India's Green Transition*

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Abstract

This chapter reviews and assesses India's possible pathway to reducing the country's greenhouse gas emissions, often framed as a target year achieving net-zero carbon emissions. It examines the speed and the components of such a "green transition," including promoting renewables for electric power generation, electrification of transportation and industry, alternative fuels such as green hydrogen, conservation, and restructuring some economic activities. The chapter discusses policies that will be needed, and institutional and political economy challenges that will arise in pursuing a green transition along with long-run economic development. Finally, it considers the financial costs of achieving the goal of decarbonization within the next few decades, and possible sources of finance.

Keywords: Climate change, carbon emissions, net zero, India, energy policy

JEL Codes: O1, Q4, Q50, Q54, Q58

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Introduction

The last few years have witnessed a major change in the realization and acknowledgement of the catastrophic consequences of not taking actions to address climate change (IPCC 2021, 2022a, 2022b): most specifically, rising temperatures caused by greenhouse gas emissions. At the 2021 COP26 – the 26th Conference of Parties that signed the United Nations Framework Convention on Climate Change in 1994 – many countries agreed to goals of achieving Net Zero by 2050. 'Net Zero' refers to offsetting new greenhouse gas emissions with other actions, to make net emissions zero. This concept has become the focal point for action to deal with global warming and climate change induced by human activities. At the time, India's government argued that this was not a suitable goal for that country, but agreed to a Net Zero target date of 2070. This position was based on concerns that a too-rapid "green transition" could conflict with objectives of economic growth and associated improvements in the material well-being of the country's residents. Many developing countries have shared these concerns. A related position has been that the current situation is the result of past choices by now-wealthy economies, and they should take on more of the costs of corrective actions. With new evidence of rising temperatures and the inadequacy of the COP26 commitments, COP28, in 2023, saw a call for more ambitious reduction targets.[1]

This paper argues that there is a plausible case that accelerating the green transition is an optimal strategy for India. This argument is based on technological possibilities and intertemporal welfare considerations. There are still concerns about costs, and institutional constraints, so those issues are also addressed. The arguments in favor of an accelerated green transition have been made in a global context (Stern, 2021; IEA, 2021a; Stern, 2022), as well as for India (Gupta, et al., 2022). At the heart of this position is the realization that developing countries will be making enormous greenfield investments as they grow, which can also be green. As stated by Bhattacharya, et al. (2022, p. 13), "Mounting evidence shows that climate action is not a cost in terms of growth, development or jobs but rather an attractive path to more inclusive, resilient and sustainable growth."[2] This chapter draws on these analyses, as well as more recent developments in India's national policies (e.g., NEP, 2023).

An important related point that is sometimes hidden by discussions of timing which focus on the net-zero target date is that cumulative emissions matter, not just the target date. If we think of a net emissions curve declining to zero over time, the area under the curve is highly relevant

[1] The trajectory of these global discussions is well-summarized in Ahluwalia and Patel (2024), along with post-COP28 revisions of targets by various countries.
[2] In this context, it is important to note that completely removing "energy poverty" globally, which can have a major impact on poverty and welfare more generally, would not lead to more than a marginal contribution to global warming, even if the path for removal is not the greenest possible: see Chakravarty and Tavoni (2013).

(Tongia, 2021). In the case of India, Gupta et al. (2022) estimate a 40 percent reduction in cumulative emissions from following an accelerated strategy. But a reduction can also be realized in a case where the target net-zero date is brought forward, without considering the myriad possibilities for the trajectory. If emissions decline linearly, then the cumulative reduction in emissions as of 2024, if the target date is advanced from 2070 to 2050 is about 43 percent.[3]

While the problem of greenhouse gas emissions is global, the impacts will vary considerably across different countries and regions. Some of these considerations imply a rationale for national action irrespective of global implications. But India is also globally an important single case, because of its population size and its relative poverty compared to the three largest contributors to global emissions, the United States, European Union, and China. Its per capita emissions are comparatively low, and it also has significant growth potential, so the nature of its growth will matter greatly for the world as a whole. While considerable attention has been focused on India as a strategic counterweight or production site alternative to China, its most important global significance is arguably as a possible model for a developing country green transition.

The remainder of this chapter is organized as follows. The next section summarizes the components of what a green transition will look like for India. Many of these components will be similar for other developing countries, but the specifics of the Indian case will be the focus here. Section 3 turns to the policy actions that a green transition will need, as well as the associated institutional requirements and challenges. Many of these challenges are generic, in the sense that development and growth in most countries are typically hindered by weak or politically constrained institutions, especially governance institutions (e.g., Acemoglu and Robinson, 2012; Besley and Persson, 2009). However, India's size and heterogeneity, in particular, introduce some distinctive features. Section 4 examines issues of financing the investments needed for the green transition, including questions of sources, particularly domestic vs. international and public vs. private. Questions of finance are also tied back in to institutional capacity for taxation and behavioral incentives, in evaluating policy options. Section 5 offers a summary conclusion for the arguments of this chapter.

