

n.17
Summer/Fall
2022



EAERE Magazine

Climate Impacts
and Adaptation

*Module 2:
India*

n.17
Summer/Fall
2022



EAERE

European Association
of Environmental and
Resource Economists

EAERE Magazine serves as an outlet for new research, projects, and other professional news, featuring articles that can contribute to recent policy discussions and developments in the field of environmental and natural resource economics. It is published quarterly in the Winter, Spring, Summer, and Fall. Contributions from the wider EAERE community, especially senior level researchers and practitioners, and EAERE Country Representatives, are included in the magazine.

EAERE President: **Phoebe Koundouri**

Editor: **Frank J. Convery**

Assistant Editor: **Katie Johnson**

Contributing Authors: **Saif Ali, Gaurav Arora, Saudamini Das, Shreekant Gupta, Muthukumara Mani, Anil Markandya**

Graphic Project: **Renato Dalla Venezia**

For questions and comments please contact:
Frank J. Convery – frank.convery@envecon.eu
or **Katie Johnson** – katie.johnson@eaere.org



Table of contents

5	Note from the Editor Frank J. Convery
----------	---

SECTION I THE INDIA MODULE

10	Climate change impacts for India: a review Shreekant Gupta
22	Climate change and living standards in India: hotspots and effective adaptation Muthukumara Mani and Anil Markandya
30	Adapting to a changing climate in India: initiatives, challenges, and future directions Shreekant Gupta and Saudamini Das
42	Climate impacts and adaptation to water stress in India Gaurav Arora and Saif Ali

SECTION II EAERE INTERVIEW

52	Interview with EAERE President Phoebe Koundouri
-----------	--



Frank J. Convery (frank.convery@envecon.eu) completed forestry degrees at University College Dublin and PhD (forestry economics) at the State University of New York, followed by careers at Duke University, Heritage Trust Professor at University College Dublin, and Chief Economist, Environmental Defense Fund. His professional passions: bringing academic research down to where things are done; finding ways that work to protect our shared climate and environmental commons with a focus on mobilizing markets and (latterly) innovation to these ends; help make Ireland and Europe exemplars thereof.

Note from the Editor

For many people of a certain age, Homer Simpson is a sort of oracle. As I reviewed the papers in this issue, I thought of this exchange. Bart: “This is the hottest summer of my life.” Homer: “This is the coldest summer of the rest of your life.”

This Issue

Our series of modules devoted to understanding the climate policy architecture, past and prospective performance, and diplomacy of the Big Four (U.S., China, EU, and India) were published in Issues 11, 12, 13 and 14 respectively and compiled in: [The Climate Policy Baseline of the Big Four \(China, European Union, India, U.S.\) for COP26](#).

Issue 16 addressed climate impacts and adaptation in the EU and this issue (which combines Summer and Fall Issues of EAERE Magazine) is devoted to the same theme in India in the following papers.

1. Climate change impacts for India: a review (Shreekanth Gupta, University of Delhi)
2. Climate change and living standards in India: hotspots and effective adaptation (Muthukumara Mani, World Bank and Anil Markandya, Basque Centre for Climate Change)
3. Adapting to a changing climate in India: initiatives, challenges, and future directions (Shreekanth Gupta, University of Delhi and Saudamini Das, Institute of Economic Growth)

4. Climate impacts and adaptation to water stress in India (Gaurav Arora and Saif Ali, Indraprastha Institute of Information Technology)

It is a truism that countries closest to the equator are already bearing a disproportionate share of the costs of climate change, while being the least culpable in causing it¹. The ground truthing of this reality in India is presented in granular and convincing detail in these papers. Only a few countries in the world have a greater self interest in finding ways that work to successfully address climate change at global level; India’s future economic vitality and social coherence depend on it. Secondly, it has a great domestic interest in finding ways that work to adapt to the climate change that is already ‘baked in.’ Because of the huge demands for domestic investment across a range of issues, economists with others can play a vital role in helping answer the following question: where, what sorts of investment and how much, are likely to yield the greatest value for money in terms of adapting to climate change? As these questions are answered, and as evidence from learning by doing accumulates, India can show the world how best to change when change is necessary and maximize its prospects of external support.

Today, it is impossible to be a credibly-informed citizen of the world and not understand how climate is impacting India, and what it is doing about it. I strongly recommend that you read these papers, and also go back and re-visit issue Issue 14 ([Fall, 2021](#)), wherein a team led by E. Somanathan will deepen your understanding of India’s: climate policy architecture, diplomacy and past and prospective performance.

¹ See: Callahan, Christopher W., and Justin Mencken, 2022. Globally unequal effects of extreme heat on economic growth, *Science Advances*, Vol 8, Issue 43, Oct 28. [Globally unequal effect of extreme heat on economic growth | Science Advances](#)

A favourite poem is by a former colleague, the late Seamus Deane:

*I'll know the library in a city
Before I know there is a slum.
I could wish the weight of
Learning would bring me down
To where things are done.*

We live in a time when our species is beginning to alter the workings of our planet, as we change our climate, and shrink the diversity of nature. Economics can be defined as the science of choice: a lot our doings are about understanding the underlying dynamics of these two earth-changing phenomena, and how to shape them to bring us to a better place. We all struggle to play our part, both personally and professionally, to bring ‘the weight of learning down to where things are done.’ Where does EAERE stand in this context, what should it be doing, and how? I recommend that you read our President Phoebe Koundouri’s answers to seven questions in this issue. You will get a great sense of where we have been, where we are and most importantly, where we could or should be going.

Some Shameless Huckstering

First, apologies: I realise that my preoccupation below is very much a minority interest.

Greenhouse gas emissions from ruminant farming (cows, beef cattle, sheep) in Ireland account for >30% of the country’s total emissions. I have devoted a lot of time over the past few years to baselining climate policy (both emissions reductions and carbon removals) for this sector and looking ahead to what can be, with a specific focus on policy instruments. Sponsored by University College Dublin’s Earth Institute, I decided to write 12 evidence-based blogs on the subject. I did this because I can and no one else will, and to help improve the quality

of the debate in the public square, which continues to be characterized by a lot of misinformation. I am reminded of the Zen saying: ‘Those who say do not know, and those who know do not say.’

Although local in focus, it can have a wider relevance. At this point, most Irish people quote Patrick Kavanagh’s poem ‘Epic’. His own work was based mainly on the local rows of country folk in his home place (rural county Monaghan) but he made the case for its wider import.

*Homer's ghost came whispering to my mind.
He said: I made the Iliad from such
A local row. Gods make their own importance*

‘Epic’ Patrick Kavanagh

Using the link below, you can both find the first five, and sign up to receive the remaining 7 as they are issued. Feel free to forward the link to others who may be interested.

<https://www.ucd.ie/earth/newsevents/climate-policy-agriculture-ireland-blog/>

Thanks and Farewell

This is the last issue of EAERE Magazine that I will edit. Life at its best when you are regularly learning new and interesting things, some of which challenge your preconceptions. Editing this magazine has ensured that the past couple of years have been very good to me, and I would like to thank the following: those who contributed to this issue and past issues of the magazine; the EAERE team in the boiler room who make it possible; you the readers

This Issue

Eudora Welty observed that: “A sheltered life can be a daring life as well, for all seriousness starts within”.

Thanks to our President for her very thought-provoking reflections, and to the 6 authors contributing to the India module. They live (relatively) sheltered lives, but they are also daring. The team was put together and led by Shreekant Gupta. When I asked him to take it on, he was already hugely over committed, but he paused, took a deep breath, and said ‘Yes’. This was before he fell and broke his wrist badly, in several places. An incapacitated hand and associated pain and hospital visits are not congenial companions at any time, but he persevered, and we are all the beneficiaries.

Previous Issues

Thanks to our contributors, most of whom fell into two categories:

The first were those who were commissioned to take on widening and deepening our understanding of climate policy (architecture, looking back, looking forward, diplomacy) for each of the ‘Big Four’ – China, European Union, India and the U.S. – and those who did likewise to deepen our knowledge of the impacts of climate change and adaptation for the EU and India. These modules re-enforce the logic of cooperation if we are to make the transition to a climate-safe world, and the best of news was to hear from the G20 meeting in Bali that president Xi and Biden have renewed their cooperation on climate change.²

The second category were those young people who had won prizes and awards from EAERE for their scholarship and were invited to summarize the essence of their work in our magazine. The main lesson from them is that the renaissance spirit (truth-seeking, courage, openness to the surprise and practical idealism) is alive and well in our association.

The EAERE Team

The following qualities add to an editor’s joy, and reduce stress to a minimum: expertise, calmness under pressure, engaging style, which includes humour imagination and kindness, and willingness always to do what needs to be done regardless of other demands. Assistant Editor Katie Johnson epitomizes these qualities and more; the great shape and style of the Magazine is a product largely of Renato Dalla Venezia; and without Ottavia Carlon its communication to you all would not happen.

The Readers

All of the above would be persiflage without you. Thanks for your presence and your feedback.

2 [Biden-Xi climate cooperation to energise COP27 negotiations | Reuters](#)



Section I

The India Module

Climate change impacts in India: a review

Shreekant Gupta

University of Delhi



Shreekant Gupta (sgupta@econdse.org) is Professor of Economics at the Delhi School of Economics, University of Delhi. His research and teaching are in environment and climate change. He received his PhD from University of Maryland and taught at National University of Singapore and Nazarbayev University. He was Fulbright Fellow at Massachusetts Institute of Technology and Shastri Fellow at Queens University. He has served as President of the Indian Society for Ecological Economics and as Director of the National Institute of Urban Affairs (India). He has also served on various committees of the Government of India, Montreal Protocol and IPCC where he was Lead Author (Sixth Assessment Report) and Coordinating Lead Author (Fifth Assessment Report).

Introduction

All countries are affected by climate change but in different ways and to a different extent. Countries such as India are especially vulnerable to climate change for three reasons. They are located in the warmer tropics and with a large population dependent on farming and allied activities which are particularly susceptible to climate change. Second, these countries have fewer resources to cope with the impacts of a changing climate. Finally, they have a large number of poor and vulnerable people¹. In India, two-thirds of its population of 1.4 billion (it will surpass China in 2023 to become the world's most populous country) is rural. Close to half of its workforce is employed in climate dependent agriculture². It also has the world's largest number people living in extreme poverty³. Regardless of how mitigation scenarios play out and whether or not the 2 degree or 1.5-degree goals are met, India has to confront the impact of climate change now and in the future. Thus, even as India presses on with significant mitigation activities under its NDCs (see papers by Sravanthi Choragudi and by Shoibal Chakravarty in [Convery & Johnson, 2021](#)), attention must be paid to the unfolding impacts of climate change on India and to adaptation. A voluminous literature documents the far-reaching impacts of

climate change on almost every aspect of human society. The economic impacts of climate change have been studied at the national, sectoral and household level for various countries including India. The chain of causation can be direct and immediate (e.g., precipitation/temperature shock leading to crop failure) or indirect and long term (e.g., early life or even *in utero* climate shocks leading to low levels of human capital and adverse economic outcomes later in life -- the *fetal origins hypothesis*⁴). That said, any economic assessment of the impacts of climate change faces "large theoretical and methodological challenges" (Bosello & León, 2022). In an excellent review of the impacts of climate change in the European Union in the [Spring 2022](#) issue of this magazine, Bosello and León (op. cit.) aptly sum up these challenges as those posed "by the long-term nature of climate change, its global dimension, and the fact that non-market values are also involved. All (this) is further complicated by the fact that the phenomena under study are nonlinear, characterized by irreversibility (and) subjected to epistemic and aleatory uncertainty." (Bosello & Leon, op. cit., p. 9)

Bearing these caveats in mind, in this and a companion paper (Mani & Markandya, 2022) in this issue of the EAERE Magazine, we focus on the economic impact of climate change for India.

1 There is an extensive literature on differential effects of temperature shocks with more adverse impacts in countries with hot climates and/or low-income countries but especially those that are both hot and poor. See, for instance, Dell et al. (2012), Burke et al. (2015), Acevedo et al. (2020) Guo et. (2021) and Kahn et al. (2021). Further, Mendelsohn (2016) shows the impacts of weather shocks are likely to be different in hot versus cold climates

2 Rainfed agriculture (without access to either irrigation or perennial snow fed rivers) accounts for 71 million hectares (51% of India's net sown area) and nearly 40% of the total food production (<https://agricoop.nic.in/en/divisiontype/rainfed-farming-system/overview>). Rainfed (i.e., arid and semi-arid) regions of India provide livelihood to nearly 50% of the rural workforce and sustain 60% of the cattle population (MNI et al., 2009).

3 Globally there were 746 million people living in extreme poverty in 2013 (defined as living with less than \$1.90/day) of which 218 million (approx. 30%) were in India alone. [World Bank (Povcal/Net)]. In this article we do not discuss poverty and climate change except in passing. A special issue of *Environment and Development Economics* 23(3), June 2018 is dedicated to papers on that subject.

4 See Almond and Currie (2011) for an early economic interpretation of fetal origins hypothesis.

The analysis by Mani and Markandya is highly granular—at the level of households aggregated to the district or province (state) level⁵. They forecast the locations in India where living standards (household consumption to be precise) will be most severely impacted by future climate—what they term as ‘hotspots’—and the policy interventions that can prevent this from happening. Their spatial analysis of where climate impacts will occur, complements this paper which takes a more aggregative view.

The paper proceeds as follows. In the next section we present a brief overview of climate trends in India. These are discussed in detail in Mani and Markandya (op. cit.) who also present climate projections for India based on a detailed analysis of 18 climate models for various Representative Concentration Pathways (RCPs). In the third section we review the evidence on the macroeconomic impact of climate change for India drawing upon some of the same studies as Bosello and León (op. cit.) but also presenting new research for India, *per se*. In the fourth section we focus on two main impacts (among several), namely, the climate vulnerable agriculture sector and on the effects of heat stress on labour productivity. Section 5 concludes the paper. Our review is selective by design – it is not possible to encapsulate a vast and disparate literature in a short essay. The objective is to focus on salient economic impacts at the macro

level and for a key sector, namely, agriculture. We also present evidence on the economic impact of heat stress on decreased labour productivity. As we show later, agriculture and health dominate in economic damages. Other impacts such as coastal and riverine flooding and extreme weather events are not discussed here.

India's climate - past, present and future

In line with global trends the climate of India is getting warmer, namely, $0.63^{\circ}\text{C}/100\text{yrs}$ for mean temperature and $0.99^{\circ}\text{C}/100\text{ years}$ for maximum temperature since 1901 when nationwide records commenced in the country (Figure 1). The previous year (2021) was the fifth warmest year on record. In fact, eleven of the warmest years in India are from the recent fifteen-year period (2007-2021) and the past decade (2011-2020) was the warmest decade on record. A particularly pernicious manifestation of this warming is greater likelihood of extreme temperatures which in turn could lead to heat waves that devastate crops and rural livelihoods⁶. The frequency, duration and intensity of heat waves in India has increased (Rohini et al., 2016)⁷.

Another crucial aspect of climate change in India is its impact on the timing, pattern and intensity of monsoon season rainfall (June-September). This season provides over 80% of

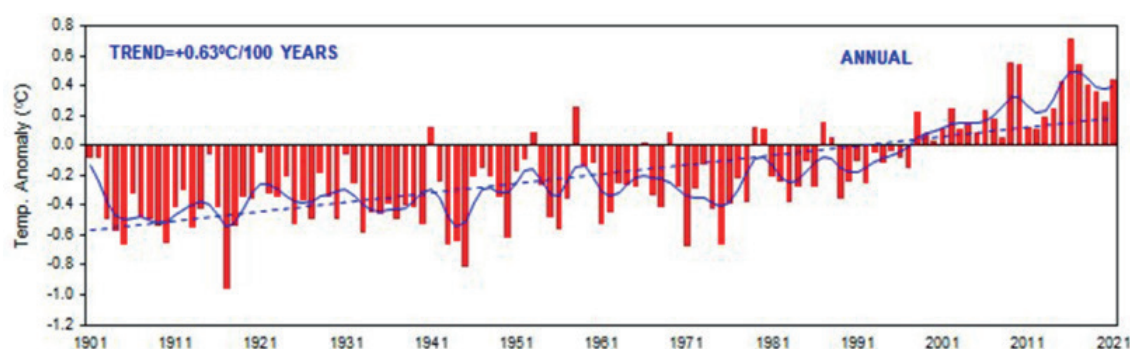


Figure 1. Annual mean land surface temperature anomalies (1901-2021) - departure from 1981-2010 LPA (long period average). Dashed line: linear trend. Solid blue line: sub-decadal time scale variation smoothed with a binomial filter. Source: GOI, 2021.

5 The district is the basic administrative unit in India. The number of districts has increased from approximately 300 in the 1950s to 640 at the last census in 2011 with an average area of 5,500 square kilometres. Districts are grouped into 28 states and 8 union territories that constitute India.

6 Heat waves are anomalous episodes with extremely high surface air temperatures, lasting for several days with serious consequences. Over India, in the past, heat waves have caused more deaths than any other natural hazard (Rohini et al., 2016).

7 “Farmer suicides soar in India as deadly heatwave hits 51 degrees Celsius,” *The Independent*, May 20, 2016. In fact, this year March-April witnessed an unprecedented heatwave – the month of March was the warmest ever in the last 122 years since 1901.

India's rainfall. Beyond its obvious impact on agriculture (which we turn to in a later section), the summer monsoon is such an economically significant weather pattern in India that it has been called its "real finance minister" (by a former Minister of Finance). Its influence on monetary policy has been acknowledged by no less than the Governor of India's central bank. A good monsoon can add half to one percentage point to growth in GDP and can influence interest rates. According to IPCC, climate change has made (and is further expected to make) Indian monsoon more unpredictable, namely, more monsoon rain in future, but also greater variability in its dispersal over the monsoon period and more localised extremely heavy rain in short spans of time^{8,9}.

Macroeconomic consequences of climate change in India

Bosello and León (2022) cite data for the EU from cross-country estimates (Dellink et al., 2019¹⁰; Kahn et al., 2021; and Guo et al., 2021) for GDP losses under various climate scenarios. In addition, they cite from an array of recent research for the EU, *per se*. Following their approach, we first extract estimates for GDP losses for India from the same cross-country studies that they consider. We next look at the few studies that specifically focus on India, in particular those that estimate the impact of climate change at the state level¹¹.

From the cross-country studies it is evident that the low concentration Representative Concentration Pathway 2.6 (RCP2.6) which is consistent with Paris goals, results in significantly lower macroeconomic losses for India, as is the case for EU. But unlike the EU where the losses are negligible or negative if Paris goals are met, for India they are non-negligible and keep rising to as much as a 2.6% to 3.7 % loss in *per capita*

GDP by the year 2100 (Kahn et al., 2021, Table 6). Likewise, in Guo et al. (2021) in an optimistic 1.5°C scenario, GDP loss by mid-century is only 0.2% for Europe but 0.8% for India. For more plausible climate scenarios, namely, 2.0 to 2.6°C increase in temperature, GDP losses in Europe remain below 1% but exceed 3% for India (Guo et al., op. cit., Table 2). Dellink et al. (2019) project an increase in temperature of about 2.5°C by 2060 with a corresponding loss of 0.4% of GDP for OECD Europe but 4.3% for India, an order of magnitude higher. In their analysis, among the 25 major regions of the world, India is the worst impacted. In the Kahn et al. (2021) study under the worst case 'no action' climate scenario (RCP8.5), per capita GDP losses in India may go up to 9.9% to 13.4% by 2100, which is twice that of the EU, namely, 4.7% to 6.7% (Kahn et al., 2021).

From these cross-country studies of the macroeconomic consequences of climate change we conclude most countries and regions will be negatively affected. However, the poorer and warmer parts of the world especially India will be worst hit whereas the impact on regions such as the EU will be relatively mild. To paraphrase a widely used term, the impact will be 'common but differentiated.' Even under optimistic climate scenarios (limiting warming to 1.5 to 2.0°C) aggregate and per capita GDP losses for India are not negligible and in fact, under more realistic scenarios of greater than 2°C warming, these losses will be fairly high (Guo et al., 2021; Dellink et al., 2019).

To make matters worse, uncertainty about equilibrium climate sensitivity (ECS) implies temperatures could be much higher than their central estimates and the consequent impact on GDP could be huge. Figure 2 shows that potential GDP losses for India which are already the highest become much larger when climate sensi-

8 "There has been a noticeable declining trend in rainfall with monsoon deficits occurring with higher frequency in different regions in South Asia. Concurrently the frequency of heavy precipitation events has increased over India while the frequency of moderate rain events has decreased since 1950 (high confidence)." IPCC 2021, AR6, WG1, Atlas p.1979: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Atlas.pdf

9 "The number of days with zero rain and very heavy rain is increasing, but the number of days with moderate rainfall, which is very good for agriculture, is decreasing," Pulak Guhathakurta, head of the Climate Research Division at IMD, Pune as quoted in <https://www.indiaspend.com/earthcheck/climate-change-is-making-indias-monsoon-more-erratic-780356>

10 This in turn based on an earlier study by the authors, namely, OECD (2015).

11 Several Indian states are as large as countries in the EU. For example, the northern state of Uttar Pradesh (UP) is the same size as United Kingdom whereas Rajasthan, Madhya Pradesh and Maharashtra are as big as Finland, Poland and Italy, respectively. In terms of population of course they are much larger - UP alone has about the same population as Germany, the United Kingdom and France combined. Thus, a state level analysis of the economic impact of climate change is informative.

tivity is higher than its central estimate of 3. In fact, they run into the double digits for (very) high values of climate sensitivity. Thus, the range of GDP loss for India is 1.9% to 8.4% by 2060 for a likely ECS uncertainty range of 1.5°C-4.5°C. With a wider ECS uncertainty range (1°C-6°C) GDP loss is between 1.2% and 12.5% (OECD, 2015; Dellink et al., 2019). These are staggering figures especially for a

op. cit., p 126-127). The answer is that under business-as-usual emissions, projected climate damages are equivalent to a massive 29% reduction in annual per capita GDP each year for the next 20 years. Even with a less catastrophic temperature increase of 3.5°C, this loss would be 10% per year for 20 years. The biases in this "what-if" scenario go in both directions – damages are understated since these are dry

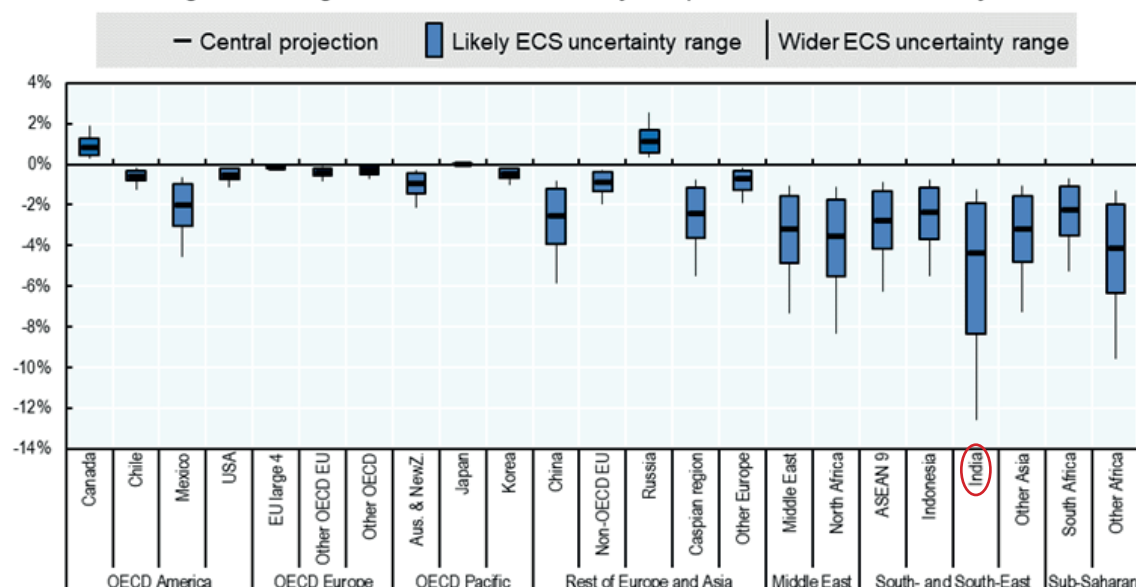


Figure 2. Percentage change in GDP in 2060 compared to no-damage baseline, showing uncertainty in damages in 2060 due to uncertainty in equilibrium climate sensitivity (ECS). Source: OECD, 2015; Dellink et al., 2019.

