released (Ritchie and Roser, 2018). Global warming has consequently accelerated and average temperatures around the world were 1°C above pre-industrial levels in 2017 (Connors et al., 2019). With rapid, ambitious and well-targeted mitigation action, it may be possible to hold the average global temperature increase to 1.5°C at the end of the century (IPCC, 2018). However, current policies will result in warming of at least 3°C above pre-industrial levels (UN Environment, 2020) – and a much more severe climate crisis, the costs of which will be borne most heavily by low-income and other marginalised groups.

India is already experiencing the consequences of 1°C of global warming. Extreme heatwaves, heavy rainfall, severe flooding, catastrophic storms and rising sea levels are damaging lives, livelihoods and assets across the country. Looking forward, the human and economic costs of climate change will only increase.

India does not bear responsibility for rising temperatures. Despite being home to 17.8% of the world's population, India accounts for only 3.2% of cumulative emissions (Global Change Data Lab, 2021). Yet India cannot achieve its development aspirations without taking climate change into account (Dubash, 2019). This statement does not in any way detract from the other enormous and urgent development challenges that India faces. However, it recognises that sustained prosperity and peace will depend on both international efforts to mitigate the extent of climate change, and domestic efforts to adapt to the global warming that is already locked in from historical emissions.

Chapter 2 of this literature review lays out the ways that the climate in India has changed and will continue to change as average global temperatures rise. Chapter 3 reviews the economic costs associated with more frequent and severe heatwaves in India's cities, changing rainfall patterns and accelerated snow and glacier melt, which are contributing to both flooding and water shortages, and steadily rising sea levels on India's long coastline, which are exacerbating the impacts of storm surge and tropical cyclones. Crucially, these costs will be borne unequally within an already highly unequal society: 91% of the adult population in India has less than $10,000 in wealth, while 0.6% has a net worth of over $100,000. There are 1,500 adults who have more than $100 million in wealth (Shorrocks et al., 2018).

The immense and unequal burden already imposed by climate change underscores the urgency of pursuing a just, low-carbon transition. Delays in mitigation and adaptation will only increase the cost of climate change and undermine the prospects for poverty eradication and economic development. Chapter 4 considers India's current efforts to reduce greenhouse gas emissions, and highlights how creating a more

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resource-efficient economy could yield multiple benefits beyond emission reductions, including cleaner air, greater energy security, faster job creation and improved access to jobs and services.

## 2. The direct impacts of climate change in India

### 2.1 How India's climate has changed already

India spans a remarkably wide range of climates. In parts of Jammu and Kashmir, the annual average temperature is an icy 2°C and temperatures in the mountains can fall as low as –45°C. The Himalayas shield most of the country from the cold winds of Central Asia, so the average temperature in some of the southern states is a balmy 29°C. The amount and frequency of rainfall across the country is equally varied. Parts of Meghalaya receive over 4,000 mm of rain a year; parts of the Thar Desert receive less than 100 mm (USAID, 2017). The south-west monsoon (June to September) brings the majority of the country's rainfall, while the north-east monsoon (October to December) plays an important role in supplying southern India. The country's coastline of over 7,500 km also influences local climate patterns.

Taken together, India's size and topography create a wide range of ecological zones, including alpine ecosystems, arid and semi-arid deserts, humid subtropical landscapes and both wet and dry tropics. The country's immense climatic and geographic diversity is key to making sense of the diverse climate change impacts different regions are experiencing.

Recently published data suggests that the average temperature across India increased by 0.62°C over the last 100 years (Government of India, 2021). Temperatures are therefore rising at a slower rate than the global average, but the impacts are nonetheless being felt. Most obviously, rising average temperatures are leading to more frequent and severe heatwaves across the country. Between 1985 and 2009, western and southern India experienced 50% more heatwave events than in the previous 25 years. Heatwaves in 2013 and 2015 killed more than 1,500 and 2,000 people across the country (Mazdiyasni et al., 2017).

Warmer air can hold more moisture than cooler air, while warmer water evaporates faster. The combination of higher air and ocean temperatures is therefore causing more frequent episodes of heavy rainfall across the subcontinent. In central India there was a threefold increase in extreme precipitation events between 1950 and 2015 (Roxy et al., 2017). The resulting floods killed thousands of people and displaced millions more. One tragic example is the floods in northern India in June 2013, where anomalously early monsoon rains melted the snow cover at the top of the mountains – usually otherwise mostly melted by the time the monsoon arrives. The combination of rainfall and snowmelt overwhelmed waterways and caused glacial lake outburst floods. The consequent landslides, debris flows and flooding killed over 5,800 people and caused catastrophic damage to housing and infrastructure (Singh et al., 2014).