[3] This is ratio is trivially derived from the formula for the area of a right triangle, where only the base changes, which gives, after canceling terms, (2070-2050)/(2070-2024). Ahluwalia and Patel (2024) offer a useful conceptual benchmark for the issue of trajectory and timing of emissions reductions (p. 352): "A logical way of avoiding this problem would have been to try to agree on a mechanism to distribute the carbon budget, as estimated by the IPCC consistent with global warming targets, in a way that gives each country its fair share. Each country could then be free to determine an emissions trajectory which keeps its total emissions within its allocated budget without overshooting. The date by which a country reaches net zero would not matter, as long as it stayed within its budget." The problem, of course, is that the information requirements for this approach, as well as the associated political obstacles, are much greater

The Shape of a Green Transition

India's per capita energy consumption is less than 40 percent of the world's average (IEA, 2020, 2021; Energy Institute, 2024, p. 13), but its energy system relies heavily on coal for power generation, as well as for industrial production. Oil is most important for transport, and biomass for residential heating and cooking. Excluding biomass, in 2019, India's total primary energy supply (TPES) was 734 million tons of oil equivalent (Mtoe), with just over half of this being covered by domestic production.[4] Total final consumption (TFC) was 410 Mtoe, with industry accounting for the largest share, 42 percent, followed by the residential sector and transport.

India's pattern of electricity generation and energy use imply that policies to achieve net zero have to have two main foci. The first is greatly increasing the role of cleaner sources of electricity generation, and the second is electrification of industrial production.[5] There are differences across the studies, in terms of modeling and assumptions, but they all emphasize cleaner electricity and electrification.

Currently, electricity accounts for just over a quarter of India's TFC (Ahluwalia and Patel, 2021). Electricity generation capacity in July 2024 was 448 GW, of which 10.47 percent was hydropower, while 1.82 percent was nuclear power.[6] Arguably, neither of these sources affords significant scope for growth in capacity. On the other hand, solar and wind power capacity was 29.95 percent of the total, or about 134 GW. The estimated current potential capacity for these two sources is a little over 1000 GW (NEP, 2023, 6-22 and 6-23), which would be an eightfold increase in the short run. In the longer run, based on a net-zero target year of 2070, substitution of green energy for fossil fuels, economic growth and electrification, together imply a total capacity of solar and wind power (depending on other assumptions) of 8,000 to 9,000 GW, with more than three-fourths of that being solar power (Chaturvedi and Malyan, 2022, Figure 1). In this scenario, solar power would account for over 60 percent of India's electricity generation, even before 2070. These estimates imply growth rates of about 10 percent for solar power capacity, and 6 percent for overall generation capacity over the whole period, which are roughly in line with recent growth rates of about 8 percent, but sustained for a much longer period.[7]

The current projections in the National Electricity Plan (NEP, 2023) imply a growth rate of slightly over 20 percent for solar capacity in the next decade, and almost 12 percent for wind

[4] This data was from https://www.niti.gov.in/edm/#balance, accessed June 17, 2022, but that page has since been removed. Updated statistics are probably similar, however: see also Ahluwalia and Patel (2021), as well as footnote 6 below.

[5] Several studies have modeled pathways for these changes in the context of achieving Net Zero by 2070 (BP, 2020; Chaturvedi, 2021; IEA, 2021; TERI & Shell, 2021; Chaturvedi and Malyan, 2022). The TERI/Shell report has a target date of 2050, while the IEA target date is 2065.

[6] See https://iced.niti.gov.in/energy/electricity/generation (accessed September 18, 2024), which is at the government's NITI Aayog site. Singh (2022) reported a higher total capacity number for 2020, which was taken from an older version of the energy dashboard (now called the Climate & Energy Dashboard). That page has since been removed, but some of the older site is archived at https://web.archive.org/web/20220515195631/https://niti.gov.in/edm/#home.

[7] Since there are several alternative scenarios, we use approximate growth rates to provide ballpark figures, rather than offering false precision. In fact, capacity figures are often adjusted after the fact.

power in the same period. These are ambitious targets, but are consistent with an accelerated green transition, in which the net-zero goal is reached by 2050. For example, using the same growth rates out to 2040 implies a solar + wind capacity of about 1800 GW by then, and slightly lower average growth rates (15 and 10 percent, respectively) for the period to 2050 imply a capacity of almost 3400 GW by the later year. These projections are consistent with estimates based on a global 2050 net-zero target, with India's numbers calculated from those based on its estimated GDP share (IEA, 2021; Bhattacharya, et al., 2022).[8] They are not that much higher than the 2050 projections along the way to a 2070 net-zero target (Chaturvedi and Malyan, 2022, Figure 1).[9] However, the magnitude of the challenge is highlighted by the fact that recent growth in solar and wind capacity has been lower than the long run targets, and *a fortiori*, even lower than the short term growth projections.[10]

Electricity generation through clean fuel sources is the single most important component of a green transition. The calculations above imply that a centerpiece of this effort involves a massive expansion of, and shift to, solar power. Using renewable sources such as solar and wind, which are subject to variability in supply, has implications for investment in storage capacity, as well as the design and quality of the electric power grid. An accelerated green transition has implications for existing coal-based generation capacity, with associated adjustment costs and political economy challenges. There are also existing efficiency and political economy issues in India's electric power sector, especially in distribution. All of these issues will be discussed in Section 3.