Used with permission of OECD, from *The Economic Consequences of Climate Change*, OECD Publishing, 2015; permission conveyed through Copyright Clearance Center, Inc.

country that already has low levels of income and a high incidence of poverty.

LoPalo et al. (2020) is a macroeconomic simulation for India, *per se*, using the RICE multi-region integrated assessment model (Nordhaus, 1996, 2010, 2014) which features India as a separate region. Thus, they are able to quantify cumulative damages from climate change for India in terms of near-term consumption-equivalent losses: “by what percent would per capita consumption need to be reduced for the next 20 years to match the total welfare losses associated with climate change? What reduction in near-term consumption would be just as bad, from the point of view of the SWF (social welfare function), as climate damages will be?” (LoPalo,

bulb temperatures and do not include the impact of humidity¹². At the same time, adaptation is not included which could reduce damages.

As stated earlier, given the size of India and its varying climatic conditions¹³, it is instructive to examine the macroeconomic impact of climate change at the subnational level (Verma, 2019; Jain et al., 2020; Sandhani et al., 2022). State level panel datasets reveal significant adverse impact of temperature on growth rates of state domestic product (SDP) and per capita SDP. A 1°C increase in contemporaneous temperature reduces SDP growth rate that year by 2.5% (Jain et al., 2020) by 2.11% (Verma, 2019) or by 1.7% (Sandhani et al. 2022). Per capita income declines by 1.94% for every 1°C increase in mean

¹² As would be the case if instead wet-bulb globe temperature (WBGT) was used. See next section for a discussion of WBGT.

¹³ It is quite common for different parts of the country to experience floods and droughts at the same time (or even within a large state such as Uttar Pradesh).

temperature (Verma, *op. cit.*). Further, the adverse impact of higher temperatures is more severe in poorer states and in the primary sector (Jain et al., *op. cit.*). Agriculture as expected is the worst impacted with a 1°C increase in temperature reducing the growth rate of agricultural output by 5.1% (Verma, *op. cit.*). Going below the state level, higher temperatures have a significant negative impact on poorer districts, with a 1°C increase in temperature leading to a nearly 4.7% fall in the growth rate of district per-capita income (Sandhani et al., *op. cit.*).

Findings on ‘growth versus level effect’ of climate change for India are inconclusive. This is an important issue since Dell et al. (2012) find higher temperatures have a permanent impact on growth rates in poor countries¹⁴. In fact, even for a rich country such as the United States, using a long (55 year) panel of all 50 states, Colacito et al. (2019) show increases in summer and fall temperatures have lasting effects on output growth. For India, Sandhani et al. (*op. cit.*) find some evidence that higher temperatures not only have level effects but also have growth effects, especially for richer districts, but Jain et al. (*op. cit.*) do not find a permanent impact of contemporaneous temperatures on future growth rates. But as they observe, it is not so much that higher temperatures do not have a permanent impact on growth rates but more likely, the dataset is not large enough to detect persistent growth rate effects.

Before we move on to a more disaggregated view of economic impacts, we note the preceding discussion has sidestepped issues of surprises, tipping points and irreversibility all of which

can lead to fat tail risks as temperatures increase (Weitzman, 2009, 2011) and which these analyses cannot capture. In that sense these numbers should be taken as indicative only. Adaptation may help reduce the impact of climate changes but not if these are abrupt and highly non marginal¹⁵.

What is driving these losses?

At a global level and for most regions, climate impacts on health and on agriculture tend to dominate. By 2060 health impacts are the largest category contributing 0.9% to GDP loss and this is true for India as well (Dellink et al., 2019)¹⁶. This is largely due to reduced labour productivity from occupational heat stress. In this section we first marshal the evidence on the economic impact of heat stress and then examine losses in the agriculture sector.

Decreased labour productivity from occupational heat stress is projected to reduce total working hours worldwide by 2.2% (equivalent to 80 million full time jobs) and global GDP by US\$2.4 trillion in 2030 (ILO, 2019)^{17,18}. These costs will be distributed unevenly across the world, with tropical regions experiencing the greatest impacts and poor communities bearing the brunt of the effects (Kjellstrom et al., 2016). South Asia (along with West Africa) will be the worst affected region. In terms of sectors, agricultural and construction workers are expected to be the worst affected globally, accounting for 60% and 19%, respectively, of working hours lost to heat stress in 2030 (ILO, *op. cit.*)¹⁹. Figures 3(a) 3(b) show the global incidence of heat stress, i.e., distribution of WBGT in 1995

14 Higher temperatures can lead to climate impacts such as coastal flooding and extreme weather events which destroy capital stock and thus have a permanent effect on the economy.

15 Other articles in this issue of the EAERE magazine consider the economics of adaptation for India.

16 For the EU, however, GDP losses are largely due to coastal damages from sea level rise and riverine floods and to a lesser extent decreased labour productivity due to heat stress in the southern and central-eastern EU. Agricultural losses are rather small (Bosello & León, 2022).

17 Heat stress refers to heat received in excess of that which the body can tolerate without suffering physiological impairment. It reduces productivity and can lead to heatstroke and, ultimately, even to death (ILO, 2019). The key concept here is wet-bulb globe temperature (WBGT) a measure that combines, within a single index, temperature, humidity, wind speed and heat radiation, all of which affect rates of heat transfer from the body. When hourly WBGT exceeds 26°C, work capacity is reduced in heavy labour jobs, and above 32°C work activity is made difficult (ISO, 1989). Wet-bulb temperature is not WBGT, but it is a key factor in the WBGT calculation. It is the lowest temperature that can be reached under current ambient conditions by the evaporation of water only. A wet bulb temperature of 32°C is usually the maximum that a human body can endure and carry out normal outdoor activities (equivalent to a dry temperature of 55°C). The theoretical maximum wet bulb temperature is 35°C—most humans, even with unlimited water supply, are likely to suffer heat strokes at this level, likely leading to death.

18 Ionnau et al. (2022) and Flouris et al. (2018) are recent meta-analyses of occupational heat stress on labour productivity. Kjellstrom et al. (2016, 2009a) highlight the important role of climate change in this regard especially with regard to low- and middle-income countries. Finally, an important contribution by Kjellstrom et al. (2009b) uses climate models to calculate current and future distributions of daily daytime WBGT (“work WBGT”) for various regions of the world and estimates potential labour productivity losses due to climate change for each major labour sector (agricultural, industrial, services).

19 Recall that nearly 46% of India’s workforce numbering 512 million in 2019-20 is employed in agriculture.

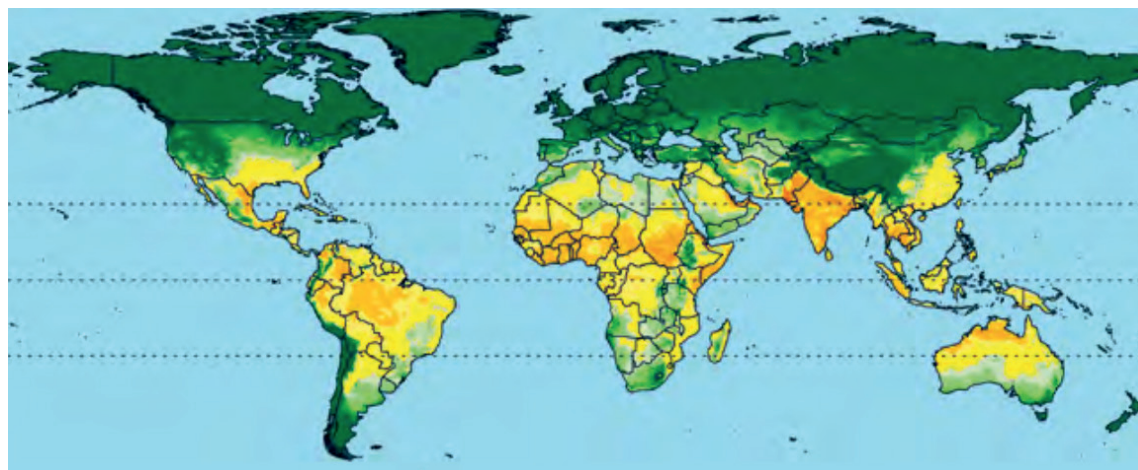


Figure 3(a). Estimated incidence of heat stress worldwide in 1995. Note: The map shows the average over 30 years (1981–2010) of estimated daily maximum WBGT (afternoon values in the shade) during the locally hottest month in 67,420 small geographical areas (grid cells) covering 50 km × 50 km at the equator. Source: IPCC, 2014.

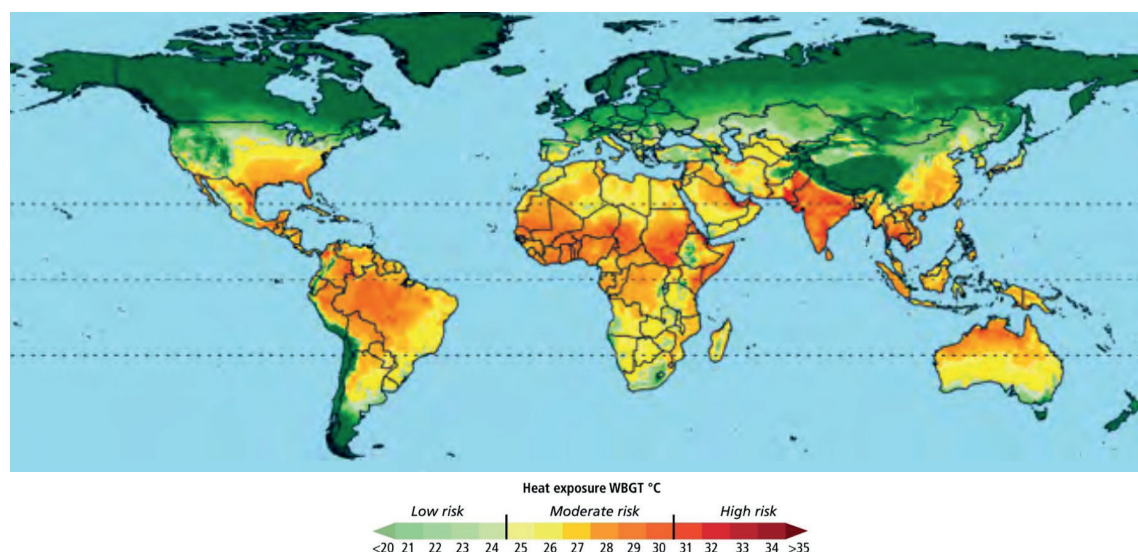


Figure 3(b). Projected incidence of heat stress worldwide in 2085. Note: The map shows the average over 29 years (2071–2099) of projected daily maximum WBGT (afternoon values in the shade) during the locally hottest month in 67,420 small geographical areas (grid cells) covering 50 km × 50 km at the equator. Projections are based on the RCP6.0 climate change pathway; the mean of the WBGT values from the HadGEM2 and GFDL-ESM2M climate models was calculated for each grid cell. Source: Map based on the HadGEM2 and GFDL-ESM2M climate models (ILO, 2019).

and projections for 2085, respectively. As expected, the hot tropics and India in particular experience the highest WBGTs, a lethal combination of heat and humidity.

India's economy is highly dependent on heat-exposed labour—as of 2017, heat-exposed work produced about 50 percent of GDP and employed about 75% percent of the labour force, some 380 million people (MGI, 2020)²⁰. In 2030,

a significant proportion of workers in India will still be working outside and about 40% of GDP will still depend on heat-exposed work. An increase in lost labour hours due to rising heat and humidity could put approximately 2.5-4.5% of GDP at risk by 2030, i.e., approximately \$150-250 billion (MGI, op. cit.). In a different study, in a nationally representative sample of 42,152 households (nearly 60,000 working individuals), each occurrence of a 'hot' day (i.e., temperature

²⁰ Exposed sectors include exclusively outdoor sectors such as agriculture mining and quarrying and transport as well as indoor sectors with poor air-conditioning penetration including manufacturing, hospitality and retail trade.

exceeding 100°F or 37.7°C) increased self-reported inability to work by 7.3% or 1/20th of a day (Heyes & Saberian, 2022). As per ILO estimates, India lost 4.3% of working hours in 1995 and is projected to lose 5.8% working hours in 2030 as a result of heat stress under RCP2.6. This is equal to 34 million full-time jobs²¹ and the loss in GDP will be nearly 6% in 2030 (ILO, op. cit.)²².

Though the impact of a warmer climate will be felt most in the agricultural sector, more and more working hours are also expected to be lost in other outdoor occupations, such as construction work, open cast mining and transportation^{23,24}. In addition, factory and workshop buildings often have no air-conditioning or other effective climate control systems and millions of workers who produce low-price clothes, etc. experience extreme heat exposures on a regular basis. Using variation in workplace temperatures caused by use of low-heat LED lighting in garment factories in India, Adhvaryu et al. (2020) show worker productivity increases when temperatures are reduced. Somanathan et al. (2021) assemble three different datasets, namely, factory data for a few units in textile and steel sectors, an all-India panel dataset for manufacturing plants and a district level panel for district manufacturing GDP. They find similar negative effects of temperature on output in all three cases. For example, annual output of manufacturing plants is predicted to fall by 2.1% if every day warms by 1°C and district manufacturing GDP declines by 3% per degree Celsius.

The next largest impact category at the global level is agriculture. Between 2040 and 2060, health damages increase less than two times globally while agricultural damages increase threefold (Dellink et al., 2019). This impact is largely due to declining yields on account of climate change which is natural given that agriculture is highly climate sensitive. While these impacts may not be significant for regions where the share of agriculture in GDP is modest such as the EU, this is not the case for India where agriculture accounts for 20% of GVA (gross value added) and is also the largest employer. Moreover, nearly two-thirds of India's population, that is, about 900 million people still live in rural areas and are intimately connected with this sector. Agricultural growth also contributes to reducing poverty (Datt & Ravallion, 1998; Datt et al., 2020²⁵) which remains widespread despite significant progress in reducing it—India has about 30% of the world's abjectly poor (living on less than \$1.90/day - see fn 3). A key aspect of poverty in India is its incidence which is rural and concentrated among landless agricultural labour²⁶.

The salience of agriculture and the current and future impact of climate change is recognised by Indian policymakers²⁷. Not only is Indian agriculture impacted by rising temperatures but is also heavily dependent on rainfall (Figure 4) which is becoming more variable as described earlier. Recall that rainfed agriculture (i.e., without access to either irrigation or perennial snow fed rivers) accounts for 51% of country's

21 As an aside the comparable figure for China which has been more successful in the structural transformation of its economy is only 5.5 million.

22 GDP loss is calculated by multiplying the equivalent number of full-time jobs lost by GDP per worker. Technological and capital changes over time are taken into account in the measure of GDP per worker. The data on equivalent full-time jobs lost in 1995 and 2030 are based on historical observations and on estimates obtained using RCP2.6 (global average temperature rise of 1.5°C by 2100).

23 Work in agriculture and construction is assumed to be carried out in the shade. The heat stress index for work in the sun in the afternoon adds around 2–3°C to the in-shade WBGT (ILO, op. cit.)

24 Farming communities are especially affected by increased heat exposures due to climate change. Studies of traditional agriculture in low- and middle-income countries have shown that up to 80% of total farming energy input (megajoules/ha/year) comes from physical work carried out by agricultural labour (Kjellstrom et al., 2016).

25 Datt et al. (2020) estimate the elasticity of national poverty with respect to primary (agricultural) sector growth to be around -0.3.

26 By the Indian government definition in the year 2011-12 (the last year for which data is available) nearly 22% (more than 1 in 5) Indians were poor and nearly 26% (more than 1 in 4) rural Indians were poor (GOI, 2022, Table 1.2) defined as daily consumption expenditure less than INR 27.2 (rural) and INR 33.3 (urban). Equally important for our analysis, nearly 50% of agricultural laborers were below the poverty line in rural areas (GOI, 2012).

27 "Agriculture represents a core part of the Indian economy and provides food and livelihood activities to much of the Indian population. While the magnitude of impact varies greatly by region, climate change is expected to impact on agricultural productivity and shifting crop patterns. The policy implications are wide-reaching, as changes in agriculture could affect food security, trade policy, livelihood activities and water conservation issues, impacting large portions of the population." (GOI, 2016, p. 60).

net sown area (71 million hectares) and accounts for nearly 40% of the total food production. It also employs nearly 50% of the rural workforce and sustains 60% of cattle population (see fn 2).

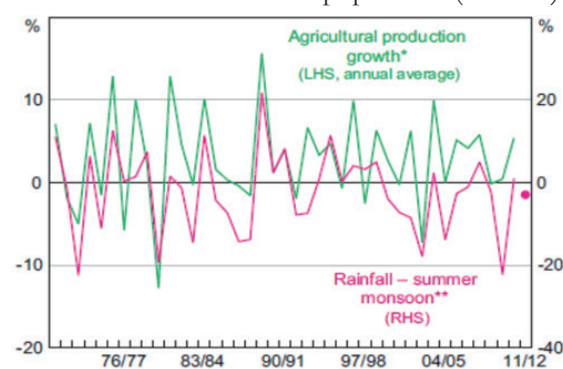


Figure 4. India: rainfall and agricultural production.
Note: ** percentage deviation from long-run average.
Source: Cagliarini & Rush, 2011.

Since warming of 1°C compared to pre-industrial has already taken place, several retrospective studies have estimated the impact of this on crop yields using panel data across countries (e.g., Lobell et al., 2011; Ortiz-Bobea et al., 2021a) or for specific countries using panel data at the subnational level, namely, county, province, district (see Ortiz-Bobea (2021b) for a discussion). For India too, district level panel datasets have been extensively used to estimate the impact of past climate change on yields/output/TFP for various crops using different estimation techniques. Examples include Dinar et al. (1998), Kumar and Parikh (2001), Sanghi and Mendelsohn (2008), Guiteras (2009), Krishnamurthy (2012), Gupta et al. (2014), Pattanayak and Kumar (2014), Gupta et al. (2017), Fishman (2016, 2018), Auffhammer and Carleton (2018), Verma et al. (2020) and Pattanayak et al. (2021). The results unambiguously show the negative impacts of temperature or climate shocks on outcome variables.

Some of these studies extrapolate these estimates using future climate scenarios and estimate potential yield loss. For instance, Guiteras (op. cit.) finds that projected climate change over the period 2010-2039 reduces major crop yields by 4.5 to 9% and the long-run (2070-2099) impact is dramatic, reducing yields by 25% or more in the absence of long-run adaptation.

A recent and more comprehensive modeling exercise estimates sector and region-specific changes in crop yields for each of the 8 crop sectors, namely, rice, wheat, other grains, fruits and vegetables, sugarcane, oilseeds, plant fibres (cotton, jute) and other crops (Dellink et al., 2019). While there are gainers and losers across regions for different crop sectors, for India yields decline significantly for all categories. The decline in yields of rice, wheat and other grains by 2050 is between 30-40% (Figure 5).

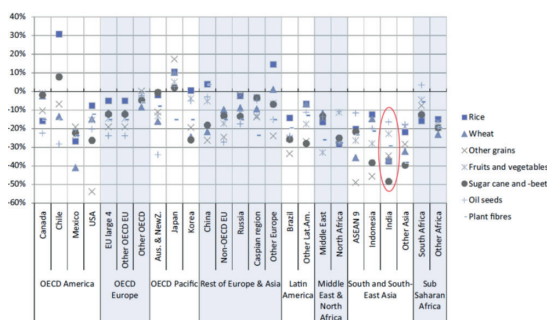


Figure 5. Impacts of climate change on crop yields in the central projection (% change in 2050). Source: IMPACT model, based on the AgMIP study (Dellink et al., 2019). Reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer Nature, *Environmental & Resource Economics, The Sectoral and Regional Economic Consequences of Climate Change to 2060*, Rob Dellink et al., 2017.

Actual numbers aside, an array of econometric studies and large-scale agricultural models all point towards significant negative impacts of expected climate change on Indian agriculture. In addition to domestic ramifications such as food security, livelihoods and poverty, this is also likely to have major international repercussions. India is a major producer, consumer and exporter of agricultural commodities. It ranks third globally in cereal production (324 million tons in 2019) after China and the United States and is the world's second largest producer of rice, wheat, groundnuts, sugarcane, tea and fruits and vegetables and the largest producer of pulses (GOI, 2016). While a large part is domestically consumed (much of agriculture is still subsistence) India is also among the world's top ten agricultural exporters and a major exporter of rice, cotton, soyabean and meat. Climate induced disruptions in Indian agriculture are likely to have a global impact.

Conclusions

As a densely populated country of 1.4 billion people situated in the hot tropics and with relatively low income, India is highly vulnerable to climate change. It has a vast rural and agrarian sector that is particularly susceptible to higher temperatures and more erratic rainfall. The economic impacts of climate change are likely to be substantial even under best case mitigation scenarios and significantly worse under less optimistic outcomes. Most macroeconomic models project large losses of GDP and per capita GDP. *Inter alia*, heat stress (high projected WBGT) and declining agricultural yields will drive these losses. Other likely impacts such as coastal and riverine flooding and extreme weather events (cyclones, flash floods, droughts) are also extremely important but have not been quantified in this article.

It is vital for India to massively enhance its rate of economic growth and to sustain it for decades to lift millions out of poverty and to reach high-income status in the next 25 years²⁸. In order to not let climate change derail this process India has to urgently climate proof its economy. To that end adaptation is going to be vital and needs more attention and resources.

²⁸ This is the goal set by the Indian Prime Minister on August 15, 2022 to be achieved by 2047 (100 years since independence in 1947): <https://www.pbs.org/newshour/world/prime-minister-narendra-modi-pledges-to-make-india-a-developed-country-in-25-years> By way of comparison India's per capita GDP (current US\$) in 2021 was USD 2,277 <https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=IN>

Note

I am grateful to Partha Sen and Frank Convery for useful comments and suggestions and to Shweta Gupta for help with the references.