While heavy precipitation events are becoming more common, there has been a steady decline in the total amount of rainfall during monsoon events (Mishra et al., 2012; Turner and Annamalai, 2012). Average precipitation is estimated to have fallen around 6% between 1951 and 2015 (Krishnan et al., 2020). The short-term effect on freshwater supplies has been partially offset by an increase in runoff from melting snow and glaciers from the Hindu-Kush Himalaya. Around 50% (by area) of all the glaciers outside the polar regions are found in the Hindu-Kush Himalaya, but those glaciers have retreated at an average rate of 18 metres a year over the last four decades (Singh et al., 2016). The rapid melt temporarily swells India's rivers, particularly in spring and summer. The ice, snow, lakes and wetlands in this mountain range provide freshwater to nearly 1.3 billion people, including many Indians (Xu et al., 2009). However, as the next chapter lays out, this water supply will decline as glaciers retreat and snow cover diminishes.

While meltwater from snow and glaciers has reduced the impact of declining rainfall, it has exacerbated the risk of flooding. In Uttarakhand in 2013, for example, the combination of monsoon rains and spring melt caused floods that swept away temples and residential buildings, killing over 4,000 people (Arcanjo, 2019). In February 2021, the disastrous collapse of the Himalayan glacier in Uttarakhand led to more massive floods in the region, killing over 100 people (Doman and Shatoba, 2021).

Climatic trends in India are intersecting with development trends in ways that often multiply risk and vulnerability. For example, as rainfall has declined, the proportion of precipitation that is infiltrating the soil and recharging aquifers has also fallen because more land is covered by hard surfaces – asphalt, cement and the like. In parallel, Indian agriculture is increasingly dependent on groundwater even as the physical supply is depleted (Zaveri et al., 2016). As a result of the interplay between climatic and development factors, a billion people in India face severe water scarcity for at least one month of the year; 180 million face severe water scarcity all year round (Mekonnen and Hoekstra, 2016). These shortages take place in a context where many people lack adequate water for drinking, sanitation or hygiene.

Higher average temperatures are also driving rising sea levels, partly because the oceans expand as they warm and partly because melting ice sheets are increasing the volume of water. Between 1993 and 2012, the north Indian Ocean rose by an average of 3.2 mm per year. It rose at above- average rates within the Bay of Bengal: over 5 mm a year (Unnikrishnan et al., 2015). Seasonal cycles of sea-level rise coincide with monsoon rains, meaning prolonged periods of inundation (Arcanjo, 2019). Higher sea levels also lead to higher storm surges, which reach further inland, causing more damage during storms, while warmer waters fuel more intense cyclones. Tropical storms have long devastated South Asia's coastline – 70% of global casualties from cyclones and storm surge last century occurred in the Bay of Bengal (Ali, 1999) – but they are becoming more severe and frequent (IPCC, 2019). With sustained wind speeds of over 240 km per hour, 2020's Cyclone Amphan was the most powerful ever recorded in the region (Khan et al., 2020). Coastal communities, particularly those in low-lying areas, are therefore already facing the prospect of permanent inundation, chronic flooding and violent winds. A third of India's population live along the coast (Swapna et al., 2020), and – as of 2000 – over 60 million of them lived less than 10 metres above sea level (McGranahan et al., 2007). The number has almost certainly risen since then.

### 2.2 How India's climate will change going forward

As climate change continues, its impacts will take an ever more serious toll. Of course, the frequency and severity of climate-related risks will depend on levels of global warming. A world that is 3°C hotter will be much more dangerous than one where humanity collectively managed to hold the average temperature increase to 1.5°C.

Going forward, climate models suggest that India will suffer from an additional two heatwaves a year, or an extra 12–18 days at high temperatures, by 2064. Between 2071 and 2099, maximum temperatures during the hottest month of the year in Delhi are projected to be around 38–43°C. This could reduce daylight work hours by almost 25% compared to current levels because it will be unsafe for people to work in such temperatures (Kjellstrom et al., 2017). When combined with high humidity, there is a serious risk that large parts of the Indian subcontinent will not be habitable without fans and air conditioners because people will not be able to maintain healthy core body temperatures (Zhang et al., 2021). The most extreme heat will be borne by central and north-western regions of India, but southern and coastal parts of the country will start to be affected by heatwaves as well (Rohini et al., 2019). Sustained high temperatures take a disproportionate toll on low-income and other marginalised urban residents, who tend to work outdoors and live in crowded, poorly ventilated homes without clean drinking water or cooling systems (Golechha and Panigrahy, 2020).

Rainfall is expected to continue declining, and both snowfall and glaciers in the Hindu-Kush Himalaya are diminishing. Consequently, the flow of water in the Indus, Ganges and Brahmaputra rivers is projected to fall by 8.4%, 17.6% and 19.6% respectively by mid-century, compared to the turn of the millennium (Immerzeel et al., 2010). Water scarcity will threaten food production in the river basins, affecting the livelihoods of 209 million people in the Indus basin and 62 million in the Brahmaputra basin – perhaps more with population growth. In parallel, more heavy rainfall events can be expected, and these events will be increasingly concentrated within a shorter period each year. India therefore also faces more frequent and severe flooding (Mirza, 2011).