Shifting industrial production and transportation away from fossil fuels to electricity requires that the generation of that electricity must be from clean sources, otherwise the emission reductions will be trivial. While some of the required investment is reflected in projections of growth in electricity generation capacity, substantial new investments will be required at the point of use. Factories that use fossil fuels directly will have to be redesigned or modified or replaced.[11] In addition to production facilities needing to be modified, electric road and rail transportation will require completely new infrastructures, much of it upfront, since they are network goods.[12] Battery exchanges and charging stations are two examples for road vehicles. At least 80 percent

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[8] These estimates are based on the author's calculations, using the projections from IEA (2021) and NEP (2023). Gupta et al. (2022, p. 11) project that solar and wind capacity in India would have to be 2,700 GW by 2050, in their "accelerated" scenario.

[9] Gupta, et al. (2022) provide estimates of the composition of India's primary energy mix (PEM), which includes energy use that is not derived from electricity generation. They consider two scenarios, which are discussed further later in this paper. A "line-of-sight" (LoS) scenario projects current trends, and does not even achieve net-zero by 2070. An "accelerated" scenario achieves net-zero by 2050. In the LoS case, solar and wind account for 26 percent of the PEM in 2050, increasing to 56 percent in 2070. In the accelerated case, the corresponding figures are 53 percent and 59 percent. See Gupta, et al., p. 22, Exhibit Q.

[10] Growth rates can be found at https://iced.niti.gov.in/energy/electricity/generation, or calculated from the capacity figures reported there.

[11] Not all industrial processes are amenable to shifting from fossil fuels to electricity, but India has an unusually high reliance on coal in such cases. This would need to be addressed through alternative fuel technologies, which are discussed later in the section.

[12] Public transportation and commercial vehicles are obvious initial segments for switching, since there can be coordination.

of road vehicles will need to be electric, rather than using fossil fuels.[13] There are significant implications for production of batteries and access to raw materials, particularly scarce minerals, which have to be incorporated into planning this aspect of electrification. Gupta, et al. (2022, Exhibit U) estimate that transportation (called "mobility" in their report) will be the second largest contributor to decarbonizing India's economy, following renewables for electric power capacity, but will require a larger investment than even the power sector.[14]

New commercial and residential buildings, which will be a part of India's growth and development, are another important aspect of infrastructure. Together, these categories of buildings account for a greater share of TFC than the transportation sector. Building design is already receiving significant attention, as is more efficient LED lighting.[15] Digital infrastructure that enables more efficient climate control in buildings (almost exclusively cooling in the Indian context) will also be an important contributor to making new buildings energy efficient, beyond their structural features. Creating and enforcing (or rewarding) green building certifications is already taking place (Gupta, et al., 2022, p. 93).[16]

While greenhouse gas emissions are typically associated with industrialization, agriculture is a major contributor to the problem, most obviously because of emissions from farm animals, but also resulting from modern agricultural practices. Agriculture accounted for about 20 percent of India's greenhouse gas emissions in 2019 (Gupta et al., 2022, Exhibit D).[17] Farm animals were responsible for 55 percent of that, but water-intensive methods of rice cultivation and overuse of nitrogen fertilizers were also major contributors, and possibly the two sources with the greatest potential for emission reduction. It is difficult to estimate what structural change in agriculture as India grows will do to these figures. India's pattern of economic development has done relatively little to pull people out of agriculture into a more modern industrial economy. This has contributed to inefficient scale in agricultural holdings, and to policies such as heavy subsidization of water and chemical fertilizer. India is the most water-constrained large economy (Singh, 2014), and access to water is often facilitated by providing subsidized or even free electricity for pumping groundwater, with disastrous environmental consequences (Liu, et al.,

[13] In practice, one would expect the proportion to reach 100 percent, since the legacy infrastructure for fossil-fuel powered vehicles will no longer be economical.

[14] It is not clear what the components of the investment are, but they likely include production facilities for electric vehicles, not just infrastructure. The cost of new infrastructure for electric vehicles is estimated to be much lower, according to numbers reported in Bhattacharya, et al. (2022), p. 30. In the Gupta, et al. (2022) modeling, the third most important contributor to decarbonization is agriculture, followed by industry, with the investments required in each sector somewhat smaller than for transportation and power, though far from small.

[15] Intermittent and unreliable electric power supplies result in wasteful investments in diesel generators, so a big push in electricity generation and distribution will have an impact.

[16] Gupta et al. (2022) do not provide separate investment estimates for green buildings: but some of the costs seem to be reflected in their industrial sector figures. The numbers reported in Bhattacharya et al. (2022) are substantially greater for green buildings than for electric vehicle infrastructure, but their figures are global, and likely include retrofitting of an extensive existing stock of buildings. In India, much of the relevant building will occur in the future. More generally, energy efficiency is a goal that has relevance in every aspect of the economy, including transportation, electric power, agriculture and industry.

[17] World Economic Forum (2021, Figure 1) reports sectoral emissions totals which imply a similar, albeit marginally higher, percentage. Their source is the World Resources Institute CAIT Climate Data Explorer.

2021). It is difficult to predict what will happen to agriculture with future structural change in the economy.