References

- Acevedo, S., Mrkaic, M., Novta, N., Pugacheva, E., & Topalova, P. (2020). The Effects of Weather Shocks on Economic Activity: What are the Channels of Impact? *Journal of Macroeconomics*, 65, 103207. <https://doi.org/10.1016/j.jmacro.2020.103207>.
- Adhvaryu, A., Kala, N., & Nyshadham, A. (2020). The Light and the Heat: Productivity Co-Benefits of Energy-Saving Technology. *Review of Economics and Statistics*, 102(4), 779–792. https://doi.org/10.1162/rest_a_00886.
- Almond, A. & Currie, J. (2011). Killing Me Softly: The Fetal Origins Hypothesis. *Journal of Economic Perspectives*, 25(3), 153–172. <https://doi.org/10.1257/jep.25.3.153>
- Auffhammer, M., & Carleton, T.A. (2018). Regional Crop Diversity and Weather Shocks in India. *Asian Development Review*, 35(2), 113–130. https://doi.org/10.1162/adev_a_00116
- Bosello, F. & León, C.J. (2022). Climate change impacts in the EU: new evidence from recent research. *EAERE Magazine*, 16.
- Burke, M., Hsiang, S.M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527, 235–239. <https://doi.org/10.1038/nature15725>.
- Cagliarini, A & Rush, A. (2011). *Economic development and agriculture in India*. Reserve Bank of Australia Bulletin, June Quarter, 15–22.
- Carleton, T. A. (2017). Crop-damaging temperatures increase suicide rates in India. *Proceedings of the National Academy of Sciences*. <https://doi.org/10.1073/pnas.1701354114>.
- Carpene, F. (2019). How do droughts impact household food consumption and nutritional intake? A study of rural India. *World Development*, 122, 349–369. <https://doi.org/10.1016/j.worlddev.2019.06.005>.
- Colacito, R., Hoffmann, B., & Phan, T. (2019). Temperature and Growth: A Panel Analysis of the United States. *Journal of Money, Credit and Banking*, 51, 313–368. <https://doi.org/10.1111/jmcb.12574>.
- Datt, G., & Ravallion, M. (1998). Farm productivity and rural poverty in India. *Journal of Development Studies*, 34(4), 62–85. <https://doi.org/10.1080/00220389808422529>
- Datt, G., Murgai, R., & Ravallion, M. (2020). Poverty and growth in India over six decades. *American Journal of Agricultural Economics*, 102(1), 4–27. <https://doi.org/10.1093/ajae/aaz043>
- Dell, M., Jones, B.F., & Olken, B.A. (2012). Temperature Shocks and Economic Growth: Evidence from the Last Half Century. *American Economic Journal: Macroeconomics*, 4 (3), 66–95. <https://doi.org/10.1257/mac.4.3.66>.
- Dellink, R., Lanzi, E., & Chateau, J. (2019). The Sectoral and Regional Economic Consequences of Climate Change to 2060. *Environmental & Resource Economics*, 72, 309–363 <https://doi.org/10.1007/s10640-017-0197-5>
- Dinar, A., Mendelsohn, R., Evenson, R., Parikh, J., Sanghi, A., Kumar, K., McKinsey, J., & Loneragan, S. (1998). *Measuring the impact of climate change on Indian agriculture*. World Bank Technical Paper No. 402, Washington, DC.
- Douglas, A., & Currie, J. (2011). Killing Me Softly: The Fetal Origins Hypothesis. *Journal of Economic Perspectives*, 25(3), 153–72. <https://doi.org/10.1257/jep.25.3.153>.

- Fishman, R. (2016). More uneven distributions overturn benefits of higher precipitation for crop yields. *Environmental Research Letters*, 11(2). <https://doi.org/10.1088/1748-9326/11/2/024004>
- Fishman, R. (2018). Groundwater depletion limits the scope for adaptation to increased rainfall variability in India. *Climatic Change*, 147, 95–209. <https://doi.org/10.1007/s10584-018-2146-x>
- Flouris, A.D., Dinas, P.C., Ioannou, L.G., Nybo, L., Havenith, G., Kenny, G.P., & Kjellstrom, T. (2018). Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. *Lancet Planet Health*, 2, 521–531. [https://doi.org/10.1016/S2542-5196\(18\)30237-7](https://doi.org/10.1016/S2542-5196(18)30237-7)
- GOI. (2012). *Press Note on Poverty Estimates, 2009-10*. New Delhi: Planning Commission, Government of India, 19th March 2012. https://niti.gov.in/planningcommission.gov.in/docs/news/press_pov1903.pdf
- GOI. (2016). *State of Indian Agriculture 2015-16*. New Delhi: Directorate of Economics & Statistics, Ministry of Agriculture & Farmers Welfare, Government of India.
- GOI. (2021). *Annual Climate Summary 2021*. Pune: Climate Monitoring & Prediction Group, Indian Meteorological Department, Government of India.
- GOI (2022). *Agricultural Statistics at a Glance 2021*. New Delhi: Directorate of Economics & Statistics, Ministry of Agriculture & Farmers Welfare, Government of India.
- Guiteras, R. (2009). *The impact of climate change on Indian agriculture*. Mimeo. University of Maryland, College Park.
- Guo, J., Kubli, D., & Saner, P. (2021). *The economics of climate change: no action not an option*. Zurich: Swiss Re.
- Gupta, S., Sen, P., & Srinivasan, S. (2014). Impact of climate change on the Indian economy: evidence from food grain yields. *Climate Change Economics*, 5(2). <https://doi.org/10.1142/S2010007814500018>
- Gupta, R., Somanathan, E., & Dey, S. (2017). Global warming and local air pollution have reduced wheat yields in India. *Climatic Change*, 140, 593–604. <https://doi.org/10.1007/s10584-016-1878-8>
- Heyes, A., & Saberian, S. (2022). Hot Days, the ability to Work and climate resilience: Evidence from a representative sample of 42,152 Indian households. *Journal of Development Economics*, 155. <https://doi.org/10.1016/j.jdeveco.2021.102786>
- ILO. (2019). *Working on a warmer planet: The impact of heat stress on labour productivity and decent work*. Geneva: International Labour Organization.
- Ioannou, L.G., Foster, J., Morris, N.B., Pül, J.F., Havenith, G., Mekjavic, I.B., Kenny, G.P., Nybo, L., & Flouris, A.D. (2022). Occupational heat strain in outdoor workers: A comprehensive review and meta-analysis. *Temperature*, 9(1), 67–102. <https://doi.org/10.1080/23328940.2022.2030634>
- ISO. (1989). *Hot Environments: Estimation of the Heat Stress on Working Man, Based on the WBGT Index (Wet Bulb Globe Temperature)*. Technical Report. International Organization for Standardization, Geneva.
- Jain, A., O'Sullivan, R., & Taraz, V. (2020). Temperature and economic activity: evidence from India. *Journal of Environmental Economics and Policy*, 9(4), 430–446. <https://doi.org/10.1080/21606544.2020.1727776>
- Kahn, M.E., Mohaddes, K., Ng, R.N.C., Pesaran, M.H., Raissi, M., & Yang, J.C. (2021). Long-term macroeconomic effects of climate change: A cross-country analysis. *Energy Economics*, 104. <https://doi.org/10.1016/j.eneco.2021.105624>
- Kjellstrom, T., Holmer, I., & Lemke, B. (2009a). Workplace heat stress, health, and productivity an increasing challenge for low and middle-income countries during climate change. *Global Health Action*, 2(1). <https://doi.org/10.3402/gha.v2i0.2047>
- Kjellstrom, T., Kovats, R.S., Lloyd, S.J., Holt, T., & Tol, R.S.J. (2009b). The Direct Impact of Climate Change on Regional Labor Productivity. *Environmental & Occupational Health*, 64(4), 217–227.
- Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., & Hyatt, O. (2016). Heat, Human Performance, and Occupational Health: A Key Issue for the Assessment of Global Climate Change Impacts. *The Annual Review of Public Health*, 37, 97–112. <https://doi.org/10.1146/annurev-publhealth-032315-021740>
- Krishnamurthy, C.K.B. (2012). *The Distributional Impacts of Climate Change on Indian Agriculture: A Quantile Regression Approach*. Working Papers 2012-069, Madras School of Economics, Chennai, India.
- Kumar, K.S.K. & Parikh, J. (2001). Indian agriculture and climate sensitivity. *Global Environmental Change*, 11(2), 147–154. [https://doi.org/10.1016/S0959-3780\(01\)00004-8](https://doi.org/10.1016/S0959-3780(01)00004-8)
- Lobell, D.B., Schlenker, W., & Roberts, J.C. (2011). Climate trends and global crop production since 1980. *Science*, 333(6042), 616–620. <https://doi.org/10.1126/science.1204531>
- LoPalo, M., Kuruc, K., Budolfson, M., & Spears, D. (2020). Quantifying India's Climate Vulnerability. In Shah, S., Bosworth, B. & Muralidharan, K. (eds.) *India Policy Forum 2018 (Volume 15)*. SAGE Publishing, New Delhi.
- Mani, M., & Markandya, A. (2022). Climate change and living standards in India: hotspots and effective adaptation. *EAERE Magazine*, 17.
- Mendelsohn, R. (2016). *Measuring Weather Impacts Using Panel Data*. Yale School of Forestry and Environmental Studies. <https://www.aeaweb.org/conference/2017/preliminary/paper/fiHy249A>
- MGI (McKinsey Global Institute). (2020). Will India get too hot to work? <https://www.mckinsey.com/capabilities/sustainability/our-insights/will-india-get-too-hot-to-work>
- Millet Network of India (MNI), Deccan Development Society (DDS) & FIAT (FoodFirst Information and Action Network). (2009). *Millet: Future of Food and Farming*. India.
- Nordhaus, W.D., & Yang, Z. (1996). A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies. *The American Economic Review*, 86(4), 741–765. <http://www.jstor.org/stable/2118303>
- Nordhaus, W.D. (2010). Economic aspects of global warming in a post-Copenhagen environment. *Proceedings of the National Academy of Sciences*, 107(26), 11721–11726. <https://doi.org/10.1073/pnas.1005985107>
- Nordhaus, W. (2014). Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches. *Journal of the Association of Environmental and Resource Economists*, 1(1/2), 273–312. <http://dx.doi.org/10.1086/676035>
- OECD. (2015). *The Economic Consequences of Climate Change*. Paris: OECD Publishing. <https://doi.org/10.1787/9789264235410-en>
- Ortiz-Bobea, A., Ault, T.R., Carrillo, C.M., Chambers, R.G., & Lobell, D.B. (2021a). Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, 11(4), 306–312. <https://doi.org/10.1038/s41558-021-01000-1>
- Ortiz-Bobea, A. (2021b). Chapter 76 - The empirical analysis of climate change impacts and adaptation in agriculture. In Barrett, C.B., & Just, D.R. (eds.) *Handbook of Agricultural Economics*, 5, 3981–4073. <https://doi.org/10.1016/bs.hesagr.2021.10.002>
- Pattanayak, A., & Kumar, K.S.K. (2014). Weather Sensitivity of Rice Yield: Evidence from India. *Climate Change Economics*, 5(4). <https://doi.org/10.1142/S2010007814500110>
- Pattanayak, A., Kumar, K.S.K., & Anneboina, L.R. (2021) Distributional impacts of climate change on agricultural total factor productivity in India. *Journal of the Asia Pacific Economy*, 26(2), 381–401.

<https://doi.org/10.1080/13547860.2021.1917094>

Rohini, P., Rajeevan, M., & Srivastava, A. (2016). On the Variability and Increasing Trends of Heat Waves over India. *Nature, Scientific Reports*, 6. <https://doi.org/10.1038/srep26153>.

Sandhani, M., Pattanayak, A., & Kumar, K.S.K. (2022). Weather shocks and economic growth in India. *Journal of Environmental Economics and Policy*. <https://doi.org/10.1080/21606544.2022.2087745>.

Sanghi, A., & Mendelsohn, R. (2008). The impacts of global warming on farmers in Brazil and India. *Global Environmental Change*, 18(4) 655-665. <https://doi.org/10.1016/j.gloenvcha.2008.06.008>

Somanathan, E., Somanathan, R., Sudarshan, A., & Tewari, M. (2021). The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing. *Journal of Political Economy*, 129 (6). <https://doi.org/10.1086/713733>.

Verma, S. (2019). *Impact of Climate Change on the Indian Economy*. Unpublished Ph.D. dissertation, Department of Economics, University of Delhi.

Verma, S., Gupta, S., & Sen, P. (2020). *Does Climate Change Make Foodgrain Yields More Unpredictable? Evidence from India*. CESifo Working Paper No. 8161. Available at SSRN: <https://ssrn.com/abstract=3555588> or <http://dx.doi.org/10.2139/ssrn.3555588>

Weitzman, M.L. (2009). On Modeling and Interpreting the Economics of Catastrophic Climate Change. *The Review of Economics and Statistics*, 91(1), 1–19. <https://doi.org/10.1162/rest.91.1.1>.

Weitzman, M.L. (2011). Fat Tailed Uncertainty in the Economics of Catastrophic Climate Change. *Review of Environmental Economics and Policy*, 5(2), 275-292. <https://doi.org/10.1093/reep/rer006>.

Suggested citation

Gupta, S. (2022). Climate change impacts for India: a review. *EAERE Magazine*, 17.

Climate change and living standards in India: hotspots and effective adaptation

Muthukumara Mani^a, Anil Markandya^b

^aThe World Bank, ^bBasque Centre for Climate Change



Muthukumara Mani (mmani@worldbank.org) is a Lead Environmental and Climate Change Economist for the Southeast Asia Region of the World Bank. Mani has been working on climate change mitigation and adaptation issues and environmental issues for most of his career. He has led several regional flagship reports on climate change, glaciers, air pollution, and water. Mani is an American national and holds a Ph.D. and Masters in Economics from the University of Maryland, College Park, USA. He has several books, policy reports, and peer-reviewed journal articles to his credit.



Anil Markandya (anil.markandya@bc3research.org) is Distinguished Ikerbasque Professor at the Basque Centre for Climate Change in the Basque Country, Spain and Honorary Professor of Economics at the University of Bath, UK. He was a lead author for the 3rd, 4th and 5th IPCC Assessment Reports on Climate Change and a contributing author for the special report on 1.5°C. He has also published widely on resource valuation and regulation in the context of sustainable development. Professor Markandya was President of the European Association of Environmental and Resource Economics from 2014-2015.

Introduction

Climate change is no longer an issue in the distant future for India. Increasing average temperatures and changes in seasonal rainfall patterns are already having an impact on agriculture across the country. Low-lying coastal areas are at risk from sea-level rise and tropical storms, while mountain areas are at risk due to changes in snow, glaciers, and natural disasters. Yet, India also contains hidden hotspots – areas that are economically at risk to climate change, but that are not often discussed.

There is a growing set of research on the relationship between weather or climate and human activities. Studies differ primarily in the effect that they seek to quantify and level of aggregation. Aggregation refers to whether a variable is reflective of conditions at a single point (in time or on the ground).

The relationship between weather/climate and societies' economic output has been estimated at the national level. Several studies identify a negative relationship between increasing temperatures and GDP (DARA, 2012; OECD, 2015; Ahmed & Suphachalasai, 2014). There is also evidence of a negative effect of climate change, especially extreme events, on GDP growth (Dell et al., 2012; Brown et al., 2013; Hsiang & Jina,

2014; Burke et al., 2015; Moore & Diaz, 2015). Other studies have identified negative impacts of climate change on health, agriculture, and labor productivity (WHO, 2015; Deschenes, 2014; Auffhammer & Schlenker, 2014; Heal & Park, 2015). Burke, Hsiang, and Miguel (2015) investigate the relationship between climate and the economy by looking at the effect of annual average temperature on productivity. They find that country-level economic production is smooth, nonlinear, and concave with respect to temperature, with an optimal annual average temperature of 13°C.

At the local level, a few studies have investigated the impacts of climate change on household living standards. Verner et al. (2010) examine the relationship between climate change and income in Latin America using municipality level data, and find a mixed set of relationships between temperature and income. For Bolivia, Brazil and Peru the relationship is clearly an inverted U (i.e., higher temperatures are good to a point, and then cause harm), while in Chile, the relationship is more or less inverse and in Mexico the relationship is not statistically significant. Skoufakis et al. (2012) and IFPRI (2017) project that climate change will lower agricultural productivity and increase food prices, but expect these changes to be offset by reductions in poverty and economic growth rates. Conversely,

Hallegatte et al. (2016) in “Shock Waves” find that while economic growth can play a major role in determining future poverty levels, an additional 100 million people could end up in poverty by 2030 due to climate change without such growth, including 42 million in India alone.

Existing studies at both the large and small scales have looked at an array of economic impacts. Hallegatte et al. (2017) in “Unbreakable” focus on the current effects of natural disasters across all income groups (they make no projections) and find such events account for varying losses in consumption across the world. In South Asia, losses are estimated at 0.4 percent of GDP in India but higher in other parts of South Asia: 0.9 percent in Pakistan, 1.6 percent in Nepal and 3.5 percent in Bangladesh. Jacoby et al. (2011) investigate the effects of rural consumption levels in India and estimate that because of climate change, rural households will face a loss of between six and 11 percent by 2040.

A detailed study to which the present authors contributed adds to this accumulated knowledge through a combination of granularity and region-specific climate change analysis (Mani et al., 2018). It used the household as the fundamental unit of analysis. The household results were then aggregated to the district or province level to appropriately represent the distribution of households within the given political unit. The report focused on effects of changes in average precipitation and temperature because changes in the average can be projected with greater confidence than changes in extreme events. It then used the results to draw some lessons of where efforts to increase resilience to climate change should be focused in India.

Historic and Projected Temperature Changes in India

Recent History

Average annual temperatures throughout many parts of South Asia including India have increased significantly, but unevenly, in recent decades. Western Afghanistan and southwestern Pakistan have experienced the largest increases, with annual average temperatures rising by 1.0°C

to 3.0°C from 1950 to 2010 (Figure 1). South-eastern India, western Sri Lanka, northern Pakistan, and eastern Nepal have all also experienced increases of 1.0°C to 1.5°C over the same time frame. Although the precise magnitude of these estimated historic temperature changes varies depending on the time frame and the observational data set, the fact that temperature changes have been occurring is unambiguous for all of India (Figure 2).

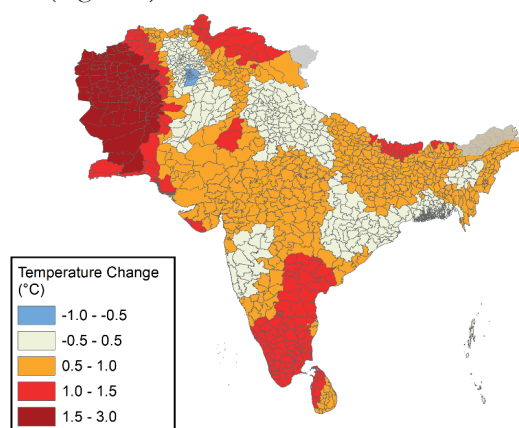


Figure 1. Temperatures Have Been Increasing in Most of South Asia, 1950 to 2010. Note: Linear trend in average annual temperature from 1951 through 2010. Areas showing 0°C change include locations where trends are not statistically significant. Source: Harris et al., 2014 (Climate Research Unit TS 2.24).

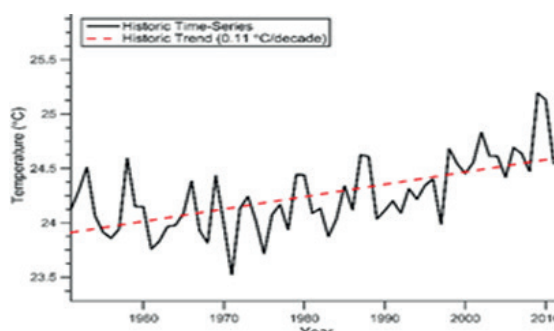


Figure 2. Unambiguous Temperature Trends in India. Source: Calculations based on CRU TS 3.22 (Harris et al., 2014).

Changes in average precipitation are much harder to detect because of large year-to-year and inter-decadal variability. From 1950 through 2010, statistically significant trends of decreasing monsoon precipitation are found for Uttaranchal and Uttar Pradesh in India, but no statistically significant trends for other regions (Figure 3). There are also contradictory scientific find-

ings on if and how precipitation is changing based on analysis of station records.

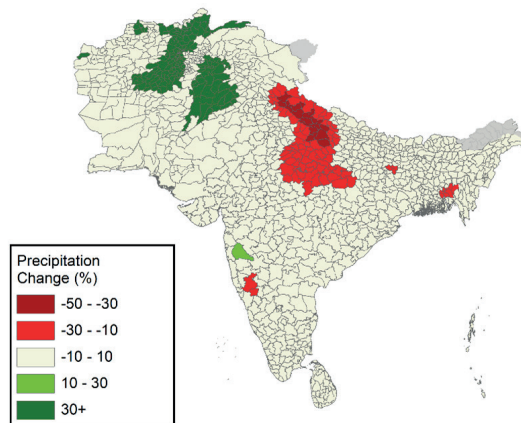


Figure 3. No Overall Monsoon Precipitation Trends for Most of South Asia, 1950 to 2010. Note: Change in monsoon precipitation based on linear trend in average monsoon precipitation from 1951 through 2010. Areas showing zero percent change include locations where trends are not statistically significant. Source: Harris et al., 2014 (Climate Research Unit TS 2.24).

There is more robust evidence for changes in monsoon wet and dry spells and overall weakening caused by human activities. For most regions in South Asia, the monsoon patterns have remained constant (similar to the findings in Figure 3). However, the core region (western and central India) has experienced increases in both intensity of extreme wet periods and the frequency of dry periods (Singh et al., 2014). The precise set of reasons for these changes is not known. It has been shown, though, that one contributing factor is an increase in the concentration of human-produced aerosols in the region. These aerosols have caused an overall drying (or weakening) of the monsoon in recent decades (Bollasina, Ming, & Ramaswamy 2011; Singh, 2016).

Climate Projections for India

Based on a detailed analysis of 18 climate models, temperatures in India are projected to increase by 1 to 2°C by 2050 under the climate sensitive scenario and 1.5 to 3°C by 2050 under the carbon-intensive scenario¹. Even by the end

of this decade, temperatures are expected to increase by 1.3°C (RCP4.5) to 1.5°C (RCP8.5) (Mani et al., 2018). The climate-sensitive scenario corresponds to Representative Concentration Pathway (RCP) 4.5, which represents a future in which some collective action is taken to limit GHG emissions and global annual average temperatures increase by 2.4 °C (range of 1.7 to 3.2 °C) by 2100 relative to pre-industrial levels. The carbon-intensive scenario corresponds to RCP8.5, which represents a future in which no actions are taken to reduce emissions and global annual average temperatures increase by 4.3 °C (range of 3.2 to 5.4 °C) by 2100 relative to pre-industrial levels.

The patterns of temperature change are not evenly distributed throughout the Sub-Continent (Figure 4). Under the climate sensitive scenario, temperatures are projected to increase the most for the Hindu Kush and Karakoram mountains and relatively more for the north west of India. Under the carbon intensive scenario, the projection is for annual average temperatures to increase 2.0 to 2.5°C for the same parts of the country, relative to 1981-thru-2010 values.

Climate and Living Standards

Living standards, measured through the money value of household consumption² are influenced by climate through several pathways. Increasing temperatures and shifting precipitation patterns can dampen agricultural productivity. Increasing temperatures and unseasonal precipitation can increase the propagation of vector-borne and infectious diseases, resulting in lost productivity and income. Extreme heat days are generally associated with declining productivity of workers. A changing climate can also force people out of their traditional occupations, resulting in lower income and consumption.

An analysis was carried out using a reduced-form model to estimate the relationship between climate change and consumption expenditure taken as a proxy for living standards. While reduced-form models tend to have greater predictive capability than structural models under a

¹ Changes are for 2036 through 2065 relative to 1981 through 2010 averages.