Looking towards the end of the century, global sea levels are projected to rise by at least 44–74 cm relative to the mid-1990s, excluding the risk of ice-sheet collapse. Sea levels along the Indian coast are not forecast to rise quite as much as the average, increasing by 20–30 cm compared with current levels (Swapna et al., 2020). Even so, this will have a severe impact on infrastructure and property, particularly in low-lying and densely settled cities such as Mumbai, Chennai and Kolkata. It will also affect low-income rural communities that depend on coastal ecosystems for food and livelihoods, as the disappearance of coral reefs, degradation of mangroves and saline intrusion into the water table affect the productivity of agricultural land and natural ecosystems.

Coastal communities also face more severe storms: cyclones in the Bay of Bengal are projected to nearly double by 2070–2100, compared to the baseline period of 1961–1990 (Sarthi et al., 2014). These storms will be characterised by faster wind speeds, but also greater storm surge due to higher sea levels. Low-income urban households are particularly susceptible, as they often live in dense settlements that lack basic services and infrastructure that could reduce risk: piped water, stormwater drainage, paved roads or decent housing. Many households also live on hazardous sites such as steep slopes, floodplains and low-lying coastal areas, where the cost of land is cheaper and/or formal development is prohibited (Satterthwaite et al., 2020).

Ultimately, the severity of climate-related risks facing India will depend on the choices made about climate change mitigation today. The Intergovernmental Panel on Climate Change (IPCC, 2018) lays out the stark physical differences between an average global temperature increase of 2°C above pre-industrial levels, compared to 1.5°C: more extreme heat, more heavy precipitation, more frequent droughts, faster sea-level rise and greater loss of species and ecosystems. Yet current climate commitments leave the world on track for a temperature increase of at least 3°C by the end of this century (UN Environment, 2020). The next chapter explores how prospects for sustainable development and poverty reduction in India will be shaped by the changing climate, and particularly by how quickly countries close the emissions gap.

## 3. The economic costs of climate change in India

### 3.1 Estimating the economic costs of climate change

Climate change is already slowing the pace of poverty reduction and increasing inequality in India. The districts that have warmed the fastest have seen gross domestic product (GDP) grow on average 56% less than those that have warmed the slowest (Burke and Tanutama, 2019). Without rapid global action to reduce greenhouse gas emissions, rising average temperatures may actually reverse the development gains of recent decades.

It is difficult to estimate the economic and financial cost of climate change impacts due to large uncertainties on every front. The total cost of heatwaves, flooding, water scarcity, cyclones, sea-level rise and other climate-related hazards will be determined by the direction and level of economic development; the choices made in spatial planning and infrastructure investment; and the way different hazards intersect with and multiply each other. Above all, the costs of climate change will depend on the extent of global warming and whether any crucial thresholds are passed that lead to catastrophic ecosystem collapse – an urgent and collective challenge that requires further consideration in debates around climate policy in India (Adve, 2019).

Economic modelling offers tentative estimates of the costs of some climate hazards to the Indian economy over the next century. At the lower end of the spectrum, Kahn et al. (2019) predict that climate change could reduce India’s GDP by around 2.6% by 2100 even if the global temperature increase is held below 2°C; however, this rises by up to 13.4% in a 4°C scenario. These results are narrowly based on projections of temperature and precipitation changes, and the effect on labour productivity in different sectors. Climate change may also affect labour productivity through additional channels, for instance by increased incidence of endemic vector-borne diseases such as malaria, dengue, chikungunya, filariasis, Japanese encephalitis and visceral leishmaniasis (Dhiman et al., 2010).

Kompas et al. (2018) looked at some of the other channels through which climate change may slow economic development in India. Focusing on declining agricultural productivity, sea-level rise and health expenditure, they find that 1°C of global warming would cost India 3% of GDP a year; at 3°C, that cost rises to 10% a year. In an analysis examining the Ganges-Brahmaputra-Meghna and Mahanadi deltas, Cazcarro et al. (2018) estimated that over 60% of cropland and pastureland in these regions is devoted to satisfying demand from elsewhere, thereby sustaining transportation, trade and services sectors as well as agriculture. Thus, the complete climate change-induced disappearance of this activity would entail local economic losses ranging from 18–32% of GDP.

Nixon (2020) takes a different approach, examining the historical relationship between temperature and GDP. This methodology was developed by Burke et al. (2015), though Nixon's analysis draws on more recent data. He finds that India's GDP would currently be around 25% higher were it not for the current costs of global warming, and predicts that, with 3°C of warming, it will be 90% lower in 2100 than it would have been without climate change. This alarming number may better capture the many impacts of climate change than other models, including both direct effects (such as declining agricultural productivity, water scarcity and a rising incidence of

**Figure 1: Projected physical and economic impacts of climate change in India**

Climate change:
physical impacts

**Rainfall patterns**

An extra two heatwaves (12–18 days at high temperatures) each year by 2064.[i]