Having considered electrification with renewables as the most important component of a green transition, as well as some examples of changes in practices, especially building design and construction, and agricultural production, we return to the possibility of alternative energy sources. Green hydrogen (from electrolysis of water) represents a possible alternative or supplement to green electrification (Hydrogen Task Force 2020; Friedmann et al. 2020; Hall et al. 2020). Detailed modeling (Chaturvedi and Malyan, 2022) indicates that if hydrogen technology can be deployed at scale, it can substitute substantially for electrification. Some projections suggest that, even if this technology is successfully developed, its likely impact would not be significant for the next three decades. However, India has announced a National Hydrogen Mission, (PIB, 2021), with an initial investment commitment of $2.3 billion made in 2023. Gupta et al. (2022) estimate that green hydrogen can be cost competitive by 2030, if initial uptake in industrial cases such as steel production is supported with subsidies, and it can contribute almost 8 percent of the incremental reduction in emissions for the accelerated vs the LoS scenario (Exhibit F), and BloombergNEF (2023, Figure 9) provides a similar estimate. From a different perspective, global 2050 net-zero scenarios estimate the contribution of green hydrogen fuels to final energy demand to be 13 percent by that end year (IEA, 2021a; Bhattacharya, et al., 2022). It should be emphasized that these estimates are all somewhat speculative and contingent on the pace of innovation and adoption, which also depend on the efficacy of government plans for action (BloombergNEF, 2023, p. 13; Ahluwalia and Patel, 2024).

In contrast to green hydrogen, biofuels are an established renewable source of energy. India has also taken steps to promote biofuels and biomass. A National Policy on Biofuels dates back to 2018, including greater blending of ethanol in transportation fuels (Gupta, et al., 2022, p. 43). However, such measures are relatively minor in the context of more fundamental changes that are required, such as electrification. Biofuels may have a more useful role to play in other contexts, such as aviation and some industrial production, but the environmental impacts of increased agricultural activity focused on biofuels rather than food production, and the emissions associated with those also have to be considered.[18]

An alternative to emissions reduction by using cleaner fuels is preventing greenhouse gases from entering the atmosphere. The functioning of natural ecosystems, particularly forests, in serving this role has long been recognized, and the scientific knowledge needed to promote these processes is increasing. Technological solutions are also becoming available at economically viable levels. Carbon Capture, Utilization and Storage (CCUS) is one such set of possible solutions, sometimes without the utilization component, so just referred to as CCS in that case.

[18] If biofuels are derived from agricultural waste, that would allay this concern, of course. In the Indian case, any method that deals with agricultural residues that does not involve the extreme environmental harms of burning the residues would represent significant progress on multiple counts, not just emissions reduction. Projections such as those of the IEA (2021a, Figure 2.5) estimated biofuels maintaining a small but constant share of total energy production in the transition to a net zero global economy, with newer types of biofuel replacing traditional uses of biomass over time. The IEA report (Chapter 2) also discusses the question of land use impacts of bioenergy.

CCUS is still to be deployed at scale, but experience to date indicates potential in retrofitted coal-fired power plants, as well as industrial plants (Hu and Zhai, 2017; Townsend and Gillespie, 2020). Current costs imply that it needs subsidies or tax credits to be deployed (e.g., Nagabhushan and Thompson, 2019 for the US). One perspective rejects CCUS/CCS as a diversion from pursuing renewable energy generation, energy efficiency and energy conservation (CAN International, 2021), but using it, even with subsidies, can reduce other costs and disruption of trying to restructure the energy system too quickly.[19] Some of these issues are discussed in the next section.

One criticism of CCUS/CCS is that many of the technological approaches that come under those headings are risky, unproven and unscalable. However, this is somewhat true of many of the proposed solutions to the challenge of emissions reduction, not just CCUS. In the case of India, Malyan and Chaturvedi (2021) suggest it could make a 2050 net-zero target achievable, even if phasing out coal rapidly is politically too costly. In their projections, with CCUS, fossil fuels could still provide 30 percent of India's total energy in 2030, versus 5 percent without it. CCUS will also require an ecosystem of new infrastructure, as well as testing and refining the new technologies. But it may be useful in India's difficult transition away from coal. Gupta et al. (2022, Figure F) also emphasize the industrial applications of CCUS, and its essential contribution to an accelerated decarbonization scenario, representing about 15 percent of the incremental reduction in emissions beyond the LoS baseline. A similar analysis is provided in BloombergNEF (2023), with a lower level (10 percent) for contributions to emissions reduction. The IEA report (2021a) also emphasizes the importance of CCUS as part of an overall global strategy for a 2050 net-zero target. Further, it recognizes that this set of technologies can be important for making existing or expanded biofuel production greener. The IEA projections suggest that the timeline for CCUS is not dissimilar to that for green hydrogen (IEA, 2021a, Figure 2.4), but the overall contribution of CCUS to emissions reduction will be greater than for hydrogen, at the global level. This is also the case for the Gupta, et al. (2022, Exhibit F) incremental projections, where the contribution of CCUS is almost double that of green hydrogen, though this relative magnitude is different from BloombergNEF (2023).

Institutions and Policies[20]

A major problem for electricity generation in India is the quality of the grid. While it is a national grid in theory, the actual transmission infrastructure is far from robust. New

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[19] The initial subsidies required may be less than the global social cost of carbon, and while the incidence of a subsidy is very different from a carbon tax, subsidies for adoption, especially when they have the potential to bring down costs more quickly through rapid scaling up and refinement of technologies are common in consumer contexts such as rooftop solar panels and electric vehicles. CAN and many others positively emphasize the separate case of carbon capture through afforestation as an important component of policy for a green transition. Tongia (2021) argues that direct air capture is unproven and expensive but acknowledges that carbon capture may be useful at the project or plant level.