² The most direct measures of living standards in the literature are income and consumption. For low-income countries especially, a strong case has been made for consumption expenditure (Deaton & Grosh, 2012). Expenditures are supposed to better reflect “long-term” or “permanent” income and are from this point of view considered to be a better measure of economic well-being (Atkinson, 1987).

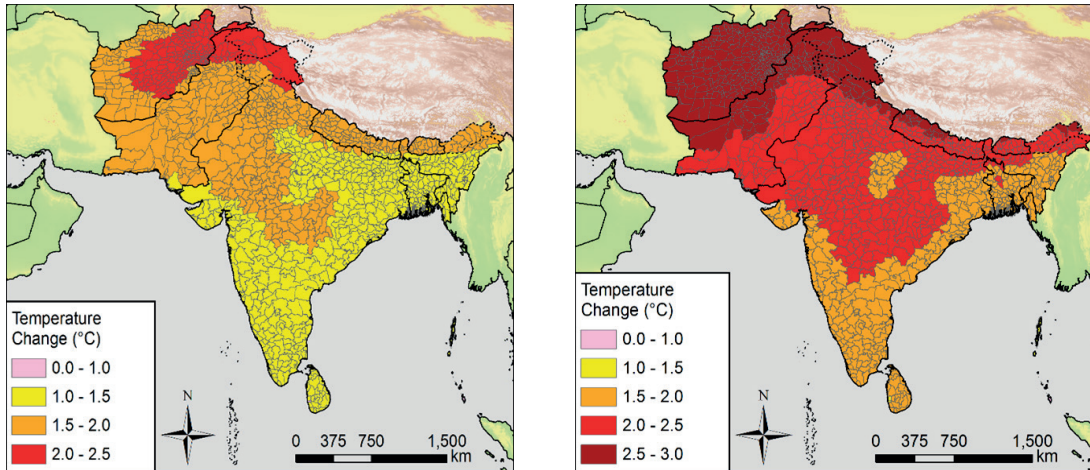


Figure 4. Annual average temperature is projected to continue increasing dramatically under the climate sensitive (left) and the carbon intensive (right) scenarios for some parts of India. Projections are for a period centered around 2050. Note: Changes are relative to 1981 through 2010 averages (Figure 2.1). Source: Climate Research Unit TS 2.24 (Harris et al., 2014) and eleven climate models cited in Box 2.1.

wider set of conditions, they cannot represent the underlying causal relationships. Despite these limitations, such models are the best means available to estimate linkages between living standards and climate because the relationships are not adequately represented in current structural models.

Using this formulation, it is found that there is an inverted U-shaped relationship between climate and living standards in India. This shape means that cold areas will see some positive benefits from climate change (to a point) and hot areas will be negatively impacted (Figure 5).

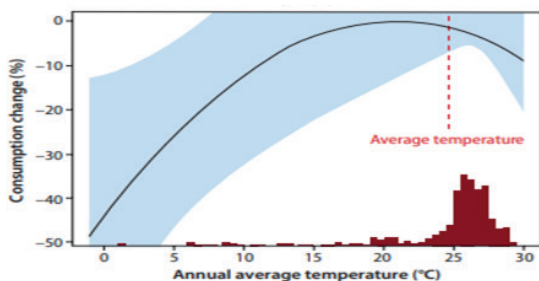


Figure 5. Temperature and Consumption Have an Inverted U-Shaped Relationship

Estimating the Relationship between Climate and Living Standards

Further, a reduced-form model in which household consumption is regressed on several vari-

ables, including seasonal temperature and precipitation was used. The model also includes a set of household, district, and geospatial control variables chosen because they help explain variations in consumption expenditure and are less correlated to climate. Details of the regression results are in Mani et al. (2018).

After extensive investigations, reduced-form model equation (1) was chosen for the analysis:

$$Y_{hit} = \alpha + \sum_{j \in (s,m,w)} (\beta_{1j} temp_{it}^j + \beta_{2j} temp_{it}^{j^2} + \beta_{3j} rain_{it}^j + \beta_{4j} rain_{it}^{j^2}) + \beta_5 X_{hit} + \beta_6 W_i + \tau_t + u_{hit}$$

where h refers to the household surveyed, i to the district, t to the survey year, Y is the log of average real annual household consumption expenditure, $temp_{it}$ is mean seasonal temperature for year t in district i , $rain_{it}$ is mean seasonal precipitation for year t in district i , X_{hit} is a vector of controls, W_i is a vector of district characteristics, and τ_t is a vector of dummy variables representing the year of survey; j takes the values s , m , and w representing premonsoon (March through May), monsoon (June through September), and post-monsoon (October through February) seasons.

While it is tempting to control for all observable and potentially confounding factors, such an approach can introduce bias into the coefficients describing the effect of climate on living stan-

dards, because these controls may themselves affect the climate. For example, elevation may cause households to make certain decisions, but elevation is also a driving factor in determining temperature. Therefore, if elevation were included in equation (1), it would not be possible to determine the portion of the modeled impact because of household choices related directly to elevation versus temperature. Such an effect is termed a *bad control* (Angrist & Pischke, 2008) and is undesirable in this setting because climatic variables may affect many of the socioeconomic factors commonly included as control variables.

Unfortunately, removing a bad control can also introduce bias. Since the household survey data used are not a true panel dataset, but rather samples within a given region in different years, one can argue for the use of some controls to reduce the chance that the results will be biased because of the exclusion of potentially important characteristics. At the same time, to keep the problem of bad controls to a minimum, the analysis uses controls that are weakly correlated with the climate indicators. Specifically, each control variable selected must have a correlation coefficient of less than 0.5 with all climate variables for the country being modeled (Booth et al., 1994; Dormann et al., 2013; Elith et al., 2006; Suzuki et al., 2008; Tabachnick & Fidell, 1996).

Overall, the analysis finds that expected changes in average temperature and precipitation will have a negative effect on living standards in India (Table 1). The results under the RCPs 4.5 and 8.5 are very similar for 2030, but they diverge substantially by 2050, with the RCP8.5 being more extreme.

The findings are also more or less consistent with the findings of other recent studies for the region.

Robustness of the model predictions was checked by estimating similar empirical models, but including different control variables and with fixed effects. These alternate specifications produce results that are qualitatively similar but with slightly reduced estimates of the effects of climate on consumption. Estimations of district and province fixed effects tend to reduce the sensitivity of living standards to changes in

average temperature and precipitation.

Time Frame	2030		2050	
Scenario	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
India	-1.3	-1,5	-2	-2,8

Table 1. Expected Changes in Consumption on Account of Climate Factors (%). Note: Figures are changes from the historic baseline assuming no changes in the control variables or other factors. They are aggregated from household level estimates for each country

Mapping Changes in Living Standards

The effects of changes in average temperature and precipitation on household living standards vary by household and location within countries. We label locations where climate change negatively impacts living standards using three categories: mild (expenditure loss of less than 4% due to climate); moderate (expenditure loss of between 4% and 8%); and severe (expenditure loss of more than 8%).

Identifying declines in living standards is not as simple as identifying the regions where changes in average temperature and precipitation are projected to be the largest. Even if climate were to change by similar magnitudes in two locations, whether the locations experience negative impacts to living standards depends on the historic relationship between climate and living standards at the two locations. The locations where climate change negatively impacts living standards for 2030 and 2050 are shown in Figure 6.

The overall picture of the region is that of concentric rings, with the outer ring (the coastal areas of India and districts in the mountains along the northern border of South Asia) not experiencing negative impacts, whereas the areas closer to the center are more affected. Low-lying inland areas appear to be more fragile to changes in average temperature and precipitation than regions along the coast or in the mountains, where historic climate is relatively cold.

By 2050, more severe hotspots emerge under RCP8.5, while RCP4.5 primarily contains moderate hotspots. Under RCP 8.5, moderate and severe hotspots are predominantly in central India. The spatial pattern of these hotspots predictions is very similar to the recent estimate of

heat vulnerability in India.

The number of people estimated to fall under different kinds of hotspots by 2050 under the climate intensive scenario are: Severe (148 million with an average change in consumption of -9.8%); Moderate (441 million with an average

perature and precipitation. Chhattisgarh and Madhya Pradesh, are the top two hotspot states, followed by Rajasthan, Uttar Pradesh and Maharashtra. Climate change therefore has important implications from a poverty reduction perspective. Coastal areas in India receive a lot of attention from the point of extreme events. It is,

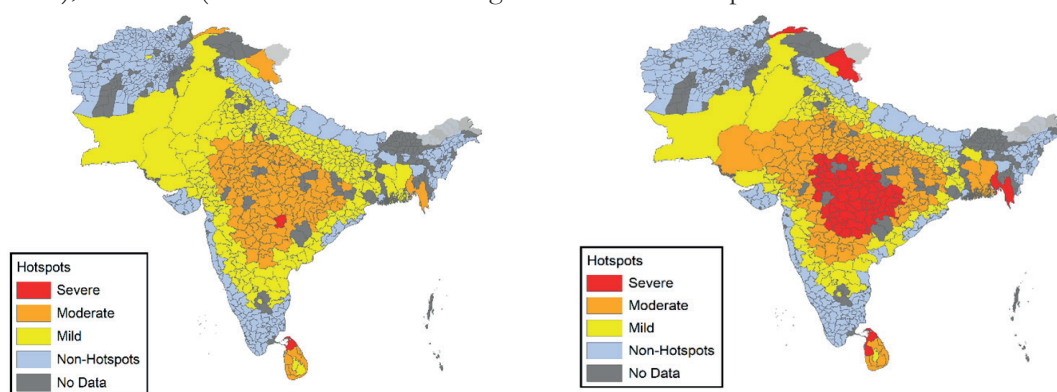


Figure 6. Hotspots by 2050 under the climate-sensitive (Left) and carbon-intensive (Right) scenarios. Source: Mani et al., 2018.

change in consumption of -5.6%). Thus approximately 600 million people in India today live in locations that would become moderate or severe hotspots by 2050 under the carbon-intensive scenario. That is almost half the country's present population.

Lessons for Adaptation to Climate Change

The first point to notice is that by 2050 many severe hotspots emerge under the carbon-intensive scenario, while the climate sensitive scenario primarily contains moderate hotspots. Under the carbon-intensive scenario by 2050 moderate and severe hotspots are present predominantly in central India. The overall pattern of hotspots predicted for 2050 under both scenarios is similar to that for 2030. This suggests that a proactive global climate action would significantly benefit India.

Second, states in the Central, Northern, and Northwestern parts of India emerge as the most vulnerable to long-term changes in average tem-

perature and precipitation. Chhattisgarh and Madhya Pradesh, are the top two hotspot states, followed by Rajasthan, Uttar Pradesh and Maharashtra. Climate change therefore has important implications from a poverty reduction perspective. Coastal areas in India receive a lot of attention from the point of extreme events. It is,

Third, households most affected in India are also more likely to be engaged in agriculture as their main livelihood. Thus a major focus has to be on such households.

The analysis identifies three major areas of intervention: enhancing education opportunities, reducing water stress, and improving opportunities in the non-agricultural sector. The analysis predicts that increasing the average duration of education by 30 percent will reduce the consumption burden from -2.8 to -2.4 percent. Reducing water stress and enhancing non-agricultural opportunities by 30 percent will yield similar benefits. See Figure 7. Therefore, it is recommended that multiple actions be taken to maximize resilience. Conversely, these results also indicate that the wrong policy actions or worsening water stress could exacerbate the impacts of climate change.

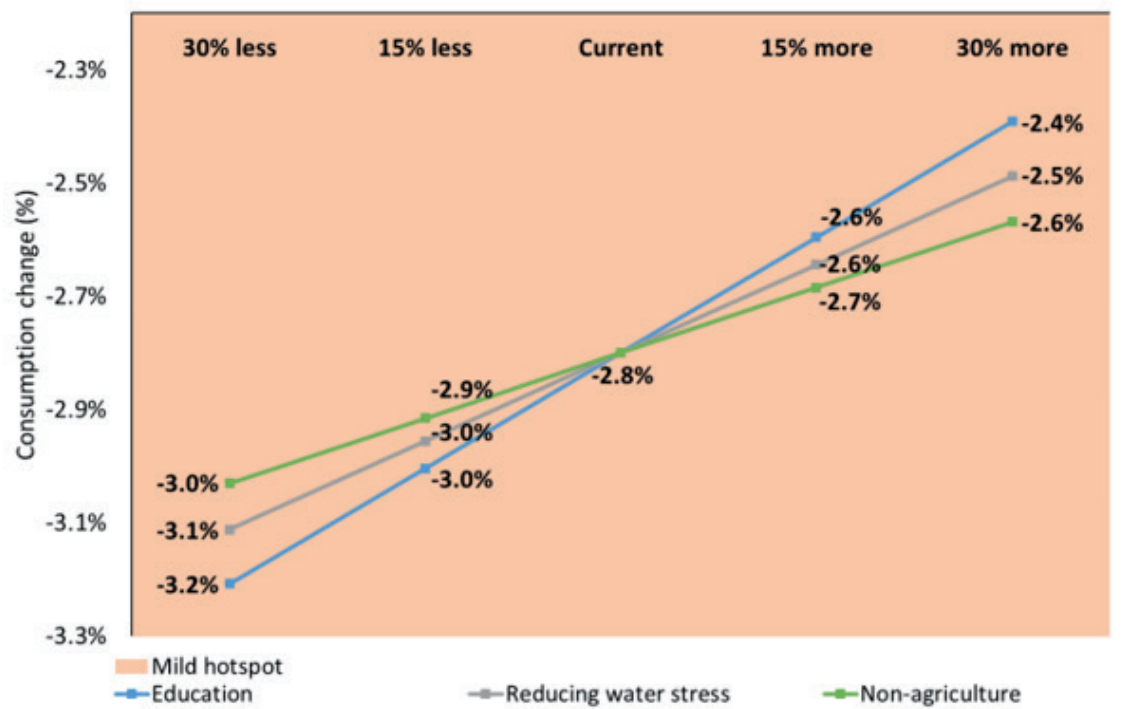


Figure 7. Investing in education, enhancing non-agricultural activities and reducing water stress will mitigate negative impacts of climate change in India. Source: Mani et al., 2018.

Note

This paper draws extensively on our joint work with Susenjit Bandyopadhyay, Shun Chonabayashi and Thomas Mosier. We thank them as well as Shreekanth Gupta and Frank Convery for comments received on an earlier draft.

References

- Ahmed, M., & Suphachalasai, S. (2014). *Assessing the costs of climate change and adaptation in South Asia*. Asian Development Bank, Mandaluyong City, Philippines.
- Angrist, J. D., & Pischke, J. S. 2008. *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton University Press, Princeton, NJ.
- Atkinson, A. 1987. On the Measurement of Poverty. *Econometrica*, 55, 749–64.
- Auffhammer, M., & Schlenker, W. (2014). Empirical studies on agricultural impacts and adaptation. *Energy Economics*, 46, 555–561.
- Bollasina, M.A., Ming, Y., & Ramaswamy, V. (2011). Anthropogenic aerosols and the weakening of the South Asian summer monsoon. *Science*, 334(6055), 502–505.
- Booth, G.D., Niccolucci, M.J., & Schuster, E.G. (1994). *Identifying Proxy Sets in Multiple Linear Regression: An Aid to Better Coefficient Interpretation*. U.S. Dept. of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT.
- Brown, C., Meeks, R., Ghile, Y., & Hunu, K. (2013). Is Water Security Necessary? An Empirical Analysis of the Effects of Climate Hazards on National-level Economic Growth. *Philosophical Transactions of the Royal Society*, 371, 1–19.
- Burke, M., Hsiang, S.M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527(7577), 235–239.
- DARA. (2012). Climate vulnerability monitor (2nd Edition). A guide to the cold calculus of a hot planet. <http://daraint.org/climate-vulnerability-monitor/climate-vulnerability-monitor-2012/data/>
- Deaton, A., & Grosh, M. (2000). *Designing Household Survey Questionnaires for Developing Countries: Lessons from Ten Years of LSMS Experience*. The World Bank, Washington, DC.
- Dell, M., Jones, B.F., & Olken, B.A. (2012). Temperature Shocks and Economic Growth: Evidence from the Last Half Century. *American Economic Journal: Macroeconomics*, 4(3), 66–95.
- Deschenes, O. (2014). Temperature, Human Health, and Adaptation: A Review of the Empirical Literature. *Energy Economics*, 46, 606–19.
- Hallegatte, S., Vogt-Schilb, A., Bangalore, M., & Rozenberg, J. (2017). *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. The World Bank, Washington, DC.
- Hallegatte, S., Fay, M., Bangalore, M., Kane, T., & Bonzanigo, L. (2016). *Shock Waves. Managing the Impacts of Climate Change on Poverty*. The World Bank, Washington, DC.
- Harris, I.P.D.J., Jones, P.D., Osborn, T.J., & Lister, D.H. (2014). Updated high-resolution grids of monthly climatic observations—the CRU TS3.10 Dataset. *International Journal of Climatology*, 34(3), 623–642.
- Heal, G., & Park, J. (2015). Goldilocks economies? Temperature stress and the direct impacts of climate change. NBER Working Paper 21119, National Bureau of Economic Research.
- Hsiang, S.M., & Jina, A.S. (2014). The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones. NBER Working Paper 20352, National Bureau of Economic Research.
- International Food Policy Research. (2017). *Global Food Policy Report*. Washington DC: International Food Policy Research Institute (IFPRI). [doi: 10.2499/9780896292529](https://doi.org/10.2499/9780896292529).
- Jacoby, H.G., Rabassa, M., & Skouas, E. (2011). *Distributional implications of climate change in India*.
- Mani, M., Bandyopadhyay, S., Chonabayashi, S., Markandya, A., & Mosier, T. (2018). South Asia's Hotspots: The Impact of Temperature and Precipitation on living Standards. The World Bank, Washington, DC. <http://documents.worldbank.org/curated/en/201031531468051189/South-Asia-s-hotspots-the-impact-of-temperature-and-precipitation-changes-on-living-standards>
- Moore, F.C., & Diaz, D.B. (2015). Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy. *Nature Climate Change*, 5, 127–31.
- OECD. (2015). *The Economic Consequences of Climate Change*. Circle Project, OECD Environment Directorate, OECD, Paris.
- Singh, D. (2016). South Asian monsoon: tug of war on rainfall changes. *Nature Climate Change*, 6(1), 20.
- Singh, D., Tsiang, M., Rajaratnam, B., & Diffenbaugh, N.S. (2014). Observed changes in extreme wet and dry spells during the South Asian summer monsoon season. *Nature Climate Change*, 4(6), 456.
- Skoufias, E., Katayama, R.S., & Essama-Nssah, B. (2012). Too little too late: welfare impacts of rainfall shocks in rural Indonesia. *Bulletin of Indonesian Economic Studies*, 48(3), 351–368.
- Verner, D., Andersen, L., Brisson, I., Hesselbjerg Christensen, J., Bjerg Geary, J., Kronik, J., & Tikjob, S.A. (2010). *Reducing poverty, protecting livelihoods, and building assets in a changing climate. Social implications of climate change for Latin America and the Caribbean*. The World Bank.
- WHO (2015). *Quantitative risk assessment of the potential effects of climate change on health*. World Health Organization, Geneva.

Suggested citation

Mani, M., & Markandya, A. (2022). Climate change and living standards in India: hotspots and effective adaptation. *EAERE Magazine*, 17.

Adapting to a changing climate in India: initiatives, challenges, and future directions

Shreekant Gupta^a, Saudamini Das^b

^aUniversity of Delhi, ^bInstitute of Economic Growth



Shreekant Gupta (sgupta@econdse.org) is Professor of Economics at the Delhi School of Economics, University of Delhi. His research and teaching are in environment and climate change. He received his PhD from University of Maryland and taught at National University of Singapore and Nazarbayev University. He was Fulbright Fellow at Massachusetts Institute of Technology and Shastri Fellow at Queens University. He has served as President of the Indian Society for Ecological Economics and as Director of the National Institute of Urban Affairs (India). He has also served on various committees of the Government of India, Montreal Protocol and IPCC where he was Lead Author (Sixth Assessment Report) and Coordinating Lead Author (Fifth Assessment Report).



Saudamini Das (saudamini@iegindia.org) is a Senior Visiting Fellow at the Institute of Economic Growth (IEG), Delhi. She was the former NABARD Chair Professor at IEG and a Maler Scholar at Beijer Institute of Ecological Economics, Stockholm. She is an Editor for journals *Ecological Economics* and *Cambridge Prisms: Coastal Futures*. She specializes on empirical research and her areas of research interest are coastal vulnerability, mangroves, non-market valuation, and evaluation of climate change adaptation policies.

Introduction

It is vital for India to maintain a high rate of economic growth for the next 2-3 decades to lift millions out of poverty and to reach high-income status in the next 25 years¹. At the same time, it is among the countries that are most vulnerable to climate change². Two-thirds of its population lives in rural areas and is economically dependent on climate-sensitive sectors such as such as agriculture, forestry, animal husbandry and fisheries. In addition, 68% cultivable land is drought prone, 12% is flood prone, and 8% is susceptible to cyclones³ and there is an increasing frequency of extreme weather events linked to climate change. Numerous studies have projected large losses of GDP and per capita GDP for India in the absence of ameliorative action (see Gupta (2022) for a discussion). To not let climate change derail the process of economic development, India needs to urgently climate proof its economy to the extent possible. To that end, adaptation is vital. India's Nationally Determined Contribution (NDC) submitted to UNFCCC in October 2015 recognises this:

The adverse impacts of climate change on the developmental prospects of the country are amplified enormously by the existence of widespread poverty and dependence of a large proportion of the population on climate sensitive sectors for livelihood. Hence for India adaptation is inevitable and an imperative for the development process. It is of immediate importance and requires action now (MoEFCC, 2015, p. 19).

In this paper we review initiatives, challenges and future directions with regard to adaptation to climate change for India. In the next section, we describe the policies for climate adaptation by the Indian government as subsumed in its very first climate action document, the National Action Plan for Climate Change (NAPCC) of 2008. This action plan was further elaborated in India's NDC as well as in the second and third biennial update reports (BURs) submitted to UNFCCC in 2018 and 2021, respectively (MoEFCC, 2018; MoEFCC, 2021). We also look at the role of Indian states under the State Action Plan for Climate Change (SAPCC). Section 3 assesses climate adaptation in a key sector that is (and will be) greatly impacted by

1 This is the goal set by the Indian Prime Minister to be achieved by 2047 (100 years since independence in 1947): <https://www.pbs.org/newshour/world/prime-minister-narendra-modi-pledges-to-make-india-a-developed-country-in-25-years> By way of comparison, India's per capita GDP (current US\$) in 2021 was USD 2,277 <https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=IN>

2 According to one recent ranking of 67 countries based on their vulnerability to climate change India was in fact found to be the most vulnerable country to climate change, followed by Pakistan, the Philippines and Bangladesh (Paun et al., 2018).

3 United Nations Development Programme. www.adaptation-undp.org/sites/default/files/downloads/undp-alm_casestudy_india_oct2012.pdf. Accessed October 2022.

climate change, namely, agriculture. We also look at India's coastal areas which are under severe climate-induced stress. Finally, in this section we present case studies on adaptation for two very different locales: farming communities in a hill district in the northern state of Uttarakhand and for the coastal megacity of Mumbai, India's financial capital. Thus, by looking at a key sector (agriculture), a key ecosystem (coasts) and at two different geographies (village and city), we illustrate the gamut of adaptation issues for India. Due to limitations of space, we do not consider natural disasters due to extreme weather events in this paper except in passing⁴. The reader can refer to the Risk and Resilience Portal⁵ of UN ESCAP, among other resources for more information. Section 4 discusses the scale of funding required for adaptation. Section 5 concludes the paper and highlights future directions for climate adaptation in India.