**Higher temperatures**

Water flow in the Ganges and Brahmaputra to fall by 17.6% and 19.6% respectively by mid-century (compared to end of previous millennium).[ii]

**Sea-level rise**

Sea levels to rise by 20–30 cm by end-century (compared to current levels).[iii]

**Storms and cyclones**

Cyclones in the Bay of Bengal are projected to nearly double by 2070–2100, compared to 1961–1990.[iv]

Climate change:
economic impacts

**GDP**

GDP in 2100 to be reduced by:

- 10% at 3°C of global warming due to declining agricultural productivity, sea-level rise and increased health expenditure.[v]
- 2.6% at <2°C global warming and up to 13.4% at over 4°C of global warming due to declining labour productivity from temperature and precipitation changes.[vi]
- 90% at 3°C of global warming, based on the historical relationship between temperature and GDP.[vii]

*Note: The source studies each adopt different methods, baselines and timeframes. GDP = gross domestic product. (i) Kjellstrom et al., 2017; (ii) Immerzeel et al., 2010; (iii) Swapna et al., 2020; (iv) Sarthi et al., 2014; (v) Kompas et al., 2018; (vi) Kahn et al., 2019; (vii) Nixon (2020).*

vector-borne disease) and indirect effects (such as inflationary pressures, transition risks and productivity shocks).

The immense costs of climate change (Figure 1) will not be borne equally within India. Climate change impacts will be mediated by socioeconomic norms and trends, including urbanisation and industrialisation (Adve, 2019). Income and wealth levels, gender relations and caste dynamics will likely intersect with climate change to perpetuate and exacerbate inequalities. For example, Skoufias et al. (2011) suggest that the combination of rising cereal prices, declining wages in the agricultural sector and the slower rate of economic growth attributable to climate change could increase India's national poverty rate by 3.5% in 2040 compared to a zero-warming scenario; this equates to around 50 million more poor people than there otherwise would have been in that year. Strikingly, while both the urban and rural poor will suffer from higher cereal prices, rural landholders will not experience significant income changes, as higher cereal prices offset declining agricultural productivity (Jacoby et al., 2011).

Neither of these studies accounts for bigger climate risks with greater uncertainties, or which have been outside the bounds of human experience so far (DeFries et al., 2019). These can devastate entire cities and regions. For example, flooding in India over the last decade caused $3 billion of economic damage – about 10% of global economic losses from flooding (Roxy et al., 2017). Cyclone Amphan in 2020 affected 13 million people and caused over $13 billion in damage after it made landfall in West Bengal (Nagchoudhary and Paul, 2020). Low-income households lose much more (relative to their wealth) than higher-income households during such disasters, making it difficult for them to accumulate assets that can enhance their security (Hallegatte and Rozenberg, 2017).

### 3.2 Case studies of the economic costs of climate change

#### Box 1: Disastrous flooding in Mumbai

Greater Mumbai is home to over 20 million people and is one of the most densely populated cities in the world. It is the financial capital of India with a large commercial and trading base. However, most of the coastal city lies less than 15 m above sea level (D'Monte, 2017) and almost a quarter lies below or at mean sea level (Kumar et al., 2008). It is therefore one of the most vulnerable port cities in the world, facing a wide range of climate-related risks including storm surge, flooding, coastal erosion and sea-level rise (Murali et al., 2020).

Climate change is certainly not the only driver of environmental risk in Mumbai. The city was originally built on a series of islands hugging the coast. However, its lakes, rivers, mudflats, wetlands, mangroves, woods and coastline have gradually been built over to serve a growing population and economy. The increase in hard surfaces and loss of tree cover has prevented rainfall from seeping into the groundwater. Instead, it runs rapidly over the asphalt and concrete, pooling in low-lying parts of the city instead of flowing into the sea (Patankar et al., 2010; Sen and Nagendra, 2019). Poor sewage and drainage systems exacerbate the health risks of flooding, which include diseases such as malaria, diarrhoea and leptospirosis (Kumar et al., 2008).

Mumbai is already experiencing catastrophic floods. Hallegatte et al. (2013) rank major coastal cities according to flooding risk, and place Mumbai fifth in the world with annual losses of $284 million. In July 2005, flooding killed 5,000 people and caused economic damage totalling $690 million (Nagendra, 2017). Floods will only get worse when combined with the heavier rains, higher sea levels and more severe storms associated with climate change. Hallegatte et al. (2013) project that annual losses from flooding will reach $6.1 billion per year in 2050. Most of these losses are uninsured and borne by individuals or small businesses (Patankar and Patwardhan, 2016).

### Box 2: Deadly heatwaves in Ahmedabad

In 2020, a number of Indian cities reported temperatures of 48°C or more (Golechha and Panigrahy, 2020). While these extremes captured international attention, there has been less scrutiny of the potentially devastating effects of the combination of heat and humidity (Zhang et al., 2021). Heat stress has long posed a threat to the health and productivity of urban dwellers in India. In 2010, one heatwave killed more than 1,300 people in Ahmedabad alone (Mazdiyasni et al., 2017).