[20] Ahluwalia and Patel (2024) provide an excellent discussion of many institutional details that we omit from the current paper, including the various regulatory and operational bodies in the power, transportation and construction sectors.

transmission infrastructure, which will require significant investment, will also have to be supplemented by substantial new storage capacity, to deal with the problem of intermittency of solar and wind power. This is well recognized in all analyses of the future of renewables for electricity generation, and the differences are mainly in terms of the details (IEA, 2021a; Bhattacharya, et al., 2022; Gupta et al., 2022; NEP, 2023; Tongia, 2023, BloombergNEF, 2023). One key issue is whether optimistic projections about storage costs, such as for grid-scale batteries (Tongia, 2023) will be borne out, since these are part of the comparison with fossil-fuel-based generation. The latest data point in that direction, for India as well as more generally (Chakravarty and Somanathan, 2021; IRENA, 2023). In the new NEP (2023), plans for future construction of coal-based power plants, while not abandoned, were pushed beyond the 10-year horizon of the plan, and replaced by higher targets for battery energy storage systems (BESS), with attention to the research and development that would be needed. While other storage technologies are also considered in the NEP, expanding BESS capacity will be particularly important, and US numbers suggest that the generation vs. capacity disparity between coal and renewables can be reduced substantially, making renewables capacity more productive.

Importantly, even without a green transition, India will need to upgrade its entire electricity grid as it pursues economic growth.[21] This is also important for reducing transmission and distribution losses, which are very high in India, on the order of 20 percent, though this current figure is an improvement on previous decades. Some of these problems are associated with the inefficiency of power distribution companies, which are almost always run by state governments, and act as employment providers in a manner that is not conducive to efficiency or innovation.[22] These institutional problems have been relatively intractable, but not insurmountable – in some cases, privatization has been politically feasible and has helped – but a green transition for electrification will require a concerted national effort.[23] In particular, the urgency of the challenge of expanding renewables capacity for power generation may allow for some new political bargains to be struck. Again, it is important to emphasize that solar power, even with costs for storage included, is already very close to being cost competitive with coal for electricity generation, so a major push on this front should not require subsidies to work, merely strategic intent and focus.

[21] There are some efforts, particularly by the Rockefeller Foundation, to introduce decentralized, small-scale solar power grids for rural areas. These may be relatively costly (Tongia, 2021), but nevertheless a useful supplementary approach for electrifying more isolated areas (Bhattacharya et al., 2022). For the Rockefeller Foundation's own account, see https://www.rockefellerfoundation.org/case-study/a-bold-bet-to-bring-renewable-power-to-the-last-mile/, as well as a partner's assessment (Sambodhi, 2019). Rooftop solar installations can also alleviate some of the strain on power grids. E. Somanathan (personal communication) has suggested to me that the cost of such installations is coming down to the point where adoption will increase more rapidly than in the past. Tax incentives may also have a role to play for such investments, as has been the case in developed countries, but other financing models are also possible (Tyagi and Kuldeep, 2023).
[22] Even without considerations of emissions reduction, calculations based on a growth model and input-output data suggest that electricity supply is the most important constraint to growth for India (Singh, 2007). More detail on the problems of the power sector can be found in Ahluwalia and Patel (2024).
[23] There is a large literature on power sector reform: see Ahluwalia and Patel (2021) for a good summary.

Land availability and acquisition are a crucial aspect of expanding renewable sources of electric power capacity. Gupta, et al. (2022) estimate that 55 million hectares out of India's total land (excluding inland water area) area of 308 million hectares is potentially available for uses such as solar panel arrays, or any other new economic activity. Their estimate of the incremental land needed for solar power would be 10 million hectares by 2050 (Exhibit R). This can be compared with an estimate derived from the NEP (2023, Table 9.23), which estimates the land needed for solar power capacity at 1,600 hectares per GW. Therefore, a solar capacity of 3,000 GW – a ballpark figure for 2050 – would require close to 5 million hectares, which is feasible in principle.[24] Of course, these calculations do not account for all the practical difficulties of acquiring land in India, as enumerated in NEP (2023, p. 9.18): the poor state of land records, land markets, and judicial systems of dispute resolution are important contributors to these difficulties. These issues are further extended when land or rights of way also have to be acquired for transmission lines and other needs, beyond geographically bounded solar panel arrays or power plants.[25]

Counterbalancing these considerations is the potential for a considerable increase in the use of solar panels on rooftops or other built areas such as parking lots, which would reduce the demand for new land. A recent analysis estimates the technical potential for residential rooftop solar installations at 637 GW, or over six times India's current solar generation capacity (Zachariah, et al., 2023). Adding commercial buildings and parking lots to this calculation could reasonably multiply that figure by a factor of two. Based on a 2050 target solar capacity of 3000 GW, and the NEP assumptions noted above, this would imply a 20-40 percent reduction in the land needed, though the remaining political economy challenges would still be significant.