Policies for climate adaptation in India

So far, India does not have a National Adaptation Plan (NAP), per se. Activities related to adaptation are subsumed under the National Action Plan for Climate Change (NAPCC) which was launched in 2008. The action plan is implemented through 8 separate "National Missions"⁶, outlining priorities for mitigation and adaptation to address climate change. Different ministries and departments of the central government are responsible for implementing these missions. Earlier when the Prime Minister's Council on Climate Change (PMCCC) was active, as an apex body, it would monitor and coordinate across

these missions. However, with the waning influence of PMCCC since 2014 (it has not met in the last 7 years) this is no longer happening⁷. In effect now each nodal ministry/department focuses on the mission it is responsible for. In November 2020, the Ministry of Environment Forests and Climate Change (MoEFCC) constituted an inter-ministerial Apex Committee for Implementation of the Paris Agreement (AIPA) which as the name suggests primarily ensures the fulfilment of India's NDCs and coordinates communications with UNFCCC such as biennial updates (MoEFCC, 2020)⁸. However, an overarching institutional structure for climate policy governance is lacking (Bhatt & Somanathan, 2021)⁹. We return to issues of climate governance in the concluding section of the paper.

Of these eight "missions" three focus explicitly on adaptation, namely, those for climate resilient agriculture, water and the Himalayan ecosystem though elements of adaptation can be seen in some of the other missions as well¹⁰. We describe these three missions briefly (nodal ministry is indicated in parentheses) and in the next section discuss the agriculture mission in more detail:

- i. **National Mission for Sustainable Agriculture:**
Devise strategies to make Indian agriculture more resilient to climate change by enhancing agricultural productivity especially in rainfed areas by adopting integrated (ecological) farming, water use efficiency, soil health management, and synergising resource conservation. [Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmer's Welfare]

4 Due to its geo-climatic and socio-economic conditions, India is vulnerable (in varying degrees) to floods, droughts, cyclones, urban flooding, landslides, avalanches and forest fires. For example, 5,700 kms. of its 7,500 km coastline is prone to cyclones, 68% of the cultivable land is vulnerable to drought and hilly areas are at risk from flash floods, landslides, and forest fires. Climate induced disaster risks in India are further compounded by unplanned urbanisation, development within high-risk zones and environmental degradation. The Government of India enacted a Disaster Management Act in 2005, providing a holistic approach to disaster management. Under this Act, a National Disaster Management Authority (NDMA) was also set up in 2005. See <https://ndma.gov.in/> for details.

5 <https://rrp.unescap.org>

6 These missions are for (i) solar energy, (ii) energy efficiency, (iii) sustainable habitat, (iv) sustainable agriculture, (v) water, (vi) Himalayan ecosystem, (vii) strategic knowledge for climate change, and (viii) Green India Mission. For details see MoEFCC (2021) Table 3.1 and <https://static.pib.gov.in/WriteReadData/specifcdocs/documents/2021/dec/doc202112101.pdf>

7 PMCCC with the Prime Minister as its chairperson, was established in 2007 and reconstituted in November 2014 when its objectives were revised to: (i) evolve a coordinated response to issues relating to climate change at the national level, (ii) provide oversight for formulation of action plans in the area of assessment, adaptation and mitigation of climate change, and (iii) periodically monitor key policy decisions. MoEFCC assists the PM's office in facilitating the work of PMCCC (see <https://pib.gov.in/newsite/printrelease.aspx?relid=111090>). As per publicly available information the last meeting of PMCCC was held in January 2015.

8 The government notification constituting AIPA lists 26 functions it is supposed to perform (MoEFCC, 2020).

9 The paper only focuses on mitigation but its conclusions are equally applicable to adaptation: "Unfortunately, it is also quite obvious that the contemporary climate architecture falls short of its potential... India's climate architecture could benefit from a high-level institution that is responsible for designing climate strategy..." (op. cit. p. 13).

10 See Patra (2016) for a comprehensive overview of adaptation policies in India.

- ii. National Water Mission: *Ensure integrated water resource management systems helping to conserve water, minimise wastage and ensure more equitable distribution both across and within states. [Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation]*
- iii. National Mission for Sustaining the Himalayan Ecosystem: *Implement measures for sustaining and safeguarding the Himalayan glacier and mountain ecosystem, as well as establishing an observational and monitoring network for the Himalayan environment. NMSHE is the only mission under NAPCC with a geographic focus, all the others being theme based. [Ministry of Science & Technology, Department of Science & Technology]*

NAPCC is supplemented by actions of state and (some) city governments, non-governmental organisations (NGOs), initiatives of the private sector, and other stakeholders. Of particular relevance are State Action Plans on Climate Change (SAPCCs). Given the vast size of the country and its quasi-federal nature, states and union territories (UTs) have an important role to play in policymaking¹¹. SAPCCs describe climate change impacts and vulnerability assessments, adaptation and mitigation options as well as financing and capacity-building needs of states to implement the identified interventions. Key sectors covered by SAPCCs include agriculture, water, habitat, forestry, health, and disaster management. As of date 33 states and UTs have prepared their SAPCCs. All the SAPCCs are endorsed by the National Steering Committee on Climate Change (NSCCC) chaired by the administrative head (Secretary) of MoEFCC¹². Figure 1 provides an overview of national and state level policies for adaptation.

While impressive on paper, SAPCCs leave much to be desired. A recent review concluded: “(W)hile some states have taken a proactive approach and put in a lot of effort in the preparation of their SAPCCs, by carrying out comprehensive stakeholder consultations and vulnerability assessments, most SAPCCs give a distinct impression of being prepared only to follow the MoEFCC instructions. Most SAPCCs miss an appropriate methodology to deal with climate challenges... SAPCCs are not a ready-to-act plan yet. Climate adaptation strategies given in SAPCCs are broad generalisations, giving the impression of a wish list. Specific, result-oriented action plans with clear-cut expected outcomes are missing... Lack of clarity about available funding affects the scope and extent of proposed action under SAPCCs” (Kumar, 2018, p. 39). These findings echo those of an earlier assessment which also found “significant weaknesses” in SAPCCs (Gogoi, 2017). The four main problems were that state action plans were (i) a top-down exercise, mandated by the central government with little buy-in and ownership by the state governments¹³, (ii) not aligned with the plans and budgets of the line ministries/departments of the state, (iii) not specific and clear enough to facilitate implementation and read like a ‘statement of intent’ (iv) drafted by the state governments under the assumption that funding would materialise for implementation, either from central government or elsewhere. However, it was later expected that states would have to leverage existing sector development budgets (op. cit.).

To conclude this section, there is no overarching policy framework for climate adaptation nor a comprehensive strategy with goals, prioritisation of actions, timelines, deliverables, and a financ-

11 India has 28 states and 8 centrally administered union territories. Several Indian states are as large as countries in the EU and with large populations. For instance, the state of Uttar Pradesh alone has about the same population as Germany, the United Kingdom and France combined.

12 While adaptation finance will be discussed in Section 4, we note in passing a budgetary requirement of almost INR 14,525 billion (USD 177 billion) has been estimated by the Indian government for the implementation of SAPCCs in a five-year timeframe (MoEFCC, 2018). The source of this funding, however, has not been stated.

13 There are notable exceptions, however, such as the eastern state of Odisha. It was the first state in India to get the second phase of its climate action plan (SAPCC-II) approved by the National Steering Committee on Climate Change (NSCCC) in 2022. Odisha’s action plan addresses the drivers of climate change, prepares for its likely impacts and establishes goals and timelines for implementation for the next 10 years. SAPCC-II estimates an ambitious investment of INR 2,450 billion (USD 30 billion approx.) between 2021 and 2030 for climate adaptation and mitigation activities in key sectors. Of the total investment 73% is for adaptation, 11% for mitigation and 16% for both. A major chunk of investment is for water resources including flood management and water conservation (see <https://www.newindianexpress.com/states/odisha/2022/sep/04/odisha-peg-s-rs-245-lakh-crore-climate-spend-in-10-years-2494753.html>). Odisha was also the first state in India to prepare a Climate Budget for fiscal 2020-21 to keep track of government spending on climate change and to support mitigation and adaptation actions.

NDC	Paris Agreement ratified	Yes, 02.10.2016
	NDC submitted	Yes, 02.10.2016
	Adaptation component in NDC	Yes
	Reference to NAP in NDC	Yes, reference to both NAPCC and SAPCC
NAPCC	NAPCC process initiated in	June 2008
	Timeframe for implementation	Not specified
	Responsible institution	Prime Minister's Council on Climate Change
	Current status	Various programmes being drafted/implemented under the 8 missions
	Financing	Available under respective National Missions
	Scope of NAPCC document	Sector and region-specific adaptation and mitigation strategies of each ministry in eight critical areas (solar energy, energy efficiency, sustainable habitat, water, Himalayan ecosystem, reforestation, sustainable agriculture, CC knowledge)
	Reference to NDC	No, since NAPCC developed prior to NDC. However, strong linkages with similar prioritised sectors.
SAPCC	SAPCC process initiated in	September 2009
	Timeframe for implementation	Provides for short, medium and long-term strategies for climate action
	Responsible Institution	Ministry for Environment, Forestry and Climate Change (MoEFCC) for coordination, state nodal climate change department/agencies for development and implementation
	Current status	33 SAPCCs have been endorsed by the National Steering Committee on Climate Change. They are in various stages of implementation.
	Financing	No dedicated financing available for SAPCC. For pilot projects under SAPCC financing available through National Adaptation Fund on Climate Change (NAFCC)
	Scope of SAPCC document	State-specific adaptation and mitigation measures in regard to climate change
	Reference to NDC	No, since SAPCCs started prior to NDC. Currently under revision for alignment with NDC

Figure 1. NAPCC and SAPCC Process. NDC = Nationally Determined Contribution; NAP = National Adaptation Plan; NAPCC = National Action Plan for Climate Change; SAPCC = State Action Plan for Climate Change. Source: Adapted from Bhatt et al. (2019).

ing plan. The NAPCC was announced 14 years ago and has not been updated since. It contains elements of adaptation but a National Adaptation Plan has not been formulated. While mitigation goals have been clearly stated in India's NDC¹⁴ and also at COP26 in 2021 (namely, India will attain net-zero by 2070), adaptation is largely a smorgasbord of programmes and projects lacking focus and direction. While these projects are undoubtedly useful (some are described in the next section, also see Patra (2016)) they are not a substitute for a NAP. Also, there is no economic analysis of these programmes and projects, for example, benefit-cost ratios (BCRs) of adaptation interventions. We return to this in the concluding section.

Climate resilience in key sectors and geographies

In this section we look at a key sector (agriculture) and a key ecosystem (coasts) and at two different geographies (village and city) to illustrate the wide range of adaptation issues for India. This discussion is meant to be illustrative and not exhaustive (for example, we do not discuss human health or forest ecosystems). It gives a sense of what climate adaptation entails in a vast and diverse country such as India.

The Sixth Assessment Report of IPCC (IPCC, 2022) predicts perceptible negative impacts (with a high or very high level of confidence) of climate change on diverse food production systems – agriculture, livestock and fisheries – in numerous regions, including South Asia. The agricultural sector in India, already identified to be highly climate-vulnerable (see Gupta (2022)),

contributes a fifth of GDP and employs nearly half of the total workforce. About 86% of farmers are small and marginal farmers (less than 2 hectares of land) with little capacity to adapt. The average size of landholding is only about 1.1 hectares (ha). Despite decades of investment in agriculture, rainfed agriculture still comprises about 51 percent of the country's net sown area of 139 million ha and accounts for nearly 40 percent of the total food production. It is subject to climate risk and characterised by low levels of productivity and low input use^{15, 16}.

There are several initiatives both at the national level and at state level to enhance climate resilience of agriculture¹⁷. In 2011 the central government launched the National Innovations in Climate Resilient Agriculture (NICRA) project to enhance climate resilience of agriculture through research and technology demonstration (in 151 climatically vulnerable districts) with a modest budget of INR 3,500 million (USD 43 million). Subsequently, the National Adaptation Fund for Climate Change (NAFCC) and UNFCCC Adaptation Fund for Climate Change have given priority to funding adaptation projects in agriculture, water, forestry, livestock, and ecosystems restoration¹⁸.

The National Mission for Sustainable Agriculture (NMSA), one of the eight Missions under NAPCC, has a strong focus on adaptation. It aims at making agriculture more climate resilient by promoting location specific integrated/composite farming systems; soil and moisture conservation measures; comprehensive soil health management; efficient water management practices and

14 Three clearly stated quantitative targets in India's NDC (as updated in August 2022) to be achieved by the year 2030 are: (i) reduce emissions intensity of GDP by 45% compared to 2005 (ii) 50% of installed electric power capacity to be from non-fossil energy and (iii) create an additional carbon sink of 2.5 to 3 billion tons of CO₂ through afforestation: <https://unfccc.int/sites/default/files/NDC/2022-08/India%20Updated%20First%20Nationally%20Determined%20Contrib.pdf>

15 <https://agricoop.nic.in/en/divisiontype/rainfed-farming-system>

16 It should be noted irrigation is also conducted largely through extracting groundwater which is a depletable resource and subject to climate risk as well. Net area irrigated by wells has been growing almost exponentially since late-1960s, and well-based irrigation now accounts for 63% of total net irrigated area in the country. Nearly 89% of the groundwater extraction for the entire country in 2020 (218 billion cubic meters (bcm) out of 245 bcm) was for irrigation use and only 11% for domestic and industrial purposes (Central Ground Water Board, 2021).

17 Under the constitutional division of functions between centre and states, agriculture is a state subject. Nonetheless, the central government with much larger financial and administrative resources at its command compared to state governments, runs a large Ministry of Agriculture with a vast network of agricultural agencies and research institutes. It also manages centrally funded schemes such as National Mission for Sustainable Agriculture (NMSA) under NAPCC.

18 <https://www.nabard.org/content.aspx?id=585>

mainstreaming rainfed technologies¹⁹. Two specific policies under NMSA worth noting are the rainfed area development programme (RAD) and increasing the area under paddy (rice) cultivation that uses climate friendly water saving techniques²⁰. *Inter alia*, RAD promotes an integrated farming system (IFS) in rainfed areas to minimise the adverse impact of crop failure due to drought, floods or uneven rainfall distribution, through diversified and composite farming systems²¹. The total area covered under NMSA-RAD since its inception in 2014 up to the end of fiscal year 2021 (31st March, 2021) is 626,000 ha (compared to total rainfed area of 70 million ha) with a total expenditure of INR 14,726 million (USD 180 million) (MoAFW, 2022). The second policy is to promote alternative techniques of paddy cultivation such as SRI (system of rice intensification) and DSR (direct seeded rice) which require 15-20% less water, entail less expenditure and give higher yields. Thus, they are especially beneficial for small and marginal farmers. Since 2012 about 1.1 million ha has been covered by these techniques out of a total area of 45 million ha under rice cultivation (MoAFW, 2021).

Activities under NMSA especially for rainfed farming are complemented by another important centrally funded scheme, namely, *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY). Launched in 2015, this umbrella project comprises a range of on-farm and off-farm activities for increasing water security. These include expanding the cultivable area under irrigation, watershed management and recharge of aquifers, adoption of micro irri-

gation to improve on-farm water use efficiency and reduce wastage of water. PMKSY was initially launched for a period of 5 years but has since been extended till 2026 with an additional budgetary outlay of INR 931 billion (USD 11.4 billion) of which INR 579 billion (62%) is for debt servicing of loans taken earlier during phase 1 of PMKSY in 2016-21²².

In addition to federal government programmes such as NICRA, NMSA and PMKSY, there are significant initiatives at the state level as well. For example, in the state of Maharashtra (population 125 million) the World Bank is supporting a multi-year USD 600 million project on climate adaptation. The “Maharashtra Project on Climate Resilient Agriculture” is being implemented in areas under rainfed agriculture to, *inter alia*, strengthen the resilience of small and marginal farmers²³. The project will benefit over 25 million people spread over an area of 3.5 million ha and cover 5,142 villages across 15 most climate vulnerable districts of Marathwada and Vidarbha regions of Maharashtra. Activities under the project include technologies such as micro irrigation systems, expanded surface water storage and aquifer recharge as well as adoption of seed varieties which have short maturity and are drought and heat resistant to help reduce risks of climate related crop failure and enhance farmer’s income.

The challenge of making small farmers adapt

Research points to cognitive, normative, and institutional barriers to adaptation like social norms which mandate people to follow caste-based live-

19 The stated targets/deliverables of NMSA are to (i) make agriculture more productive, sustainable, remunerative, and climate resilient, (ii) conserve natural resources through appropriate soil and moisture conservation measures, (iii) adopt comprehensive soil health management practices, (iv) optimise the utilisation of water resources through efficient water management, and (v) develop the capacity of farmers and stakeholders.

20 Since rice is a water intensive crop it is particularly climate sensitive. It is also by far the most important food crop in India both in terms of production and cultivated area. India has the world’s largest area under rice cultivation (over 45 million hectares) and is the world’s second largest producer. However, 90% of the area under rice belongs to relatively poor marginal, small and medium farmers with low productivity—rice yield in India (2390 tons/ha) is only a third that of China (6710 tons/ha). Also, as mentioned earlier these farmers have little capacity to adapt.

21 As the phrase suggests, IFS integrates various on-farm activities such as crops (field crops, horticultural crops), agroforestry, livestock, fishery, mushroom and bee culture in a synergistic way so that the wastes of one process become the input for other processes for optimum farm productivity. For example, crop residues after harvesting can be used for animal feed and animal manure can be used as organic fertiliser. Rice based IFS comprising rice and pisciculture not only improves fish production but also increases rice yield as fish improve soil fertility by increasing the availability of nitrogen and phosphorous. IFS is particularly useful for small and marginal farmers as a diversified portfolio of activities that act as a hedge against climate risk.

22 <https://www.hindustantimes.com/india-news/cabinet-approves-93-068-crore-irrigation-plan-to-aid-2-2-million-farmers-101639593581515.html>

23 <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/704731519959668277/india-maharashtra-project-on-climate-resilient-agriculture-project>

lihood choices (Jones & Boyd, 2011; Jain et al., 2015). In such cases, the scope for adaptive behaviour shrinks tremendously (Grothmann et al., 2013; Shackleton et al., 2015). Thus, in the presence of strong social norms and caste systems in India, simply providing the farmers with adaptive options or finance to change their agricultural practices may not work. A nuanced understanding of farmer decision-making is important for adaptation policy and practice in order to help identify entry points for facilitating behavioural change (Singh et al., 2016). A recent survey of farm-level adaptation noted the strong influence of socio-economic characteristics of households on adaptation with education as one of the key determinants (Bahinipati & Patnaik, 2022). Literate households were able to access information on various adaptation options, and were thus more likely to adapt. Similarly, richer households opted for several adaptation mechanisms because of access to resources, assets, and income (op. cit.) These findings are corroborated by Singh et al. (2019) and by Jain et al. (2015). The latter found that assets, access to irrigation, weather perceptions, and risk aversion were the strongest factors associated with adaptation decisions.

Coastal adaptation

Coastal areas and ocean-based livelihoods in India are amongst the world's most vulnerable to the impacts of climate change which include extreme temperatures, changes in precipitation patterns, increased incidence of extreme weather events, sea-level rise, and coastal erosion. Nearly 250 million people in India reside within 50 km of the country's coastline which is endowed with the world's highest mangrove cover, rich corals, seagrass beds, and other coastal ecosystems that support a range of livelihoods. Coastal adaptation projects have received attention following multiple mega disasters but are mostly engineering solutions such as building cyclone shelters, sea-walls, groynes, etc. The role of natural ecosystems in disaster mitigation has been largely ignored though there is some recognition in recent years of nature-based adaptation in national as well as UNFCC-funded adaptation projects.

In this context, mangroves acted as a bio-shield and saved lives and property during the 1999 super cyclone that hit the coastal state of Odisha bordering Bay of Bengal and killed nearly 10,000 people (Das & Vincent, 2009; Das & Crépin, 2013). The bay is an area of cyclogenesis and the east coast of India gets hit by cyclones regularly. Odisha's coast had more than 30,000 hectares of mangroves much of which were destroyed over the years due to urbanisation, farming, aquaculture, ports and coastal development. It had 17,000 hectares of mangroves when the super cyclone hit which were able to reduce 35% of potential deaths (Figure 2) and provide substantial protection to houses from wind and surge damage (Figure 3). Conservation, regeneration and enrichment of coastal natural habitats needs to be taken seriously in coastal adaptation planning and implementation. There is strong evidence of nature-based adaptations being low cost and no-regret options with benefit-cost ratio (BCR) strongly in favour of natural adaptation measures (Baig et al., 2016). It is also important to account for the social and gender dimensions in coastal adaptation planning (Prakash et al., 2022).

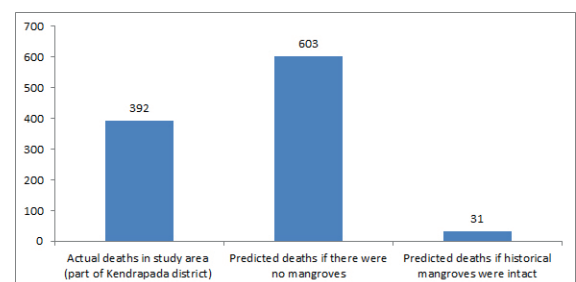


Figure 2: Human deaths averted by mangroves during super cyclone. Source: Das, 2011.

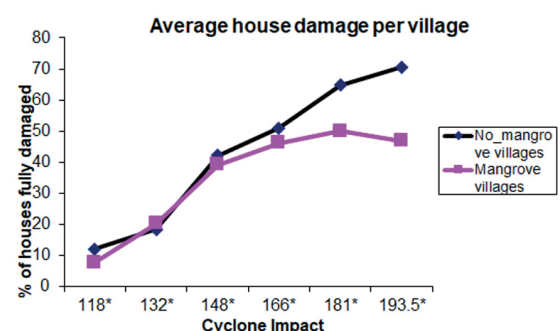


Figure 3: House damage averted by mangroves during super cyclone. Cyclone impact is defined as wind speed in km/hour. Source: Das & Crépin, 2013.

Case study: adaptation in farming communities in a hilly region

Champawat is a poor, hill district spread over 1,766 km² in the state of Uttarakhand in the Himalayan region of North India with an average annual household income of USD 476. It is highly vulnerable to climate change with a vulnerability score of 0.35 (1 being least vulnerable). 82% of the population is engaged in agriculture and allied sectors. Over 90% of cultivated land is rainfed and 85% of the villages are on mountain slopes making them vulnerable to water scarcity, landslides, and non-climate hazards like earthquakes²⁴. A small UNFCCC-funded project²⁵ (USD 0.97 million) was initiated in 2016 in 10 villages to improve the adaptive capacity of farmers through climate smart farming technologies such as rainwater harvesting, drip irrigation, constructing low-cost bamboo polyhouses (small greenhouses made of polythene) and other interventions such as the formation of community-based organizations (CBOs) with at least 33% women members. Evaluation reports of the project showed the interventions to be effective and resulted in increased availability of water. But the biggest success was the polyhouses which revolutionised vegetable farming and enabled the farmers to grow 3-4 crops in a year. While these structures last for 8-10 years, given their low cost, break-even (cost recovery) happens in one crop cycle itself (NABARD, 2021). A positive outcome of this project is that poly farming is now being implemented on a wider scale in hill communities to make them more climate resilient and to increase incomes.