Low-income urban residents are disproportionately vulnerable to high temperatures. Studies in Ahmedabad show that homes in informal settlements are more likely to have roofs made of uninsulated metal or asbestos sheets, which can aggravate heat impacts. Informal settlements are also likely to have less tree cover or green space that can mitigate extreme heat (Mahadevia et al., 2020). People who work outdoors, such as street vendors and construction workers, are also particularly at risk. Studies in Chennai found that heat stress reduces the productivity of construction workers by 18–35% (Chinnadurai et al., 2016).

Based on its tragic experience in 2010, Ahmedabad has developed a Heat Action Plan to address health threats from extreme temperatures. The city has established an early warning system to alert residents about heatwaves, and provides cool spaces and potable water to vulnerable communities during these events. Ahmedabad has also undertaken extensive public outreach to raise awareness about heat preparedness, and trained health care professionals to prevent and manage heat stress. These preventative measures save an estimated 1,100 lives every year (Hess et al., 2018).

### Box 3: Climate change and agriculture

With only about 9% of the world's arable land, agriculture in India feeds about 17.2% of the global population. Over 56% of the country's total agricultural area is rainfed. This means that India's food security and agricultural livelihoods depend heavily on the monsoon, which makes it particularly vulnerable to climate change (Goyal and Surampalli, 2018).

Climate change has already affected hundreds of millions of rice producers and consumers in India. Auffhammer et al. (2012) found that rice yields would have been nearly 6% higher on average were it not for more frequent droughts, warmer nights and lower rainfall. In combination, these changes would have increased the cumulative harvest during 1966–2002 by an amount roughly equal to a fifth of the increase caused by better farming technologies. This is also equivalent to the rice consumption of an additional 30 million people every year over that period (FAO, 2017).

Some agricultural regions are more susceptible than others. South-eastern, western and northern India may be able to maintain or improve rice yields with adaptation, and parts of south-west and central India may benefit from increased rainfall. However, parts of south- west, central and northern India will face lower rice yields even with climate adaptation measures – with a mean reduction across the considered emission scenarios estimated to be around 7% in 2050 and 10% in 2080 (Soora et al., 2013). Wheat yields are projected to decline by 22% by 2100 (Birthal et al., 2014), and yields could become more erratic in response to extreme weather and other climate hazards. There would therefore be years with crop failure, causing food insecurity, income loss, and/or displacement (Naqvi et al., 2020).

These trends also threaten livelihoods. Some 70% of Indian households still depend substantially on agriculture, with 82% of farmers having small or marginal plots of land (FAO, 2020). According to Sarkar (2018), the 2017–2018 Economic Survey released by the Indian government predicted a fall in farm incomes as much as 25% in some areas due to the impacts of climate change.

**Box 4: Climate change and energy**

In 2018, 72% of India's greenhouse gas emissions could be attributed to the energy sector (WRI, 2021), and the country's power-generation systems are vulnerable to the impacts of climate change. Most of India's thermal power plants require a sufficient water supply for cooling and, as outlined above, India faces growing risks of water scarcity. Forty per cent of the country's thermal power plants are in regions with high water stress and consequently have a capacity factor that is 21% lower than their counterparts in regions with low or medium water stress (Luo et al., 2018). In 2016, India lost 14 terawatt-hours of thermal power generation due to water shortages – nor was this an isolated case. Between 2013 and 2016, 14 of India's 20 largest thermal utility companies experienced one or more shutdowns due to water shortages, at a cost of more than 91 billion Indian rupees ($1.4 billion) in potential revenue from the sale of power (ibid.).

Renewable energy offers a partial solution. India is the world's seventh largest producer of hydropower and has immense, untapped potential. Moreover, all seven of India's largest reservoirs are in regions that are projected to be up to 18% wetter by the end of the century (Ali et al., 2018). However, other regions will experience smaller stream flows and less precipitation, so hydropower does not offer a solution for these communities. Solar photovoltaics have immense potential since India receives an average of 300 days of sun each year (Shukla et al., 2018); concentrated solar power will need to play a smaller role in water-stressed parts of the country as it also depends on water for cooling.

Lastly, a large part of India's fossil-powered energy infrastructure lies in areas with high exposure to climate-related hazards. For example, one of the world's largest oil and gas facilities, the Jamnagar refinery in Gujarat, is only slightly above sea level (Roy and Sharma, 2015). Ports where crude oil is imported are similarly vulnerable (Garg et al., 2015). This is not a risk limited to fossil fuel infrastructure: the construction of new solar farms, hydropower plants and other renewable energy systems should be informed by robust projections of future climate conditions.

### 3.3 The existential threat posed by climate change

The physical and economic risks discussed so far have significant impacts in their own right, but also tend to be interconnected in ways that are not always clear or obvious. Considering individual hazards without considering the probability that they will compound one another and multiply existing threats may therefore lead to a dangerously narrow picture of the impacts of climate change. In the case of India, global warming is just one of the myriad stressors facing a country that still has more people living below the poverty line than any other – but it deserves particular attention because of its potential to aggravate other threats (World Bank, 2020).