Another major policy issue with political economy implications is the question of what to do about the losers in a transition away from coal-fired power. Defenses for continuing to use coal are possible (Tongia, 2021), even absent rhetorical complaints of "carbon imperialism." Coal-based generation has been advanced as part of a push for rapid electrification to reduce "energy poverty." To the extent that countries like India have relatively new coal-based generation plants, they may have higher efficiency than older plants in developed countries. As noted earlier, some projections (Chaturvedi, 2021; Malyan and Chaturvedi, 2021) estimate that fossil fuels in primary energy production would have to fall to 5 percent of the total by 2030 to reach a 2050 net-zero target, in the absence of additional measures such as CCUS. In a related calculation, based on Ministry of Power figures, Gupta, et al. (2022, p. 3) estimate that the proportion of

[24] The calculation in Gupta et al. (2022, p. 58) is somewhat more demanding. A projected 2050 solar capacity of 2,000 GW is expected to require 1.3 percent of India's land surface, or 4 million hectares. This is estimated to be about a quarter of India's wasteland. Note that it works out to 2,000 hectares per GW, slightly higher than the NEP figure used above.

[25] Developing this generation and transmission infrastructure in new locations can also create new environmental challenges. In his conference comments, Shoumitro Chatterjee pointed out that the Great Indian Bustard, which is critically endangered, had to be rescued by the Supreme Court from the threat of new overhead transmission lines in Rajasthan. The lines had to be buried, and this dramatically raised the cost. Again, economic development is always confronted with these challenges, but they will arise in new locations and new forms with a green transition.

fossil fuels in India's commercial energy mix, currently 75 percent, would go down to about 17 percent in their 2050-net-zero scenario, which does include CCUS.

Countering conservative projections with respect to the use of coal, Chakravarty and Somanathan (2021) calculate that, as early as 2018-19, coal-fired plants were becoming uneconomical when compared to renewable alternatives. According to these calculations, some coal-fired plants were uneconomical based on private operating cost, another fraction when private total cost was considered, and almost all such plants when social costs associated with air pollution and environmental damage were added in (Chakravarty and Somanathan, 2021, Figure 2).[26] It is also argued that an early and orderly transition away from coal would require lower adjustment costs, and that there could be a net increase in jobs with the shift to renewables (Pai, et al., 2021). National policy (NEP, 2023) has begun to shift toward the latter view, shelving the planning new coal-fired power plants, instead focusing on storage technologies that will make renewables more productive sources of power. However, a detailed plan for the transition away from existing coal-fired generation does not appear to have been developed.

It is still possible to argue that the negative employment, fiscal, restructuring, and development impacts of abandoning coal too quickly could be too high to be politically tolerable or possibly even welfare-optimal.[27] However, focusing on the speed of the transition away from coal masks a much deeper set of problems. Slowing growth and domestic energy market dysfunctions were already creating problems for coal-fired power plants in 2018 (Worrall, et al., 2019; Buckley, et al., 2019). This was part of a much larger problem of non-performing assets that has now been hanging over the Indian economy for over a decade, and has not been dealt with effectively. However, in contrast to cases where non-performing assets were the result of a speculative investment boom in the early 2000s, the problems in the power sector can be traced to issues of pricing, regulation, infrastructure, and logistics within that sector. While the government's encouragement of renewables may have been a contributing factor to these problems, the central issue is that the entire power sector needs massive reform.[28] Of course, the disruptions of Covid-19 and the government's responses to the pandemic made these existing problems worse, as well as more apparent (Gupta, et al., 2022, p. 10).

Analyses of the problem of how to avoid a disorderly or damaging transition away from coal-fired power emphasize the need to make sure that the losses suffered by unlucky industrial investors are not disproportionately passed on to workers and communities that depend solely on the mining of coal. These problems will arise in a handful of states – in some cases in specific subregions of those states. This is recognized in the earlier studies of non-performing or potentially stranded assets (Worrall, et al., 2019; Buckley, et al., 2019) as well as in aggregate analyses of India's green transition. Bhandari and Dwivedi (2022a) analyze the fiscal, employment and other economic implications of the transition away from fossil fuels for each

[26] The bulk of this social cost is associated with air pollution and resulting excess mortality, an issue we return to later in the chapter.
[27] Most of the coal used is domestic, so the implications for energy security are very different than for oil, the second most important fossil fuel for India.
[28] Again, Ahluwalia and Patel (2024) is a useful summary reference, but there are numerous analyses of the problems of India's power sector, spanning several decades.

Indian state. A positive take-away is that the geographically concentrated nature of the social and economic impacts will make it a bounded and financially feasible problem to solve, provided that the national government can work productively with the relevant state governments. The workings of Indian federalism are not always optimal, but there is enough evidence to suggest that cooperation can work in this case. Perhaps a more serious issue is how intentions at the national and state levels translate into local implementation – this is one of the areas where India's governance is weakest, in multiple aspects that affect people's welfare (Kapur, 2020; Singh, 2024).