Case study: adaptation in a mega city (Mumbai)

Mumbai (population 12.44 million, 2011 census²⁶) is the capital of the state of Maharashtra, India's richest state in terms of GDP (approximately

USD 400 billion or 14% of national GDP). It is also the financial capital of India. With its peculiar geography (surrounded on three sides by the Arabian Sea), high population density (28,000 per sq. km) and with 42% of its inhabitants living in slums²⁷, the city is extremely vulnerable to climate change. Urban flooding, coastal risks (storm surges, coastal inundation and erosion), cyclones, landslides and heat waves are the main climate risks (MCAP, 2022). Mumbai ranks 5th among the world's cities most at risk of flooding, recording annual losses amounting to USD 284 million (Hallegatte et al., 2013). A catastrophic flood in 2005 killed around 5,000 people and caused economic damages of up to USD 690 million (Nagendra, 2017). It is estimated by 2050 annual losses from flooding and heavy rain events will increase up to USD 6.1 billion per year (Picciariello et al., 2021)²⁸. Earlier this year, the city government announced an ambitious 20-year plan to make the city net zero by 2050 (20 years before the rest of India) and also to make it climate resilient. The Mumbai Climate Action Plan (MCAP) is a combination of mitigation (decarbonisation of electricity generation, clean fuels, public transport, green buildings, etc.) and adaptation (flood resilience, water conservation, urban greening, early warning systems, etc.). The main focus is, however, on decarbonisation of the city through renewables, zero-emissions vehicles, public transport and energy-efficient buildings. With regard to adaptation, especially on managing urban floods, increasing green cover, and other climate resilience measures, the plan would benefit from setting quantifiable targets and timelines and from a concrete financing plan without which it reads like a (laudable) statement of intent. Interestingly, MCAP does not mention an earlier large project to prevent floods in Mumbai. The Brihanmumbai (Greater Mumbai) Storm Water Disposal (Brimstowad) project was launched in 2005

24 <https://www.nabard.org/demo/auth/writereaddata/File/BAIF%20AFB%20Flyer%20-%20Uttarakhand.pdf>

25 <https://www.adaptation-fund.org/project/climate-smart-actions-and-strategies-in-north-western-himalayan-region-for-sustainable-livelihoods-of-agriculture-dependent-hill-communities/>

26 There has been no census in India after 2011. The population of greater Mumbai metropolitan area at present is approx. 21 million.

27 As an aside Mumbai also has the world's most expensive private home, a USD 2 billion, 60-story high-rise owned by billionaire Mukesh Ambani.

28 Most of these losses are uninsured and borne by individuals or small businesses (Patankar & Patwardhan, 2016) leading to devastating impacts on livelihoods and household incomes.

after the disastrous floods in the city to augment drainage, desilting of drains and several other measures. Despite a cost overrun of more than 3 times (INR 40 billion instead of INR 12 billion) less than half of the project was completed. Going forward it would be useful to absorb learnings from this failure. On the whole, however, MCAP is a progressive and pathbreaking initiative worth emulating by other city governments. In fact, cities like Kolkata (India), Dhaka (Bangladesh), and Karachi (Pakistan) are planning their climate action plans on similar lines²⁹.

Financing of climate adaptation

In the absence of a National Adaptation Plan (NAP) and clearly defined goals, it is difficult to assess the scale of adaptation finance required though it is likely to be very large (some back of the envelope estimates are mentioned below). There is also no attempt to quantify benefit-cost ratios (BCRs) for specific adaptation interventions/projects that are being implemented. Given competing demands on limited public funds, the case for adaptation would be stronger if projects could demonstrate high BCRs. More broadly in terms of attracting domestic (public and private) and international funds at scale, a strong case could be made through a 'marginal adaptation cost curve' at state/urban/sectoral level.

India's NDC provides some figures for adaptation finance but the basis for arriving at them is not provided--"expenditure on programmes with critical adaptation components has increased from 1.45% of GDP in 2000-01 to 2.82% during 2009-10. Expenditure on human capabilities and livelihoods viz. poverty alleviation, health improvement and disease control and risk management, constitutes more than 80% of the total expenditure on adaptation in India." (MoEFCC, 2015, p. 20) The document further states, "(P) reliminary estimates indicate that India would need around USD 206 billion (at 2014-15 prices) between 2015 and 2030 for implementing adaptation actions in agriculture, forestry, fisheries infrastructure, water resources and ecosystems.

Apart from this there will be additional investments needed for strengthening resilience and disaster management." (op. cit., p. 30).

A recent government committee has attempted to elaborate on these figures by equating climate adaptation with meeting SDGs: "(A)s a starting point of adaptation financing assessment, the programme costs of policies that contribute to the achievement of various SDG goals was estimated and aggregated... Specific SDGs were selected based on their contribution to improving resilience... *The financial needs for meeting these SDGs were taken to represent the need for financing to adapt to climate change.*" (Ministry of Finance, 2020, p. 16, emphasis added). In this manner, the cumulative expenditure for adaptation up to the year 2030 was estimated at INR 85.6 trillion (USD 1.04 trillion) at 2012 prices (op. cit.). While this may suffice as a back of the envelope estimate, it is not a substitute for careful costing of adaptation. An early example of the latter is Markandya and Mishra (2011) which considers additional adaptation measures for India under different climate scenarios, focuses on the medium-term (2030 to 2050) and covers five key sectors – human health, coastal zones, water, agriculture, and forest ecosystems, using a bottom-up methodology.

The National Adaptation Fund for Climate Change (NAFCC) was launched in 2015 to fund adaptation actions not otherwise covered under ongoing schemes/ programs. In particular, its objective is to provide grants to state governments for implementing adaptation projects under SAPCCs. As of 2021 only 30 projects worth approx. INR 8,346 million (USD 102 million) had been approved by MoEFCC under this fund and are at different stages of implementation. These projects are being implemented in agriculture, water, forestry, and coastal sectors to enhance adaptive capacity in terms of the availability of improved water and food security, livelihoods, and ecosystem services. In its 2018 biennial update to UNFCCC, the Indian government also stated INR 14,525 billion (USD 177 billion) would be required to implement SAPCCs over a five-year

²⁹ As reported in *The Economist*, 17th March 2022.

period (MoEFCC, 2018). The basis for this figure was not provided.

Conclusions and future directions

Adverse changes in India's climate such as erratic monsoon, droughts, and heatwaves are already evident and will get more pronounced. This poses serious risks to economic growth and will have other negative societal impacts as well. Therefore, it is imperative to enhance the resilience of the economy to climate change. There is a need for an overarching policy framework for climate adaptation and a comprehensive strategy with clear goals, deliverables, prioritisation of actions, timelines, and a financing plan. We have discussed several useful projects that are being implemented by different departments of the national government and by states and cities, but without much coordination or a clear sense of "how much" adaptation should take place as a whole or how should actions be sequenced (short, medium, long-run). The total expenditure so far is also fairly modest for a USD 3.5 trillion economy where climate change could easily knock off 1% or more from GDP. All of this reflects a deeper problem of climate governance that remains unaddressed. As Bhatt and Somnathan (2021) point out "(T)he climate policy architecture in this current period is characterized by centralized decision-making by the Prime Minister's office with the Prime Minister's Council on Climate Change and other bodies becoming defunct. Moreover, state actions have been only sporadically supported by the centre. Therefore, even though mitigation policymaking has been active, the Prime Minister's office is its only focal point, and the institutional structure of Indian climate governance remains weak." (op. cit., p. 40)

A National Adaptation Plan (as part of a National Climate Plan or otherwise) would begin with

recognising that "how much" adaptation is required depends inversely on the speed and extent of global GHG mitigation. Thus, a 1.5-degree warmer world would require less adaptation than one with higher levels of temperature stabilisation³⁰. The NAP would then assess the potential for adaptation to reduce these impacts which in other words is the benefits of adaptation (i.e., avoided damages). These benefits could then be compared with the costs of adaptation. Ideally this analysis is done 'at the margin' (marginal benefit and marginal cost) since reducing impacts to very low levels involves potentially disproportionately high (marginal) adaptation costs. "Such a framework can be used to assess the costs and benefits of adaptation and (theoretically) the economic (sic) optimal level of adaptation." (Watkiss and Preinfalk 2022, p. 19). Admittedly this is a tall order for any plan and has huge information requirements. As a second best it would still be useful to have specific goals like the ones for mitigation³¹ even if they are not economically "optimal" in a textbook sense.

At the very least an immediate task would be to quantify benefit-cost ratios for individual projects to justify public investment in them when there are competing demands on government budgets. For instance, our case studies show the efficacy of nature-based approaches (mangroves) for coastal protection and of low-cost bamboo polyhouses in hill agriculture. Programmes designed to scale up these and similar interventions should urgently find a place in adaptation policies.

30 To compound matters of endogeneity in adaptation, there is also *autonomous* adaptation (e.g., a farmer *sho moto* adjusting water and other inputs to counter changed weather conditions) versus *planned* adaptation by governments (e.g., an irrigation scheme). In this example, the farmer's revenue loss can be considered as an upper bound for autonomous adaptation, assuming she will spend at least that much on autonomous adaptation strategies.

31 As stated earlier, these goals are to: (i) reduce emissions intensity of GDP by 45% compared to 2005 (ii) 50% of installed electric power capacity to be from non-fossil energy and (iii) create an additional carbon sink of 2.5 to 3 billion tons of CO₂ through afforestation, all by the year 2030.

Note

We would like to thank (without implicating) Frank Convery and Gaurav Arora for helpful comments and suggestions on this paper.

References

- Bahinipati, C.S., Patnaik, U. (2022). What Motivates Farm-Level Adaptation in India? A Systematic Review. In: Haque, A.K.E., Mukhopadhyay, P., Nepal, M., Shammin, M.R. (eds.) *Climate Change and Community Resilience: Insights from South Asia*. Springer, Singapore. https://doi.org/10.1007/978-981-16-0680-9_4
- Bhatt, T.R., & Somanathan, E. (2021). Climate Policy Architecture in India. *EAERE Magazine*, 14. <https://www.eaere.org/wp-content/uploads/2021/10/EAERE-Magazine-N.14-Fall-2021.pdf>
- Bhatt, S., Na-Hyeon, S., Awasthi, K., Maas, V. & Sprenger, M. (2019). *India: NAPCC Process Country Case Study*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Bonn, Germany. <https://www.adaptationcommunity.net/wp-content/uploads/2019/04/giz2019-en-factsheet-nap-india-low-res.pdf>
- Central Ground Water Board. (2021). *National Compilation on Dynamic Groundwater Resources of India, 2020*. Central Ground Water Board, Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti, Government of India. Faridabad, India. http://cgwb.gov.in/documents/2021-08-02-GWRA_India_2020.pdf
- Das, S. & Vincent, J.R. (2009). Mangroves protected villages and reduced death toll during Indian Super Cyclone. *Proceedings of the National Academy of Sciences*, 106(18), 7357-7360. <https://doi.org/10.1073/pnas.081044010>
- Das, S. & Crépin, A.-S. (2013). Mangroves can provide protection against wind damage during storms. *Estuarine, Coastal and Shelf Science*, 134, 98-107. <https://doi.org/10.1016/j.ecss.2013.09.021>
- Gogoi, E. (2017). *India's State Action Plans on Climate Change: towards meaningful action*. Oxford, UK: Oxford Policy Management. <https://www.opml.co.uk/files/Publications/corporate-publications/briefing-notes/id-state-action-plan-climate-india.pdf>
- Grothmann, T., Grecksch, K., Wines, M., & Siebenhüner, B. (2013). Assessing institutional capacities to adapt to climate change: integrating psychological dimensions in the Adaptive Capacity Wheel. *Natural Hazards and Earth System Sciences*, 13(12), 3369-3384. <https://doi.org/10.5194/nhess-13-3369-2013>
- Gupta, S. (2022). Climate change impacts for India: a review. *EAERE Magazine*, 17.
- Hallegatte, S., Green, C., Nicholls, R.J., & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. *Nature Climate Change*, 3, 802-806. <https://doi.org/10.1038/nclimate1979>
- IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK. <https://doi.org/10.1017/9781009325844>
- Jain, M., Naeem, S., Orlove, B., Modi, V., & DeFries, R.S. (2015). Understanding the causes and consequences of differential decision-making in adaptation research: Adapting to a delayed monsoon onset in Gujarat, India. *Global Environmental Change*, 31, 98-109. <https://doi.org/10.1016/j.gloenvcha.2014.12.008>
- Jones, L. & Boyd, E. (2011). Exploring social barriers to adaptation: Insights from Western Nepal. *Global Environmental Change*, 21(4), 1262-1274. <https://doi.org/10.1016/j.gloenvcha.2011.06.002>
- Kumar, V. (2018). *Coping with Climate Change: An Analysis of India's State Action Plans on Climate Change*. Centre for Science and Environment, New Delhi. http://cdn.cseindia.org/attachments/0.40897700_1519110602_coping-climate-change-volIII.pdf
- Markandya, A. & Mishra, M. (eds.). (2011). *Costing Adaptation: Preparing for climate change in India*. The Energy and Resources Institute (TERI), New Delhi, India.
- MCAP. (2022). *Mumbai Climate Action Plan 2022: Towards a Climate Resilient Mumbai*. Brihanmumbai Municipal Corporation (Municipal Corporation of Greater Mumbai). <https://mcap.mcgm.gov.in/about/>
- MoAFW. (2021). *Annual Report 2020-21*. Department of Agriculture & Farmers Welfare Ministry of Agriculture & Farmers Welfare, Government of India. <https://agricoop.nic.in/en/annual-report>
- MoAFW. (2022). *Annual Report 2021-22*. Department of Agriculture & Farmers Welfare Ministry of Agriculture & Farmers Welfare, Government of India. <https://agricoop.nic.in/en/annual-report>
- MoEFCC. (2015). *India's Intended Nationally Determined Contribution: Working towards climate justice*. Ministry of Environment, Forest and Climate Change, Government of India. <https://unfccc.int/sites/default/files/NDC/2022-06/INDIA%20INDC%20TO%20UNFCCC.pdf>
- MoEFCC. (2018). *India: Second Biennial Update Report to the United Nations Framework Convention on Climate Change*. Ministry of Environment, Forest and Climate Change, Government of India. <https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf>
- MoEFCC. (2020). Notification S.O. 4259(E) creating the Apex Committee for Implementation of Paris Agreement. Published in the Gazette of India: Extraordinary CG-DL-E-27112020-223382 on 27 November, 2020. Ministry of Environment, Forest and Climate Change, Government of India. <https://static.pib.gov.in/WriteReadData/userfiles/AIPA%20Gazette%20Notification.pdf>
- MoEFCC. (2021). *India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change*. Ministry of Environment, Forest and Climate Change, Government of India. <https://unfccc.int/documents/268470>
- Ministry of Finance. (2020). *Report of the Sub-Committee for the Assessment of the Financial Requirements for Implementing India's Nationally Determined Contribution (NDC)*. Department of Economic Affairs, Ministry of Finance, Government of India. <https://dea.gov.in/divisionbranch/climate-change-finance-unit> and <https://dea.gov.in/sites/default/files/Sub%20Committee%20Report%20Final.pdf>
- NABARD (2021), *Mid-term Evaluation of Climate Change Adaptation Projects funded from UNFCC Adaptation Fund*. NABARD Research Study-20, pp. 34-70. Department of Economic Analysis & Research, National Bank for Agriculture and Rural Development (NABARD), Mumbai, India. <https://www.nabard.org/auth/writercaddata/flipbook/2022/mar/nrs-20-mid-term-evaluation-of-climate-change-adaptation-projects/index.html>
- Nagendra, H. (2017). Mumbai floods: what happens when cities sacrifice ecology for development. *The Conversation*, September 1. <https://theconversation.com/mumbai-floods-what-happens-when-cities-sacrifice-ecology-for-development-83328>
- Patankar, A., & Patwardhan, A. (2016). Estimating the uninsured losses due to extreme weather events and implications for informal sector vulnerability: a case study of Mumbai, India. *Natural Hazards*, 80(1), 285-310. <https://doi.org/10.1007/s11069-015-1968-3>
- Patra, J. (2016). *Review of Current and Planned Adaptation Action in India*. CARIAA Working Paper no. 10. International Development Research Centre, Ottawa, Canada and UK Aid, London, United Kingdom. <https://www.iisd.org/publications/report/review-current-and-planned-adaptation-action-india>

Paun, A., Acton, L. & Wai-Shin, C. (2018). *Fragile Planet: Scoring climate risks around the world*. HSBC Global Research, March 2018. <https://www.sustainablefinance.hsbc.com/carbon-transition/fragile-planet>

Picciariello, A., Colenbrander, S., Bazaz, A., & Roy, R. (2021). *The costs of climate change in India – A review of the climate-related risks facing India, and their economic and social costs*. ODI Literature review. ODI, London, UK. <https://odi.org/en/publications/the-costs-of-climate-change-in-india-a-review-of-the-climate-related-risks-facing-india-and-their-economic-and-social-costs/>

Prakash, A., McGlade, K., Roxy, M.K., Roy, J., Some, S. & Rao, N. (2022) Climate adaptation interventions in coastal areas: a rapid review of social and gender dimensions. *Frontiers in Climate*, 4:785212. <https://doi.org/10.3389/fclim.2022.785212>

Shackleton, S., Ziervogel, G., Sallu, S., Gill, T., & Tschakert, P. (2015). Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. *Wiley Interdisciplinary Reviews: Climate Change*, 6(3), 321-344. <https://doi.org/10.1002/wcc.335>

Singh, C., Dorward, P., & Osbahr, H. (2016) Developing a holistic approach to the analysis of farmer decision-making: implications for adaptation policy and practice in developing countries. *Land Use Policy*, 59(31), 329-343. <https://doi.org/10.1016/j.landusepol.2016.06.041>

Singh, N.P., Anand, B., Singh, S., & Khan, A. (2019). Mainstreaming climate adaptation in Indian rural developmental agenda: A micro-macro convergence. *Climate Risk Management*, 24, 30-41. <https://doi.org/10.1016/j.crm.2019.04.003>

Watkiss, P., & Preinfalk, E. (2022). The economics of climate adaptation in the EU: new evidence from recent research. *EARE Magazine*, 16. <https://www.eare.org/magazine/#1612524805076-3237dfc3-679c>

Suggested citation

Gupta, S., & Das, S. (2022). Adapting to a changing climate in India: initiatives, challenges, and future directions. *EARE Magazine*, 17.

Climate resilience in the presence of water-related stress and hazards in India

Gaurav Arora, Saif Ali

Indraprastha Institute of Information Technology



Gaurav Arora (gaurav@iiitd.ac.in) is Assistant Professor of economics at the Department of Social Sciences and Humanities, Indraprastha Institute of Information Technology Delhi (IIIT-Delhi). His research focuses on decision problems at the intersection of agricultural production and natural resource management. His long-term interest in employing spatially-delineated datasets for statistical and econometric analyses has led to a certification course for the National Programme on Technology Enhanced Learning in India. Gaurav received his PhD from Iowa State University, M.S. from University of Arizona and B.Tech. from Indian Institute of Technology (Indian School of Mines), Dhanbad.



Saif Ali (mail.saifali@gmail.com) is a doctoral candidate in economics at the Indraprastha Institute of Information Technology, Delhi. He formerly worked in Silicon Valley on high-performance computing problems. He investigates environmental economic issues putting computation and data to advantage. To examine groundwater level dynamics, vehicle pollution, and news coverage trends, Saif has developed models that creatively utilise data from remote sensing, Twitter, and big digital-news corpora.

Introduction

India supports 18% of world's population while sustaining only 4% freshwater resources on 2.4% global land mass. Water stress in India manifests as economic reliance on Southwest Monsoon rainfalls as documented in British-era administrative records (Ray et al., 2021) and contemporary monetary policy reports (Sabnavis, 2008, p.110). About 40% of India's agricultural production is entirely fed by the Monsoon rains that typically occur from June to September each year. Monsoons exhibit large regional variation in rainfall intensity. Industrial sectors like electricity generation, mining, manufacturing, infrastructure development, among others, all depend upon freshwater availability. The Reserve Bank of India (RBI) recently reported that energy sector water demand was projected to increase eight-fold (from 15 billion cubic meters (bcm) to 130 bcm) during 2015-2050. India's energy security is hence closely tied to its freshwater security given that the country seeks to transition away from coal and oil based economic production to electricity, natural gas and renewable energy sources (Holland et al., 2015; Ministry of Environment & Climate Change, 2015). In addition, freshwater demand for food production and do-

mestic consumption are projected to increase by 20% and 30%, respectively, during this period (RBI, 2022).

Global warming impacts the hydrologic cycle by altering long-term rainfall patterns (Fishman, 2018; Konapala & Mann, 2020) and shrinks the glacial and polar ice cover leading to sea-level rise. Sea-level rise entails reduced freshwater access for all economic sectors including agriculture and fishery due to the intrusion of saline waters into ground and surface water resources (Lal, 2001). Recent projections by the Intergovernmental Panel for Climate Change (IPCC) suggested that a large landmass of India's coastal regions will be submerged by 2050, specifically in the eastern states of West Bengal, Orissa and Andhra Pradesh, and the western states of Gujarat, Maharashtra and Kerala¹. The areas that are under threat of submergence comprise productive agricultural lands as well as prime real-estate such as the special economic zones. Global warming also leads to higher inland water scarcity due to increased evapotranspiration. A 2°C global temperature rise would result in new water scarcity regions in north-west India's Sabarmati and Indus river basins (Gerten et al., 2013)² - which overlap with the major food-grain

1 See 'Coastal Risk Screening Tool' made available by Climate Central (2021). Last accessed on July 13, 2022.

2 See 'Aquastat' made available by the United Nation's Food and Agricultural Organization. Last accessed on July 13, 2022.

producing states of Punjab and Haryana, thereby inducing food insecurity concerns in the future.

Apart from intensifying seasonal and annual variability in rainfall patterns, a changing climate would lead to an increased risk and severity of extreme events such as droughts and floods (Tebaldi et al., 2006; Arnell & Gosling, 2016). A large and forthcoming literature has documented the economic impacts of climate change extremes into two broad categories: the direct impacts and the indirect impacts. Direct impacts are a consequence of large-scale rainfall variability that causes destruction of crops, property and human lives (Parida, 2020). The indirect impacts, on the other hand, are routed through reduced water storage in river basins, canals, tanks, ponds and groundwater acquirers due to environmental shocks. Lack of water access has been shown to increase food insecurity, poverty, farmer distress and social conflicts (Parida et al., 2018; Blakeslee et al., 2020; Jain et al., 2021; Sekhri, 2014; Ray et al., 2021) and reduced scope for adaptation (Fishman, 2018).

A primary function of climate policy is capacity-building for society, production systems and the bureaucratic structures in a manner that facilitates effective response to seasonal weather variability and environmental shocks like droughts, floods, hailstorms, cyclones and so on. Of particular interest to policy are the distributional impacts of such stressors. There are several mechanisms in India, including natural endowments, social, economic, cultural and historical stratification, and the extent of administrative accountability, which systematically influence the scope for climate change adaptation among communities facing climatic and water-related stress. The pre-existing water access differentials are associated with long-term development outcomes like wealth and income levels, property rights, education and skills, which in turn determine people's ability to adapt to weather changes.