Globally, there is widespread evidence that climate change can fuel insecurity. Extreme weather events can contribute to instability, particularly in contexts of vulnerability and exclusion: Ide et al. (2020) found that, between 2015 and 2018, political unrest broke out within two months of a quarter of severe flood events across Africa, Asia and the Middle East. The direct climate impacts above (food insecurity, extreme weather, water shortages and so on) can also interact and multiply to drive resource competition, political fragility, economic weakness or large- scale migration (Evans, 2010), which make it even harder to deliver peaceful, inclusive and sustainable development.

However, the pathways between climate change impacts and insecurity vary significantly among regions. As of 2018, there were only nine peer-reviewed studies looking at these dynamics in India (Nordqvist and Krampe, 2018), so country-specific dynamics remain poorly understood. However, there is evidence that loss of agricultural income or loss of natural resources such as fish stocks, timber and water can fuel local tensions and internal displacement (Eynde, 2016). Bhavnani and Lacina (2015) found that irregular rainfall is already contributing to greater rates of internal migration in India, which increases the risk of socioeconomic vulnerability. These examples indicate how climate change is already exacerbating instability and insecurity in India, creating a challenging environment for social capital, entrepreneurship and investment. These trends erode the space for inclusive, sustainable development.

Climate change further threatens India's development aspirations through so-called 'non-linear events', where an ecosystem fundamentally shifts after passing a specific environmental threshold. After this critical tipping point, ecological change can happen rapidly and irreversibly (Hoegh-Guldberg et al., 2018) – a profound threat for a country where most people still depend heavily on subsistence agriculture and natural resources for their livelihoods. In high-emission scenarios, some of the tipping points that might particularly affect India include:

- The collapse of the summer monsoon. Currently, the temperature and pressure gradients across the Asian highlands and Indian Ocean carry moist air over India. As the ocean warms and albedo (reflection of solar energy) increases, the pressure gradient will fall. If it slips below a critical value, the circulation of the summer monsoon may collapse (Zickfeld et al., 2005; Lenton et al., 2008). Such a catastrophic climatic shift would massively increase water scarcity and reduce agricultural output across India.
- The dissolution of coral reefs in the Indian Ocean. Coral reefs in the Indian Ocean are already in decline due to pollution, habitat destruction and eutrophication. They face an additional threat from ocean acidification, caused by the absorption of carbon dioxide. Above a certain level of acidity, the calcium carbonate in many corals dissolves faster than it can be built (Lam et al., 2019). India therefore faces the precipitous disappearance of coral reefs that provide important fish breeding grounds, buffers against storm surge and tourist attractions. The economic costs will be borne particularly by communities living in the gulfs of Mannar and Kutch and on the Andaman, Nicobar and Lakshadweep Islands, which depend on the reefs both for livelihoods and for protection against the sea.
- Loss of Greater Himalayan ice and snow. The Greater Himalayas have the largest area of glacial ice outside the polar regions, as well as permanent snow and seasonal snow packs. Ice and snow melt has long offset periods of drought in India; more recently, higher rates of melting have offset declining precipitation. However, glaciers and snow cover are retreating rapidly across the Greater Himalayan region. When they either disappear or find new equilibria, Indians who depend on rivers such as the Indus and Brahmaputra will face severe water shortages (Xu et al., 2009).

Much depends on India's policy, investment and diplomatic choices over the next decade. As the only country in the G20 that currently has a '2°C compatible' Nationally Determined Contribution (NDC) (Climate Transparency, 2020), India is already doing its fair share of climate mitigation. However, pursuing a more carbon-efficient and resilient pathway would enable India to climate-proof its development gains (Naswa and Garg, 2011; Sadhukhan, 2019). This will require deliberate and transparent governance to meet Indians' social and economic needs within an increasingly stringent carbon budget (Dubash, 2019). The words 'climate' and 'development' are therefore inevitably and closely linked in India for decades to come. The next chapter explores the economic advantages of a just, low-carbon transition.

## 4. Securing a 'triple win' from low-carbon development

### 4.1 India's current climate policies

The Climate Action Tracker rates India's NDC as '2°C compatible'. This means that, although not consistent with the Paris Agreement's target of holding global temperatures to well below 2°C, India's climate commitment in 2030 is considered to represent a fair share of global effort based on its historic responsibility and current capability (Climate Action Tracker, 2020). According to this evaluation, India's NDC outperforms any other G20 country.

