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Literature review

The costs of climate change in India

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

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Key messages

India is already feeling the impacts of climate change. Heatwaves are becoming more common and severe, with many cities reporting temperatures above 48°C in 2020. Heavy rain events have increased threefold since 1950, but total precipitation is declining: a billion people in India currently face severe water scarcity for at least one month of the year. Rising sea levels are also creating risks as a third of India's population live along the coast, where the north Indian Ocean has risen by an average of 3.2 mm per year over the last two decades.

The economic costs of climate impacts in India are already immense. In 2020, a single event – Cyclone Amphan – affected 13 million people and caused over $13 billion in damage after it made landfall. Declining agricultural productivity, rising sea levels and negative health outcomes were forecast to cost India 3% of gross domestic product at 1°C of global warming.

Low-income and other marginalised groups are most vulnerable to the impacts of climate change. Sustained high temperatures take a disproportionate toll on those who depend on manual outdoor work or live in crowded, poorly ventilated homes. Floods, storm surge and cyclones wreak the most havoc on densely settled, low-income communities not served by risk-reducing infrastructure. One study suggests that declining agricultural productivity and rising cereal prices could increase India's national poverty rate by 3.5% by 2040 compared to a zero-warming scenario; this equates to around 50 million more poor people that year.

Lower-carbon development could yield immediate benefits such as cleaner air, greater energy security and rapid job creation. India's climate targets are considered to be '2°C compatible', i.e. a fair share of global effort. However, pursuing a cleaner, more resource-efficient path could stimulate a faster, fairer economic recovery and secure India's prosperity and competitiveness in the long term.

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About this publication

ODI is currently developing a new programme of work on identifying and managing climate-related financial risks. This includes partnerships to equip leading banks in India with the knowledge and skills to consider climate risks in their financial decisions, and to evaluate policy options available to the Reserve Bank of India to introduce climate risk into its supervision of financial institutions. This literature review of climate-related risks in India has been produced rapidly to inform this work, and hopefully provides a useful summary for policy-makers and practitioners in this space. Warm thanks to our anonymous reviewers for their helpful comments and suggestions.

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Acronyms

CO_2	carbon dioxide
GDP	gross domestic product
G20	Group of Twenty – international forum for global economic cooperation
NDC	Nationally Determined Contribution

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 (CO_2) 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 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 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).

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).

Boxes 1, 2, 3 and 4 examine how climate change impacts may play out in specific cities and sectors.

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).

Box 2 Deadly heatwaves in Ahmedabad (continued)

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).

Box 3 Climate change and agriculture (continued)

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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