The Policy Context

Climate resilience, also known as climate-resilient development, is a policy priority of the

Indian government that is embedded in the quest for attaining sustainable development in the face of a changing climate. The governance approach is to search for “co-benefits” and “positive linkage(s)” in addressing climate change alongside economic development, which was originally provided for in the 2008 National Action Plan on Climate Change (NAPCC). The contemporary climate change governance has been documented to exhibit a centralized management structure with low accountability and lack of inter-ministerial communication mechanisms (Bhatt & Somanathan, 2021). A natural query for our essay is: how does climate change governance contrast with water resource management, and what is the intersectionality (or a lack of it) between the climate and water policy architectures in India?

In stark contrast with its climate policy architecture, India's water resources are monitored and managed in a highly decentralized manner. Hydrological structures that govern natural water flows in river basins and groundwater aquifers act as geographic constraints in providing a rationale for decentralized water resource management. In addition, the management of water resources is often undertaken separately by the federal and state-level agencies for common hydrological units like the groundwater aquifer. For example, the groundwater monitoring network maintained by the Central Groundwater Board (CGWB) is distinct from those maintained by the state-level groundwater boards. The CGWB and the Uttar Pradesh Groundwater Department (UPGWD) independently provide groundwater levels data (see India-WRIS³). In 2017, the UPGWD monitored 8,028 wells, almost eight times the 973 monitoring wells managed by the CGWB in that year. However, the CGWB data are collected four times every year as compared to the two-times-a-year frequency of UPGWD data, and go back much further in the past to 1997 relative to the UPGWD data that commenced from 2009. Although the state and national agencies conduct independent monitoring, they coordinate to generate comprehensive reports on “Dynamic Ground Water Resources of India” every three to five years (Central Groundwater Board, 2019). These assessment

³ IndiaWRIS. Last accessed on July 13 2022.

reports categorize administrative blocks⁴ into ‘safe’, ‘semi-critical’, ‘critical’ and ‘overexploited’ categories, based on which the National Bank for Rural Development (NABARD) regulates institutional financing for development of irrigation wells (National Bank for Rural Development, 2018).

We now provide an account of the inefficiencies in water resource management that are caused, at least in part, due to lack of inter-ministerial coordination in India. The state governments of Punjab and Haryana proposed a policy initiative in 2009 for delayed paddy transplantation (from mid-May to mid-June) to reduce the dependence of paddy cultivation on groundwater irrigation. This shift in schedule was later shown to cause higher incidence of crop burning, mediated by the shorter window between paddy harvest and wheat sowing as well as labor shortage, thereby worsening the regional air pollution crisis and carbon footprint of paddy cultivation (Sawhani et al., 2019; Mukherji, 2022). Another example is the adoption of solar irrigation pumps - supported by the National Solar Mission under the ‘co-benefits’ paradigm of NAPCC. Majority solar irrigation pumps were adopted in states facing precarious groundwater condition (Shah, et al., 2018), possibly worsening groundwater depletion. Similar deficiencies have been reported in India’s urban development policy. Technical assessments of climate change risks, coordinated by The Ministry of Environment and Forests, have found limited reflection in city development plans, which are coordinated by the Ministry of Urban Development (Revi, 2008). These ‘unintended’ policy consequences can be interpreted as driven, at least in part, due to the centralized climate change policy architecture and a deficient inter-ministerial communication capacity in India, especially in large-scale projects that necessitate inter-sectoral governance.

A critical function of climate resilient policy is to provide measures of impacts and adaptation scope in the presence of water stress. While there is strong evidence for climate change induced water stress in India, the measurement of the resulting damages is a work-in-progress. The assessment of economic losses from higher

climate change induced water stress is difficult due to uncertainty and regional variability in the ‘change’ predictions (Kundzewicz et al., 2014; Long et al., 2016; Arnell et al., 2016), diversity in local biophysical and socioeconomic contexts (Chindarkar & Grafton, 2019; Sikka et al., 2022) and transmission mechanisms of economic impact that are not immediately evident or amenable to direct measurement (Revi, 2008; Dalin et al., 2017).

The Adaptation Barriers

Water stress in India is enmeshed with the political economy of agricultural reform and energy policy. Mukherji (2022) has argued that the sustainable development of groundwater resources needs a “water-food-energy nexus” approach. The reason is that the unsustainable irrigation practices of the ‘present’ emanated from post-Independence agricultural reforms that preceded the “Green Revolution”-era. These reforms were aimed at ensuring national food security and promoted tube-well irrigation with an ambition of realizing the ‘full’ potential of untapped national groundwater resource. The farmers were subsequently given electricity subsidy and minimum support prices to promote paddy and wheat production. India’s irrigated area expanded by 150% between 1950 and 1990 (Mukherji, 2022). Then in the early 1990s concerns around groundwater depletion emerged (Chandrakanth & Romm, 1990). The narrative has since shifted from “groundwater development” to “groundwater management” (Dantwala, 1976) because the emerging scarcity of the resource that fuelled agricultural expansion in the past now poses a threat to national food security. A study reported that in the dry (winter) season, there was a 3% decline in mean rice yields at the national scale for every one-meter depletion in local groundwater table (Bhattarai et al., 2021).

Adaptation measures in response to climate change induced water stress range from promoting agricultural water-use efficiency (Fishman et al., 2015), electricity pricing interventions and metering (Shah, et al., 2008; Fishman et al., 2016; Gupta, 2021), encouraging a shift in cultivation

⁴ In India, administrative blocks are disaggregated units that are much smaller than districts and are meant to serve the purpose of localized governance of various matters of public policy.

acreage from ‘water-thirsty’ crops to ‘water-efficient’ coarse cereals (Kumar, 2005; Notaro et al., 2017), expansion of water resource monitoring efforts (Central Groundwater Board, 2019) and participatory management of the common-pool water resource. However, the scope of adaptation is limited because of barriers like weak institutions, behavioral constraints (e.g., low trust), unclear property rights, overwhelming influence of political institutions, and a gap between institutional and indigenous knowledge systems.

A study projected that adoption of efficient irrigation technologies could reduce unsustainable water extraction by 50%; however these gains are lost after taking into account for farmer decisions to expand irrigated area enabled by water savings delivered by the use of new technology (Fishman et al., 2015). The mainstreaming of adaptation strategies into policy-making is a challenge since adaptation burdens public finance whereas its future benefits are uncertain and the evidence of such benefits in the Indian context is meagre (Blakeslee et al., 2020) and where evidence does exist implementation of strategies are adversely impacted by political and technological barriers (Fishman et al., 2016). Farmer politics extends considerable influence on energy subsidies and minimum support prices. An experiment with voluntary adoption of electricity metering in rural Gujarat found a significant shift toward metered connections where 75% of the invited participants agreed to install water meters. The down side being that the program incurred substantial costs of imple-

mentation without producing any significant change in water usage (Fishman et al., 2016). There is also evidence of farmer-led adaptation to water stress through income diversification via non-agricultural means of industrial employment in near proximity, which offsets the loss of agricultural income but leads to higher debt and reduction in long-term incomes (Blakeslee et al., 2020).

Economic instruments such as credit and crop insurance are examples of institutional coping mechanisms that are meant to empower farmers in their adaptation response to farming risks including those caused by climate change and water stress. Insurance is plagued with low uptake in India (Arora & Agarwal, 2020) and agricultural credit was found to be ineffective in terms of reducing yield risk on farms that experience high rainfall and temperature variability in the semi-arid regions (Shukla & Arora, 2021).

Case study – Uttar Pradesh Groundwater Monitoring Impacts of Drought Intensification

Measurement of climate change impacts is fundamental for designing effective decision support systems to address adaptation and mitigation strategies. In this section we demonstrate that more frequent and higher intensity droughts can leave existing groundwater monitoring networks inadequate through *truncation* of depleting groundwater levels and resulting *false optimism* about regional groundwater situation (Hora et al., 2019).

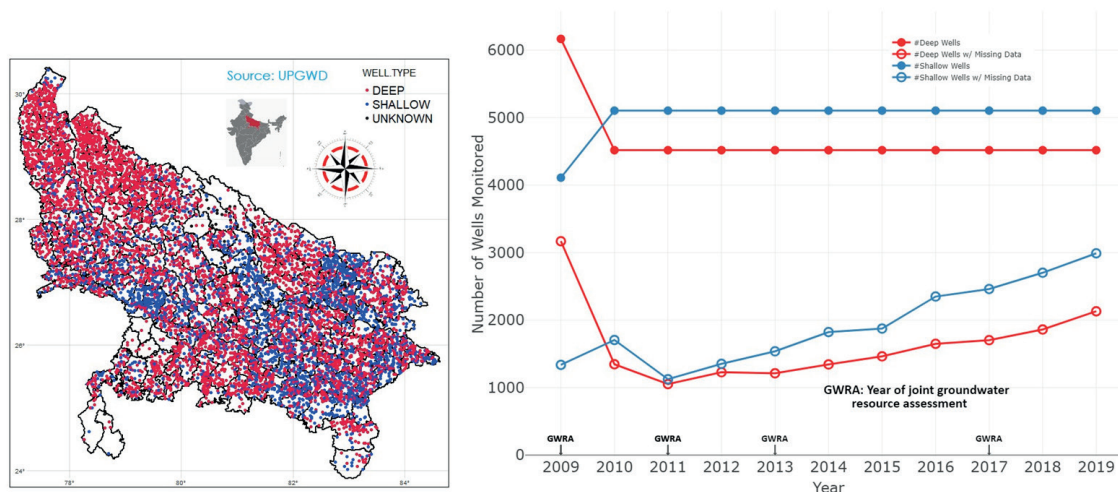


Figure 1. Groundwater monitoring network of UPGWD, 2009-2019. Source: Ali & Arora, 2021.

We consider the utility of groundwater monitoring data maintained by the UPGWD for resource management in the state amidst a changing climate. UPGWD monitored groundwater levels twice every year: pre-Monsoon (May) and post-Monsoon (September), from 13,602 agency-owned wells during 2009-2019. Figure 1 presents the spatial distribution of all shallow and deep wells monitored during the years 2009-2019 (i.e., left panel); and a time-series visualization of how the monitoring network evolved in Uttar Pradesh (i.e., right panel). A peculiar feature of these data is the significant presence of missing observations (Figure 2). Clearly, missing values in any given year could range from 10%-45%. Overall, about 30% of data are missing during 2009-2019.

Ali and Arora (2021) examined the data missingness causes via text-mining of the UPGWD data. Figure 3 shows that the agency provided records of a ‘missingness cause’ for one-third of such cases, specifically ‘dry well’, ‘closed well’, ‘choked well’, ‘damaged well’ and so on. Among these missingness causes the most pertinent for measuring climate change impacts is ‘dry well’. A monitoring well is categorized to be “dry” if the water level inside that well falls to a point below its floor (US Geological Survey 2018⁵).

Figure 4 provides a schematic of dry and producing wells. The dry wells yield a missing value in a non-random fashion, i.e., deeper groundwater levels will be systematically truncated out.

Here, note that deep wells (see Figure 1) represent an advancement in monitoring technology because these can assist in groundwater assessments in scenarios where shallow wells will not. However, a naïve deletion of missing groundwa-

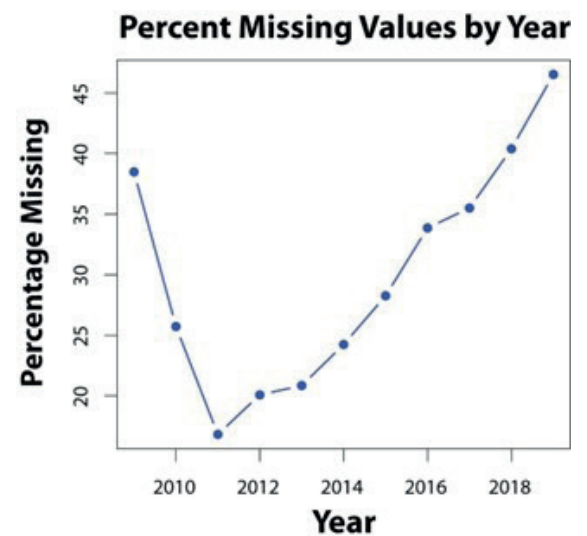


Figure 2. Percentage of missing observations by year, UP, 2009-2019. Source: Ali & Arora, 2021.

ter levels data from these ‘dry wells’ would *bias* the mean groundwater level *downwards* (hence leading to false optimism about groundwater situation in an administrative unit like district or block), and even interfere with the estimation of rainfall impacts on groundwater levels in a region (Ali & Arora, 2021).

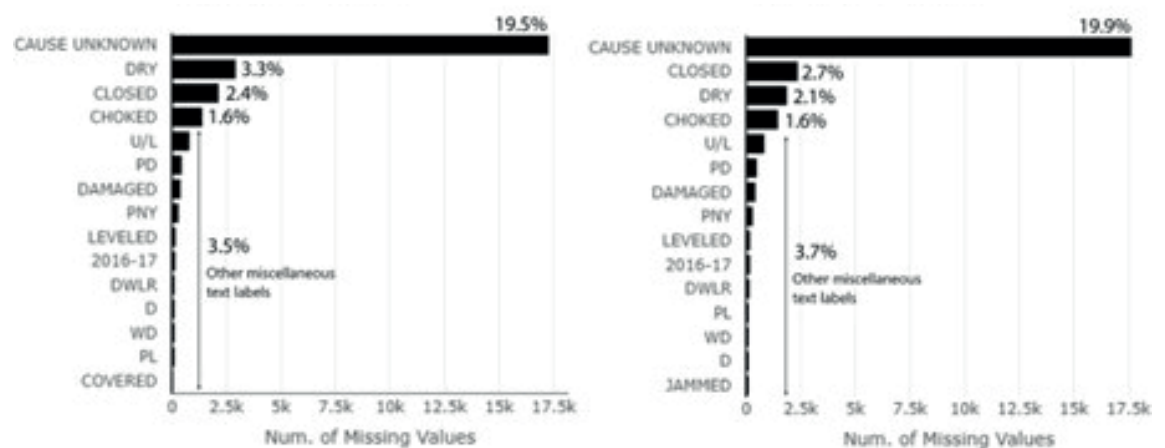


Figure 3. Textual labels indicating “missingness causes” of missing data reported for $\approx 30\%$ of UPGWD groundwater data during 2009-2019 period. Just over 3% of the labels had no immediately clear interpretation which we classify as “other miscellaneous” causes. Source: Ali & Arora, 2021.

5 Dry Well, USGS. Last accessed on July 13 2022.

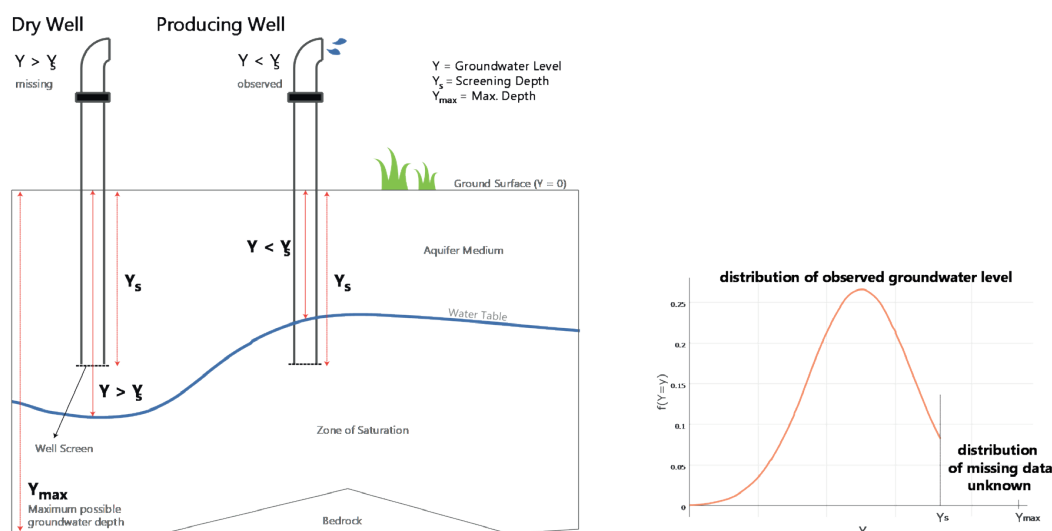


Figure 4. (Left) A schematic of two monitoring wells: one of them yields a valid data point (i.e., producing well) while the other yields a missing value (i.e., dry well). (Right) A representation of a truncated density function for groundwater levels due to the existence of dry wells. Source: Ali & Arora, 2021.

The above discussion raises an important concern for groundwater monitoring in India and elsewhere under future climate scenarios that project higher incidence of droughts. Technological advancements provide an alternative, e.g., satellites-based groundwater monitoring (Richey et al., 2015), however these efforts are in early stages, and as such can generate significant errors (Long et al., 2016).

Conclusions

This article identifies three broad focus areas for researchers and policymakers who are entrusted with the task of ensuring an effective climate change response in the presence of water-related stress and hazards in India. First, inter-ministerial communication and coordination is an imperative across federal as well as state levels in India. A centralized climate policy infrastructure was shown to be either ineffective or yield unintended negative consequences from adaptation and mitigation policy initiatives. Second, it is important that policymakers understand the social barriers in the adoption of technology or adaptation strategies as guided through policy. Perhaps an important starting point is reconciliation of gaps between institutional and indigenous knowledge systems that are pertinent to climate change risk perception. Lastly, a sustain-

able data generation ecosystem for monitoring climate change impacts, especially given that climate change directly impacts water resources - in quantity as well as quality - will require consistent upgradation and financing in the future.

Note

We would like to thank (without implicating) Shreekanth Gupta and Frank Convery for helpful comments and suggestions on this paper.

References

- Ali, S., & Arora, G. (2021). *Well-level Missingness Mechanisms in Administrative Groundwater Monitoring Data for Uttar Pradesh (UP), India, 2009-2018* (2021 Annual Meeting, August 13, Austin, Texas). Agricultural and Applied Economics Association. [https://ageconsearch.umn.edu/record/314038/files/Abstracts 21 06 30 14 11 54 69 106 210 96 147 0.pdf](https://ageconsearch.umn.edu/record/314038/files/Abstracts%2006%2030%2014%2054%2069%20106%20210%2096%20147%20.pdf) doi: 10.22004/agecon.314038
- Arnell, N., & Gosling, S. (2016). The impacts of climate change on river flood risk at the global scale. *Climatic Change*, 134(3), 387-401. <https://ideas.repec.org/a/spr/climat/v134y2016i3p387-401.html> doi: 10.1007/s10584-014-1084-5
- Arora, G., & Agarwal, S.K. (2020). *Agricultural input use and index insurance adoption: Concept and evidence* (2020 Annual Meeting, July 26-28, Kansas City, Missouri). Agricultural and Applied Economics Association. <https://ageconsearch.umn.edu/record/304508/files/18969.pdf> doi: 10.22004/agecon.304508
- Bhatt, T., & Somanathan, E. (2021). Climate policy architecture in India. *EAERE Magazine*, 14.
- Bhattarai, N., Pollack, A., Lobell, D.B., Fishman, R., Singh, B., Dar, A., & Jain, M. (2021). The impact of groundwater depletion on agricultural production in India. *Environmental Research Letters*, 16(8), 085003.
- Blakeslee, D., Fishman, R., & Srinivasan, V. (2020). Way down in the hole: Adaptation to long-term water loss in rural India. *American Economic Review*, 110(1), 200-224. <https://www.aeaweb.org/articles?id=10.1257/aer.20180976> doi: 10.1257/aer.20180976
- Central Groundwater Board. (2019). *National Compilation on Dynamic Groundwater Resources of India 2017*. Central Groundwater Board. [http://cgwb.gov.in/GW-Assessment/GWRA-2017 -National-Compilation.pdf](http://cgwb.gov.in/GW-Assessment/GWRA-2017-National-Compilation.pdf)
- Chandrakanth, M., & Romm, J. (1990). Groundwater depletion in India—institutional management regimes. *Natural Resources Journal*, 30(3), 485-501. <http://www.jstor.org/stable/24883588>
- Chindarkar, N., & Grafton, R.Q. (2019). *India's depleting groundwater: When science meets policy*. Asia and the Pacific Policy Studies No. 201907. Crawford School of Public Policy, The Australian National University. <https://ideas.repec.org/p/aen/appswp/201907.html>
- Dalin, C., Wada, Y., Kastner, T., & Puma, M.J. (2017). Groundwater depletion embedded in international food trade. *Nature*, 543(7647), 700.
- Dantwala, M. (1976). *Agricultural policy in India since independence*. 1976 Conference, July 26-August 4, 1976, Nairobi, Kenya No. 182350. International Association of Agricultural Economists. <https://EconPapers.repec.org/RePEc:ags:iaae76:182350>
- Fishman, R. (2018). Groundwater depletion limits the scope for adaptation to increased rainfall variability in India. *Climatic Change*, 147(1), 195-209. doi: 10.1007/s10584-018-2146-x
- Fishman, R., Devineni, N., & Raman, S. (2015). Can improved agricultural water use efficiency save India's groundwater? *Environmental Research Letters*, 10(8), 084022. <https://doi.org/10.1088/1748-9326/10/8/084022> doi: 10.1088/1748-9326/10/8/084022
- Fishman, R., Lall, U., Modi, V., & Parekh, N. (2016). Can electricity pricing save India's groundwater? field evidence from a novel policy mechanism in Gujarat. *Journal of the Association of Environmental and Resource Economists*, 3(4), 819-855. <https://doi.org/10.1086/688496> doi: 10.1086/688496
- Gerten, D., Lucht, W., Ostberg, S., Heinke, J., Kowarsch, M., Kreft, H., ... Schellnhuber, H. J. (2013). Asynchronous exposure to global warming: freshwater resources and terrestrial ecosystems. *Environmental Research Letters*, 8(3), 034032. <https://app.dimensions.ai/details/publication/pub.1027743105> doi: 10.1088/1748-9326/8/3/034032
- Gupta, D. (2021). *Free Power, Irrigation and Groundwater Depletion: Impact of the Farm Electricity Policy of Punjab, India*. Working papers No. 316. Centre for Development Economics, Delhi School of Economics. <https://ideas.repec.org/p/cde/cdewps/316.html>
- Holland, R.A., Scott, K.A., Florke, M., Brown, G., Ewers, R. M., Farmer, E., ... Eigenbrod, F. (2015). Global impacts of energy demand on the freshwater resources of nations. *Proceedings of the National Academy of Sciences*, 112(48), E6707-E6716. <https://www.pnas.org/doi/abs/10.1073/pnas.1507701112> doi: 10.1073/pnas.1507701112
- Hora, T., Srinivasan, V., Basu, N.B. (2019). The groundwater recovery paradox in South India. *Geophysical Research Letters*, 46(16), 9602-9611. <https://doi.org/10.1029/2019GL083525>
- Jain, M., Fishman, R., Mondal, P., Galford, G.L., Bhattarai, N., Nacem, S., ... (2021). Groundwater depletion will reduce cropping intensity in India. *Science Advances*, 7(9), eabd2849.
- Konapala, G., Mishra, A.K., Wada, Y., & Mann, M.E. (2020). Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. *Nature Communications*, 11. doi: 10.1038/s41467-020-16757-w
- Kumar, M.D. (2005). Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: Analysis from Western India. *Energy policy*, 33(1), 39-51.
- Kundzewicz, Z.W., Kanae, S., Seneviratne, S.I., Handmer, J., Nicholls, N., Peduzzi, P., ... (2014). Flood risk and climate change: global and regional perspectives. *Hydrological Sciences Journal*, 59(1), 1-28.
- Lal, M. (2001). Climatic Change — Implications for India's Water Resources. *Journal of Social and Economic Development*, 3(1), 57-97. <https://ideas.repec.org/a/sch/journl/v3y2001i1p57-87.html>
- Long, D., Chen, X., Scanlon, B., Wada, Y., Hong, Y., Singh, V., ... Yang, W. (2016). Have grace satellites overestimated groundwater depletion in the northwest India aquifer? *Scientific Reports*, 6. doi: 10.1038/srep24398
- Ministry of Environment, Forest and Climate Change, Government of India. (2015). *First biennial update report to the United Nations Framework Convention on Climate Change*.
- Mukherji, A. (2022). Sustainable Groundwater Management in India Needs a Water-Energy-Food Nexus Approach. *Applied Economic Perspectives and Policy*, 44(1), 394-410. <https://ideas.repec.org/a/wly/apecpp/v44y2022i1p394-410.html> doi: 10.1002/apecpp.13123
- National Bank for Rural Development. (2018). *Sectoral paper on water resources*. Farm Sector Policy Department, NABARD Head Office, Mumbai.
- Notaro, V., Padulosi, S., Galluzzi, G., & King, I.O. (2017). A policy analysis to promote conservation and use of small millet underutilized species in India. *International Journal of Agricultural Sustainability*, 15(4), 393-405.
- Parida, Y. (2020). Economic impact of floods in the Indian states. *Environment and Development Economics*, 25(3), 267-290.
- Parida, Y., Dash, D.P., Bhardwaj, P., & Chowdhury, J.R. (2018). Effects of drought and flood on farmer suicides in Indian states: an empirical analysis. *Economics of disasters and climate change*, 2(2), 159-180.
- Ray, R., Bhattacharya, A., Arora, G., Bajaj, K., Horton, K., Chen, S., ... Bazaz, A. (2021). Extreme rainfall deficits were not the cause of recurring colonial era famines of southern Indian semi-arid regions. *Scientific Reports*, 11. doi: 10.1038/s41598-021-96826-2
- RBI. (2022). *Reserve Bank of India Bulletin*.