India's NDC includes a target of 40% of total installed power-generation capacity coming from clean energy, and a 33–35% reduction in emission intensity of GDP by 2030.The country is making rapid progress towards its energy goals, including extending electricity connections to hundreds of millions of people, encouraging the adoption of energy-efficient lighting and massively expanding renewable electricity, especially solar power. In parallel, many new metro systems have or are being constructed and ambitious goals for vehicle and railway electrification have been announced (IEA, 2021). India is also mainstreaming climate considerations into agriculture and water policies (Dubash, 2013). All of these trends have the potential to raise living standards while reducing greenhouse gas emissions (compared to business-as-usual trends) and enhancing resilience. In many cases, these low-carbon options are more cost-effective than their high- carbon counterparts (Colenbrander et al., 2016); in other cases, they advance urgent political and social priorities such as improving air quality or access to quality jobs and services (Tibrewal and Venkataraman, 2020).

Since the Covid-19 pandemic struck, India has allocated at least $35.37 billion of its fiscal stimulus package to clean energy, including renewables (especially solar power) and energy efficiency. Still more public support has gone to green transport, afforestation and other spending consistent with low-carbon development (IISD et al., 2020; Climate Transparency, 2020). Yet as of April 2021, $29.02 billion had also been allocated in ways that encourage high-carbon production and consumption. For example, funding has been provided for a new coal-fired thermal power plant in Bihar and to purchase new equipment for coal production, such as heavy earth movers (IISD et al., 2020). Coal remains an important source of jobs and public revenues in many parts of India. However, continued support for coal represents a missed opportunity to help these regions pursue a cleaner, more productive and resource-efficient trajectory, a transition that is especially urgent in the wake of a devastating respiratory pandemic.

As a federal country, both the central and state governments shape the carbon intensity of India’s development (alongside other actors such as businesses, international agencies, civil society organisations and local authorities). As early as 2009, the central government urged Indian states to develop their own climate plans, which Jogesh and Dubash (2015: 248) describe as ‘perhaps the largest effort in regional climate planning globally’. Given India’s size and governance arrangements, there is significant diversity in levels of climate ambition, extent of citizen participation and prioritisation of climate issues across the country: for example, Sikkim’s early climate plans focused on water conservation and Himachal Pradesh sought to harness payments for ecosystem services (ibid.). The recommendations of the 15th Finance Commission to maintain fiscal support to state governments and expand their borrowing space suggests that state-level climate policies will continue to play an important role in enabling India to meet and raise its national emission reduction targets.

### 4.2 Charting the way forward

India has low historical and per capita emissions. Average incomes remain low and millions still lack access to decent housing, basic services and secure livelihoods. Accordingly, India has many other urgent priorities and less of a global obligation to mitigate climate change, as recognised by the principle of ‘common but differentiated responsibility’ in the climate accords. This understanding has long shaped debates about climate policy within India, as well as the country’s position in global climate negotiations (Dubash, 2013).

Yet there are two compelling reasons for India to set more ambitious mitigation targets for itself and assume a global leadership role on climate change. First, higher levels of global warming will have devastating human and economic costs. Second, a more climate-smart development trajectory would potentially yield a range of benefits, including cleaner air, higher rates of job creation and greater energy, food and water security. These considerations are shifting domestic narratives around climate change policy, including high-level debates about whether or not to commit to carbon neutrality by mid-century (Chaudhary et al., 2021).

Stronger emission targets do not need to compromise India’s development aspirations. Gradually ending public support for coal and improving the performance of electricity distribution systems would free up fiscal space at a moment when public debt is rising rapidly, or could create the space to support economic diversification in regions that heavily depend on coal for jobs and revenues. Supporting clean electricity generation could tackle the scourge of air pollution while creating hundreds of thousands of jobs. Constructing and extending mass transit systems could also offer substantial new employment opportunities, while stimulating economic growth in the future through agglomeration economies. Conserving and enhancing carbon-rich ecosystems such as forests and wetlands could boost agricultural productivity and enhance resilience to environmental shocks, as well as sequestering carbon dioxide. Pursuing a cleaner, more resource-efficient path could therefore underpin faster, fairer economic growth in India.

These advantages will be especially important in the wake of the pandemic. Covid-19 continues to take a devastating toll on public health and poverty rates. It has highlighted stark inequalities and exposed new vulnerabilities, including the links between air pollution and the severity of Covid-19 infections (Gupta et al., 2021). Once the country has suppressed the virus, a bold and coordinated response will be needed to shore up the economy.

In this context, ambitious climate action could offer a 'triple win' in response to the triple crisis that India currently faces: (1) the health crisis, whereby the devastating impact of Covid-19 is exacerbated by high levels of pollution, as well as water scarcity and extreme heat; (2) the economic and fiscal crisis, whereby extensive poverty and infrastructure deficits are compounded by the recent economic slowdown and rising public debt; and (3) the climate crisis, the impacts of which are being borne first and foremost by low-income and other marginalised groups, exacerbating existing poverty and inequalities.

Securing this 'triple win' will not necessarily be easy: decision-makers will have to carefully craft policies and investments to navigate potential trade-offs and maximise benefits (Kanitkar et al., 2019). For example, a low-carbon energy transition might reduce the cost of improving air quality but increase the cost of enhancing food security or energy access (McCollum et al., 2018). This puts a heavy onus on decision-makers to carefully design and sequence their interventions to minimise the potential costs of low-carbon development, particularly for low-income and other marginalised groups. However, considering the immense human and economic costs associated with a global temperature increase of more than 1.5°C, the advantages of pursuing a green, inclusive recovery cannot be understated.