As noted, counterbalancing the costs of phasing out coal (whatever the speed of that transition), a major additional benefit, besides cutting emissions, will be a reduction in air pollution, which has reached alarming levels in much of India.[29] Carbon capture in the context of coal-based power plants and industrial production could provide this benefit in circumstances where coal still has to be used. The health and mortality costs of this air pollution in India are quite large (e.g., Chakravarty and Somanathan, 2021; Cropper et al., 2021). Retrofitting coal-based generation plants and factories to capture particulate pollution in general would seem to be socially optimal based only on domestic benefits, without taking account of global emission reduction.[30] There is also evidence that reducing particulate air pollution would improve rainfall patterns over South Asia (Fadnavis et al., 2021): these have already begun to suffer from climate change, with serious implications for agricultural productivity.[31]

Even just focusing on green electrification in the power, transportation and industrial sectors brings out the complexities of policy making and institutional capacity that are faced in a country like India. But these are just an extension of the same challenges that act as obstacles to economic growth and development. The list of areas in which incorporating sustainability into development goals and economic policies matters is a long one: agriculture, water, forests, urbanization and housing, sanitation, health and education (including "skilling"), biodiversity, energy use efficiency, climate risk mitigation, and adaptation. Many of these areas, most obviously, health and education, would require better policies even in the absence of a prioritization of policies to control global warming, if India is to achieve substantive long run economic growth and improvements in welfare.

India also has some special characteristics that ought to be shaping policy more strongly than they have to date. As noted earlier, India is the most water-scarce large nation in the world, and it uses water remarkably inefficiently (Singh, 2014). Climate change is already affecting rainfall

[29] A large number of the list of the world's cities with the worst air quality are in India. IEA (2021a) and Gupta, et al. (2022) both acknowledge the benefits of clean energy technologies for pollution reduction. Chakravarty and Somanathan (2021) estimate the social cost of air pollution, based on a "value of a statistical life" (VSL) methodology. NEP (2023) provides a detailed enumeration of the benefits of pollution reduction, including water pollution as well as air pollution, in its assessments of future power capacity plans. Of course, the challenges are how to incentivize multiple economic actors to take socially preferable actions with respect to technology choices – pollution is the classic negative externality example in the history of economic thought.

[30] Again, Chakravarty and Somanathan (2021) make a case for replacing coal more quickly, which would reduce the need for investment in CCUS/CCS technologies.

[31] More generally, India is one of the most vulnerable countries to climate change, as measured by the negative impacts of extreme weather events (Eckstein, et al., 2019).

patterns and glaciers in India and its neighbors, leading to impacts beyond the direct effects of atmospheric and oceanic warming, which are potentially catastrophic by themselves. All this is well documented by now, in many of the references cited here, as well as numerous other studies and reports. As another example, India's record on health, sanitation and education has often been judged to be below what might have been expected in light of its overall economic growth. This situation is almost tautologically a problem of political economy (Kapur, 2020; Singh, 2024), and the challenge is whether a crisis situation can alter the current political economy equilibrium, or whether the equilibrium makes it impossible to change things as dramatically as is needed.

The case of agriculture illustrates some of the difficulties associated with political economy. Indian agriculture, judged by its productivity, is inefficient in multiple ways, related to the small size of holdings, the relative market power of intermediaries, lack of industrial capacity and infrastructure for processing or transportation of agricultural products, poorly functioning input and product markets, pervasive distortionary subsidies, and so on. Many of these characteristics contribute to wasteful use of scarce resources such as water and electric power, and overall inefficiencies in production. They also contribute to carbon emissions and pollution. The best-known example is that of rice growing in Punjab and Haryana (Liu, et al., 2021), where attempts to curb overuse of water, caused by input subsidies, through regulation of the date of sowing have led to increased burning of rice stubble and massive increases in regional pollution. Attempted solutions that focus on the last step in this causal chain are likely to be futile unless the entire system of procurement that incentivizes growing too much rice in the wrong places is reformed. The 2020-21 agricultural reform bills that focused on deregulation and liberalization of the later stages of the agricultural value chain seemed to neglect the largest source of current problems in the sector, with a process that lacked adequate consultation and analytical underpinnings. These problems, if repeated, can make it difficult to deal with climate change on top of all the other developmental aspects of policy making. The agriculture sector already requires concerted policy attention with respect to land and water use, production technologies, cropping patterns, and electricity pricing and access (Ahluwalia and Patel, 2021; NEP, 2023). Issues such as land use for solar power or adaptation to changing water availability only add to the agricultural policy agenda, in a situation that is already politically fraught.

It is beyond the scope of this chapter to consider all the different aspects of developmental and welfare policies that are affected by the imperative to reduce greenhouse gas emissions, but many of these issues are discussed in global contexts (IEA, 2021a; Bhattacharya, et al., 2022), and for the specifics of the Indian case (Gupta, et al., 2022). We also return to these broader concerns in the next section, in the context of finance, and in the chapter's conclusion.

At the heart of all policies designed to support the implementation of a green transition is the concept of carbon pricing. Greenhouse gas emissions are higher than is globally optimal, because the negative externality that they create is not properly priced when individual, corporate or governmental decisions are made. One way of ensuring that decision making reflects the global cost of emissions is through taxes, but in some circumstances, subsidizing alternative choices may be preferable, for distributional reasons. Quantity controls such as standards for emissions have implicit carbon prices associated with them. Limits on emissions can be accompanied by tradability of these permits, which notionally allows for increases in efficiency when the initial allocation of limits is not optimal for some reason. As can be imagined, the correct price of carbon and the best instruments for its implementation in a range of contexts are both difficult to determine or agree on.