Revi, A. (2008). Climate change risk: an adaptation and mitigation agenda for Indian cities. *Environment and urbanization*, 20(1), 207–229.

Richey, A.S., Thomas, B.F., Lo, M-H., Reager, J.T., Famiglietti, J.S., Voss, K., ... Rodell, M. (2015). Quantifying renewable groundwater stress with grace. *Water resources research*, 51(7), 5217–5238.

Sabnavis, M. (2008). *Macroeconomics demystified*. Tata McGraw Hill Education Pvt. Limited. <https://books.google.co.in/books?id=FWqxQAACAAJ>

Sawhani, R., Agnihotri, R., Sharma, C., Patra, P.K., Dimri, A., Ram, K., & Verma, R.L. (2019). The severe Delhi smog of 2016: A case of delayed crop residue burning, coincident firecracker emissions, and atypical meteorology. *Atmospheric Pollution Research*, 10(3), 868–879.

Sekhri, S. (2014). Wells, water, and welfare: the impact of access to groundwater on rural poverty and conflict. *American Economic Journal: Applied Economics*, 6(3), 76–102.

Shah, T., Bhatt, S., Shah, R., & Talati, J. (2008). Groundwater governance through electricity supply management: Assessing an innovative intervention in Gujarat, western India. *Agricultural Water Management*, 95(11), 1233–1242. <http://www.sciencedirect.com/science/article/pii/S0378377408001030> doi: <https://doi.org/10.1016/j.agwat.2008.04.006>

Shah, T., Rajan, A., Rai, G.P., Verma, S., & Durga, N. (2018). Solar pumps and south Asia's energy-groundwater nexus: exploring implications and reimagining its future. *Environmental Research Letters*, 13(11), 115003.

Shukla, S., & Arora, G. (2021). *The impact of agricultural credit on farm yield risk: A quantile regression approach in conjunction with propensity score matching* (2021 Annual Meeting, August 1-3, Austin, Texas). Agricultural and Applied Economics Association. [https://ageconsearch.umn.edu/record/314027/files/Abstracts 21 06 30 02 09 26 50 103 25 231 101 0.pdf](https://ageconsearch.umn.edu/record/314027/files/Abstracts%2006%2030%2002%2009%2026%2050%20103%2025%20231%201010.pdf) doi:10.22004/agecon.314027

Sikka, A., Alam, M.F., & Mandave, V. (2022). Agricultural water management practices to improve the climate resilience of irrigated agriculture in India. *Irrigation and Drainage*. doi: 10.1002/ird.2696

Tebaldi, C., Hayhoe, K., Arblaster, J.M., & Meehl, G.A. (2006). Going to the extremes. *Climatic change*, 79(3), 185–211.

Suggested citation

Arora, G., & Ali, S. (2022). Climate resilience in the presence of water-related stress and hazards in India. *EAIERE Magazine*, 17.



Section II

**EAERE
Interview**



Interview with EAERE President Phoebe Koundouri

Phoebe Koundouri (pkoundouri@aueb.gr) is Professor at the School of Economics and Director of ReSEES Research Laboratory, Athens University of Economics and Business; Professor at the Department of Technology, Management and Economics, Technical University of Denmark (DTU); Director of Sustainable Development Unit, Athena Information Technologies Research Center; President of the European Association of Environmental and Resource Economists; Chair SDSN Global Climate Hub; Co-chair SDSN Europe & Greece, Chair of the Alliance of Excellence for Research and Innovation on Aephoria (AE4RIA). Phoebe Koundouri is listed in the official Stanford University list of the top 2 % most cited world scientists, is an European Research Council grantee, member of the Nobel Prize in Economics nominating committee, elected fellow of Academia Europae and elected fellow and trustee of the World Academy of Arts and Science.

1. For the last 2 years the EAERE Annual Conference has been held online and this year we are using the hybrid format. What do you see as being the main advantages and disadvantages of the transition to annual hybrid conferences for the Association?

The COVID situation has showed that we can work quite efficiently online. Nothing can replace in person meetings, however, an online connection to our conferences can be a way to increase inclusivity towards groups that are not able to attend. The first group includes those who do not like to go to conferences, members of our community who prefer to work in more isolated ways but would be interested to follow some of the plenaries and sessions.

Then we have people that cannot afford to go to the conferences. These are mainly people outside Europe. Our Association has members from 63 different states. People from Africa, Asia, Latin America, etc. might want to connect or to watch recorded sessions. Even in Europe, some people might not have travel budgets.

Also, being a mother of three and raising my children while advancing my career, it is really very useful for young parents to have the ability to follow the conference without traveling. Ultimately it is about inclusiveness, also for disabled people. It is about following the trend that has showed that virtual connections are really a compliment to physical presence.

The first EAERE online conference was organized by the amazing Berlin team¹ in 2021, with nearly 5,000 people following different sessions, proving that we can increase our outreach quite a lot. Although there was no fee for the first online conference, we plan to provide virtual access for a low fee in the future, allowing us to capture a big proportion of the outreach that we saw during the first Berlin conference.

¹ Thanks to Georg Meran, Klaus Eisenack, Jens Weibezahn, Markus Siehlow, Achim Hagen, Christian von Hirschhausen, Elisa Krammer, Lukas Barner and Christina Arndt

2. How do you plan to use the EAERE Policy Outreach Committee to further enhance the impact of the Association in policy? What could environmental economists do to have a stronger policy influence?

The Policy Outreach Committee (POC) is a very important within our Association. I thank Jos Delbeke and Simone Borghesi for taking the lead, and all members for their contributions. Jos, Simone and I are working on a procedure to enhance the gender equality within the committee because we see that there is a serious gender imbalance there, and we are not proud of it.

Through the POC, we want to increase our impact on policy. At the moment, in Europe, we have the European Green Deal, which is basically our cross strategy. It includes many economic considerations, many policies and regulations that need to be analyzed in an economic framework in order to understand their impact, both for the transition, but also for social cohesion, income equality and so on. We also have different funds: the EU Next Generation and the Recovery and Resilience Facility are going to finance the different investments that will allow us to recover from COVID and accelerate the transition. We have the EU Taxonomy, which is the new way that the European Commission (EC) is trying to streamline capital to sustainable investments. We have the proposal for the Corporate Sustainability Reporting Directive about regulating companies to become more sustainable. We have the Fit for 55 package, 13 different legislative proposal, most of them with very deep economic roots and effects. Even after the energy crisis and the war crisis, we have Repower EU, which again is about investing away from fossil fuel and reconnecting our supply chains.

All of these policy frameworks can be informed by economic analyses, and EAERE is a powerful community of economists that do work analyzing these issues. We have excellent science on the best way to design the policies and the financial instruments to incentivize a transition towards the green digital direction. We also have excellent science on measuring the impacts of different policies and providing recommendations for additional refinements. All of this is very valuable, but it is not communicated to the national policy makers, to the European Commission policy makers. Given that many of our members, including myself, have strong links to the European Commission, to the different Directorates-General (DGs), to the European Economic and Social Committee, to the United Nations (UN), we need to really start building a strong interface and influencing these policies.

My vision is that the POC and institutional members who want to use EAERE as a platform for communicating their policy assessments create policy reports to further provide recommendations to policy makers. This will increase our potential impact on the community and accelerate this impact as well, because it is always much more efficient to work in groups rather than individual researchers at individual institutions. It is about collaboration - Sustainable Development Goal (SDG) 17 - collaboration, collaboration, collaboration to increase our impact!

3. How do you foresee EAERE's initiative on Diversity, Equity and Inclusion contributing to an inclusive environment in the economic profession?

The idea is to have an initiative where we support the inclusion and the engagement of more groups. This committee will be focusing on gender, color, geographical distribution, and other different forms of diversity. An important form of diversity is age and seniority in the profession. We want to identify and map the problems and map the examples of good practices. Then we are going to provide solution pathways for the different problems. All this will be done using a living lab approach. It would be a big achievement if any member of our

community could come into a living lab and openly discuss issues, bottlenecks, and co-design solution pathways.

My team in Greece, Alliance of Excellence for Research and Innovation on Aephoria, will provide support for coordinating and developing these labs with assistance from Environment for Development. These are two very experienced institutions running living labs on issues on diversity across the world; this is relevant as the aim of the initiative is to bring together environmental economists in Europe and across the different continents. We would also like the possibility to work in a bilateral mode, where somebody with a problem can still find support even if they are not ready to share it in the big living lab. There will be a leader on a particular issue, for example a gender issue, with whom he or she can talk, and then come back to the living lab in an anonymous way to identify solutions.

4. Which research areas in environmental and resource economics do you personally think deserve more attention? Is there a role for EAERE to become more involved?

Without highlighting a particular research area, the issue of deep uncertainty is very important. We are faced with phenomena that we do not know enough about, then asked to construct pathways for nations, for the whole world, that will guarantee sustainable development while these phenomena are taking place. We have so many crises for which we really cannot know the probabilities of the unknown events: the COVID crisis, the pandemic, the economic recession that derives from it, the parameters that affect economic recession; climate change, biodiversity collapse, the population crisis, the energy crisis, the geopolitical crisis that aggravates the energy crisis, and the food price crisis.

Environmental economists, including the members of our Association, are working on these issues. An umbrella difficulty for all of them is deep uncertainty. There is ambiguity on how these different phenomena, some of them not economic phenomena, are going to evolve over time, and how to integrate this ambiguity in our models to make projections with some robustness and accuracy to suggest policies that can help the evolution of national and global development towards sustainability.

Not one of these phenomena can be analyzed fully within the silos of one discipline, let alone a field within a discipline. One crucial mission of environmental economists is to highlight, through practicing science, the importance of interdisciplinary work. We are the economists that are more explicitly connected with other sciences and are among the best equipped economists to really understand and engage in interdisciplinary work. It is important for our Association to produce work and communicate work that is based on a firm genuine effort to become more interdisciplinary.

The SDGs are a good way for us to start thinking about the importance of interdisciplinarity. They are basically a holistic investment program where each country needs to figure out how to integrate the different sectors and systems within the country in order to evolve along a holistic, integrated, sustainable pathway.

5. What do you see as being the biggest challenges during your EAERE Presidency? How do you plan to address and overcome them?

The non-scientific challenge is to make sure that our conferences are led academically and scientifically by our members without overloading the scientists with administrative work. What we want to do is provide inhouse support for the administrative aspects, for the conference organization aspects. The idea is to have a permanent collaboration with professional

conference organizers that we will supervise and support with the knowledge of the Secretariat and Monica Eberle's huge experience. At the same time, we will have inbuilt capacity that will be growing year after year and accumulated by the same professional organizer. This professional organizer will be supervised by the Secretariat, and the institutional organization of the university who will be chosen to organize the conference will only need to take the scientific part on board.

Other challenges are already being translated and transposed into our initiatives. Our policy outreach is important. Our outreach to the technology development wealth is important. There is a lot of action in the innovation ecosystem that produces tools, decision, support systems, many other innovative technologies, either purely technical or social innovations, and all this can be greatly informed by economic thinking. However, our community is not close to this innovation system, and I think it is important to bring them together. This is why we are organizing an additional seminar series, which is about bringing together our science with policy makers, with businesses and financial institutions, but also with technology developers. It will be the start of building this interface.

Another issue is the collaboration with other continental Associations. At the moment, we have the World Congress of Environmental and Resource Economists, composed of the European Association, the U.S. Association, and the Asian Association. We have already started communicating with the Latin American Association and the African Association, and we plan to begin discussions with the Australian and New Zealand Associations. The idea is to bring these Associations together, not just for a meeting or a web conference every four years, but to identify where we can synergize in order to advance our collaboration for better scientific output, for better impact on policy, and for better impact on other communities that we want to reach like businesses, financial institutions, technology development, and the innovation ecosystem, which is crucial because innovation drives transition.

It is an innovation driven transition to sustainability because without technological innovation, we just do not have the time to make the transition. It is important to understand innovation well, then contribute to the incubation of the best possible efficient technologies that integrate economic principles. We want a global effort to synergize for better science, but also for more powerful impact. If you go to the European Commission and tell them, this is what EAERE does, then it is okay. But if you go to the UN, then Europe is just a small part of the problem. One global initiative could be to extend the SDGs target beyond 2030 instead of having to negotiate another agenda. We already know now that the SDGs are working and have been integrated in most national policies. They are considered as the major driver for the transition, even for the European Commission. Campaigning for the SDGs to be extended to 2050 could be a global initiative for the World Council.

6. Do you have any plans or strategies to increase the financial sustainability of the Association? Are there any funding opportunities that you have already identified and would like to pursue?

Income is another challenge because all of these initiatives that we are talking about need to be financed. Income raising activities are important. The webinar series that has been proposed by Sergio Vergalli is an income raising activity. There are also many opportunities under Horizon Europe that we can apply for, working with different institutions in order to attract funding for our initiatives, given the in-house expertise of our institutional members. We should also welcome sponsorships. We must do our due diligence to very carefully decide who we work with. But in general, if companies and public institutions and financial institutions see something that makes sense, and it can have an impact, they have money to sponsor.

Now with the Environmental, social, and governance (ESG) expansion and the need for all big companies and institutions to have a sustainability report, then there will be budgets in these institutions and companies for the work that we do. We should be clever enough to capitalize on this and increase our return on investment (ROI) impact.

7. **What legacy would you like to leave with the Association at the end of your EAERE Presidency? Is there anything else that you would like the EAERE community to know about yourself or your plans during your term as EAERE President?**

The legacy is to make explicit the need for interdisciplinary science. Then make explicit the need to have outreach to policy making. Unless we try, the policy decision makers cannot try. They cannot understand what we are doing. We must explain what we are doing and how it can affect their policy making. The effort is on our side. It is important to have this outreach to the technology development world and to the business and financial institutions, and it is important to have community cohesion. This includes the cohesion between the different continental Associations, because if we manage to have really a robust and good working global council and even elect a president there as well to represent people, then we really can have the impact we want on these other different interfaces in a much more powerful way.



EAERE Membership

CALL FOR 2022 EAERE Individual Membership

Join EAERE in calendar year 2022. Individual membership is open to persons who by their profession, training and/or function are involved in environment and resource economics as a science. EAERE offers a rich portfolio of benefits for individual members, making the return on a membership more valuable than ever.

Individual benefits

- A free personal subscription for the electronic version of the Association's official journals: Environmental and Resource Economics (ERE), published by Springer and Review of Environmental Economics and Policy (REEP), published by University of Chicago Press; Members are offered a discount subscription fee to the paper version of these journals.
- A discounted personal subscription rate for the journals: Annual Reviews; Environment and Development Economics; International Review of Environmental and Resource Economics; Journal of Environmental Economics and Management; Resource and Energy Economics; Resources Policy; Strategic Behavior and the Environment Water Resource and Economics
- A 40.00% discount on books published by Springer;
- Eligibility to participate to the EAERE Annual conference;
- Eligibility to apply for participation in the EAERE Winter and Summer Schools;
- The right to post announcements in the Association's Highlights issued monthly;
- The right to post announcements in the contributed pages of the EAERE website;
- Access to the EAERE membership full directory;
- The right to vote in the EAERE General Assembly and in the EAERE Elections;
- The right to send nominations for the EAERE Awards;
- A discount on personal membership fee for our sister Association AERE (Secondary Membership).

Collective benefits

Supporting EAERE in: Lobbying for environmental and resource economics research funding from the European Commission and elsewhere; Advancing the science of economics; Advancing the application of environmental economics in the development and application of policy; Advancing the application of environmental economics in business and commerce; Advancing communication between scholars, teachers, students and practitioners

Membership options and prices

EAERE provides two mutually exclusive options.

EAERE Annual membership (Until Dec 2022): FULL €70.00 or REDUCED €15.00

EAERE Triennial membership (Until Dec 2024): FULL €189.00 or REDUCED €40.50

New members applying for an annual membership can purchase a one-year subscription at discounted rate to the print version of one or both of the EAERE's official journals ERE (€97,76) and REEP (€18.00).

Subscription prices will be added to the membership fee.

If you are a member of AERE in calendar year 2022 you can apply for a EAERE Secondary Membership with a discounted fee.

Payments can be done by credit card, bank transfer or Western Union Money Transfer. Please note that an administrative fee of €20.00 will be charged to payments made by bank transfer and Western Union Money Transfer.

CALL FOR 2022 EAERE Institutional Membership

Join EAERE in calendar year 2022. Institutional membership is open to associations, and public and private institutions which operate in fields connected with the aims of the Association or which pursue the aims and materially support the activities of the Association or individual initiatives promoted by the Association, by providing human, organisational or financial resources.

Incomes from institutional membership fees will be used exclusively and completely to further the aims of the Association. EAERE offers a rich portfolio of benefits for institutional members, making the return on a membership more valuable than ever.

Benefits

- One non-transferable registration for institutional staff to the EAERE Annual Conference
- One 2022 individual membership in EAERE for a designated staff member (inclusive of an electronic subscription to ERE and ERE, a paper subscription to ERE)
- Two complimentary 2022 individual memberships in EAERE to Ph.D. students
- Recognition at the Annual Conference
- The right to post free announcements in the contributed pages of the EAERE website at no charge
- The right to post announcements and articles in the Association's Highlights issued monthly
- Listing on the EAERE website
- Listing in every issue of Environmental and Resource Economists
- The right to send nominations for the EAERE Awards
- 10% discount for the payment of "group membership" for a minimum of 10 individual members

Collective benefits

Supporting EAERE in: Lobbying for environmental and resource economics research funding from the European Commission and elsewhere; Advancing the science of economics; Advancing the application of environmental economics in the development and application of policy; Advancing the application of environmental economics in business and commerce; Advancing communication between scholars, teachers, students and practitioners.

Membership options and prices

EAERE provides two mutually exclusive options.

1. Full institutional membership: € 1,200.00 or € 3,600.00 for a triennial (2022-2024) membership
2. University institutional membership: € 300.00 or € 900.00 for a triennial (2022-2024) membership.

Only Universities, University departments, and University centres can apply for this membership category.

Payments can be done by bank transfer.

Further information

Further information is available at: www.eaere.org/institutional-membership

EAERE Full institutional members – 2022*

- Basque Centre for Climate Change – BC3, Spain
- The Beijer Institute of Ecological Economics, Sweden
- Fondazione Eni Enrico Mattei – FEEM, Italy
- Potsdam Institute for Climate Impact Research – PIK, Germany
- Research Institute of Capital Formation, Development Bank of Japan Inc. – RICF DBJ, Japan
- Resources for the Future – RFF, USA
- Toulouse School of Economics, National Research Institute for Agriculture, Food and Environment – INRAE – TSE-R, France
- University of Manchester – UoM, UK

EAERE University institutional members – 2022*

- Aalto University, Finland
- Ca' Foscari University of Venice, Department of Economics – UNIVE DSE, Italy
- Centre for Environmental & Resource Economics – CERE, Sweden
- Centre for Research in Geography, Resources, Environment, Energy and Networks – GREEN, Bocconi University, Italy
- Charles University – CUNI, Czech Republic
- Climate Economics Chair – CEC, France
- The Cyprus Institute, Republic of Cyprus
- Environment for Development Initiative – EfD, Sweden
- Euro-Mediterranean Center on Climate Change Foundation – CMCC, Italy
- John von Neumann University – NJE, Hungary
- The Grantham Research Institute on Climate Change and the Environment – GRI, UK
- Mercator Research Institute on Global Commons and Climate Change – MCC, Germany
- Norwegian University of Life Sciences – NMBU, School of Economics and Business, Norway
- Oslo Metropolitan University Business School – OsloMet, Norway
- Paris School of Economics – PSE, France
- Peking University, College of Environmental Sciences and Engineering – CESE-PKU, China
- Research laboratory on Socio-Economic and Environmental Sustainability – ReSEES, Athens University of Economics and Business, Greece
- School of Geography and the Environment, University of Oxford – SSEE, UK
- Technical University of Denmark, Department of Technology, Management and Economics – DTU, Denmark
- Technische Universität Berlin – TU Berlin, Germany
- Tilburg Sustainability Center (TSC), Tilburg University, Netherlands
- University of Bologna, Department of Economics, Italy
- University of Brescia, Italy
- University of Exeter, UoE, UK
- University of Ferrara, Sustainability Environmental Economics and Dynamics Studies – SEEDS, Italy
- University of Graz, Wegener Center for Climate and Global Change, Austria
- University of Helsinki, Department of Economics and Management, Finland
- University of Lodz, Faculty of Economics and Sociology, Poland
- University of Santiago de Compostela, Instituto de Estudios y Desarrollo de Galicia – IDEGA, Spain
- University of Southern Denmark, Department of Sociology, Environmental and Business Economics, Denmark
- Venice International University – VIU, Italy
- Wageningen University, Environmental Economics and Natural Resources, Netherlands

EAERE is grateful to its 2022 Institutional Members for their support!

** As of November 2022*



The European Association of Environmental and Resource Economists (EAERE) is an international scientific association whose aims are:

- _to contribute to the development and application of environmental, climate and resource economics as a science in Europe;
- _to encourage and improve collaboration and communication between scholars, researchers, policymakers, students in environmental, climate and resource economics in different European countries;
- _to develop and encourage the cooperation across universities and research institutions in Europe.

Founded in 1990, EAERE has approximately 1200 members in over 60 countries from Europe and beyond, from academic and research institutions, international organisations, the public sector, and the business world. Membership is open to individuals who by their profession, training and/or function are involved in environmental, climate and resource economics as a science, and to institutions operating in fields connected with the aims of the Association.

www.eaere.org