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# News and Announcements

## American Geophysical Union

**Future of Water Science, Security and Resilience at the Frontiers in Hydrology Meeting**

**June 19 – 24, 2022**

**San Juan, Puerto Rico and Online**

AGU and CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc.) will host the first biennial Frontiers in Hydrology meeting (#FIHM22) in San Juan, Puerto Rico and online, 19 – 24 June 2022. Join us for more than 900 talks and poster presentations on the future of water. Topics include urban and agricultural water systems, green infrastructure, climate resiliency, scarcity and environmental justice.

For more information, click **here**.

## American Meteorological Society

**20th Conference on Mountain Meteorology**

**June 27 – July 1, 2022**

**Park City, Utah**

The Conference on Mountain Meteorology serves to advance and disseminate multidisciplinary research and applications related to complex terrain and of importance to weather, water, and climate. We look forward to bringing the community together during the 2022 conference! The 20th Conference on Mountain Meteorology is hosted by the American Meteorological Society and organized by the Committee on Mountain Meteorology.

For more information, click **here**.

## American Society of Civil Engineers

**International Conference on Coastal Engineering**

**December 4 – 9, 2022**

**Sydney, Australia**

The International Conference on Coastal Engineering (ICCE) is the premier coastal engineering conference held biennially under the auspices of the Coastal Engineering Research Council of the Coasts, Oceans, Ports, and Rivers Institute (COPRI) of ASCE. The Local Organizing Committee is responsible for conference planning and organization. The conference theme is “The Present State of the Art and Science of Coastal Engineering.”

For more information, click **here**.

## American Society Landscape Architects

**Landscape Architects Take Action to Address Systemic Inequities Within Their Profession**

The American Society of Landscape Architects (ASLA) Fund announced today the inaugural class of the Women of Color Licensure Advancement Program.

The program, which launched in February 2022, is designed to support women of color in their pursuit of landscape architecture licensure and provide mentorship opportunities that position women for success. The program aims to increase racial and gender diversity within the profession and was inspired by ASLA's Racial Equity Plan of Action, which was released in 2020.

The first class of the program includes 10 women who identify as African American, Latin, Asian, and Native Hawaiʻian – groups that are among the most statistically underrepresented in the profession of landscape architecture.

To keep reading, click **here**.

## American Water Resources Association

**WEBINAR: MAR in Action: The Role of Managed Aquifer Recharge in Meeting Water Policy Goals**

**June 22, 2022**

**Virtual**

World Water Day's theme, "Groundwater, Making the Invisible Visible," is extending throughout 2022, and Managed Aquifer Recharge (MAR) figures prominently in discussions and publications focused on policy option for addressing water management challenges. Deliberately adding water to an aquifer is recognized as a key mechanism for enhancing water quantity and quality, especially as climate change is placing additional stress on water resources. Using Arizona as a case study, this webinar presentation focuses on how a sound regulatory framework for MAR is foundational to deployment of underground storage and recovery programs designed to meet multiple water policy goals, including those related to Colorado River utilization and shortage conditions.

Sharon B. Megdal, Director of the University of Arizona Water Resources Research Center and AWRA Board member, will draw upon years of MAR experience to discuss Arizona's MAR accomplishments – and challenges.

For more information, click **here**.

## Geological Society of America

**GSA Connects 2022**

**October 9 – 12, 2022**

**Denver, Colorado and Online**

*Geological Society of America returns to Denver — face-to-face with option for full participation online*

Boulder, Colo., USA: Media registration is open now for The Geological Society of America's Connects 2022 meeting, to be held 9–12 October 2022 at the Colorado Convention Center (700 14th Street) in Denver, Colorado, USA. The organizing committee is pleased to be planning a robust meeting with face-to-face scientific exchange along with a fully hybrid option that gives remote attendees full access to participation.

For more information, click **here**.

## Society of Environmental Toxicology and Chemistry

**SETAC North America 43rd Annual Meeting**

**November 13 – 17, 2022**

**Pittsburgh, Pennsylvania and Online**

We are thrilled to tell you that the plan for this meeting is a hybrid format with in-person (yay, face-to-face!) and virtual components (yay, increased inclusivity!) as we continue to support a growing SETAC “neighborhood.” By November, it will have been three, long years since we last met in person. The SETAC North America annual meeting in Toronto in 2019 seems like such a long time ago. So, mark your calendars for 13–17 November, and submit your abstracts, because it’s time to go to Pittsburgh, the Steel City, home of the Steelers and Pirates, the University of Pittsburgh and Carnegie Mellon University. This is no longer the Pittsburgh of the 1970s. It is a showcase for innovation, community and vibrancy.

For more information, click **here**.

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