Despite the complexity and complications across different situations, it is useful to have a benchmark figure that acts as a generic target of carbon pricing. Stern and Stiglitz (2017) suggested CO_2 prices of $50-$100 per ton by 2030 as an appropriate guide for production decisions, if not quite an estimate of marginal damages in all circumstances.[32] A recent effort to estimate the price-equivalent of a full range of emission-control policies by each country, as well as globally, has created a "carbon barometer," to measure the overall tightness of such policies (Carhart, et al., 2022; Litterman, 2023). The figures for 2021 provide a sobering indicator, with a global figure of only $18 per ton. The US and India both have carbon barometers close to this number, with China even lower, and only a set of Western European countries, along with Canada and South Korea, are in the $50-$100 range. In addition to the Stern and Stiglitz guidelines, the actual social cost of carbon has been estimated at $51 in 2020 by the US Environmental Protection Agency (EPA), but as high as $185 by a study from Resources for the Future (Rennert, et al., 2022, Litterman, 2023). These numbers provide an important indicator of how far India and several other major countries, including larger emitters such as the US and China, have to travel, if any meaningful progress in global emissions reduction is to be achieved. Note that Gupta et al. (2022) use a carbon price of $50 a ton as benchmark, whereas earlier studies have used a much lower number of $25 per ton as a recommendation (Parry et al., 2021; Ahluwalia and Patel, 2021).

If the current carbon barometer for India is close to the global average of $18 per ton, can one get a sense of current values in different sectors? The most important sector is power generation, and renewable energy will have lower carbon impacts, but not necessarily zero. Clearly, fossil fuel-based generation is not priced to take account of carbon emissions. In the light of the earlier discussion of social costs of adjustment, policies could involve subsidizing CCUS/CCS, rather than taxing such generation plants. On the demand side, electricity pricing in India is poorly managed (Abeberse, 2017), reflecting unclear welfare goals and hurting the growth of firms, while subsidizing better-off consumers. The expansion of electricity generation has to be accompanied by more rational electricity pricing, as well as markets to improve the allocation of electricity across groups and regions (Ahluwalia and Patel, 2021; Tongia, 2023; Ahluwalia and Patel, 2024). There can be significant challenges in designing markets for electric power, since they can be subject to market power and manipulation (Wolak, 2019; Graf, et al., 2021), but they are not insurmountable, especially after the last two decades of experience in developed economies. Much of these reforms would be needed even in the absence of a green transition, so the latter may provide an opportunity for reforms that have otherwise proved politically infeasible.

[32] See also Stern (2022, p. 1278), where the issue of the proper discount rate in such calculations is also discussed.

Similar considerations apply to India's transportation sector, where pricing of road use and railways (passengers vs freight) displays similar characteristics of cross-subsidization without explicit welfare calculations. However, there are significant taxes and duties on petroleum products that are used in most road transportation. These are estimated to be the equivalent of a carbon price of $100 per ton of CO_2 (Ali and Tongia, 2020; Tongia, 2021), or even higher ($140-$240, Gupta et al., 2022). Of course, these revenues from petroleum taxes in the transportation sector are not earmarked for the country's green transition. They will disappear with electrification of transportation, but meanwhile they could play a role in subsidizing the adoption of electric vehicles.

In any case, explicit or implicit carbon pricing has to play a role in managing demand, along with changes in technologies, since the global warming externality will remain even with greener technologies (Stern and Stiglitz, 2017). Designing and implementing carbon pricing schemes is not an easy task, either technically or politically.[33] Chandra (2021) reviews India's current implicit and piecemeal approach to carbon pricing, and the political economy factors that come into play for implementation of a more comprehensive, explicit approach. To some extent, as recognized in all studies (Gupta, et al., 2022; Stern, 2022, BloombergNEF, 2023), there is no single approach that can work across the entire economy. Based on experience as well as theory (Weitzman, 1974; Tang, et al., 2019; Auffhammer, 2019), standards for emissions, inputs and technologies[34] can all play a role in incentivizing or achieving a green transition in production and consumption activities, often mixed with price-based incentives. Areas such as building codes are particularly suitable for this approach, and enforcing a switch to electric vehicles represents a global shift that obviates the need for emissions standards and monitoring that currently is used for fossil-fuel-powered vehicles.

Emissions standards are based on emissions intensity. A different approach to quantitative, vs price-based, regulation is the imposition of aggregate limits on emissions. If these limits are implemented through permits or licenses, there is a theoretical case for improving allocative efficiency by allowing these permits, often labeled carbon credits, to be tradeable. There are several national and international mechanisms for trading carbon credits, but their working, and impacts on emissions reduction, are unclear. In particular, initial allocations of carbon credits may be too generous, or be associated with emissions that are not actually occurring, so that the trading has no effect. However, these are market design issues, not arguments against tradeable permits, and some emissions trading systems in the US and European Union seem to be effective (Anjos, et al. 2022). India has just begun designing an emission trading system (ETS), which is planned to be introduced in 2025. Ahluwalia and Patel (2024) discuss the challenges of designing an ETS, and make recommendations for initial allocations, in particular. These include determining initial quantities, possible reductions over time, and pricing. Charging for initial

[33]Tongia (2021) notes the additional complications for carbon pricing associated with flattening the emissions curve, rather than just focusing on a target date for net-zero emissions.

[34] Technology choices can have implications for emissions directly, such as electric vs gasoline vehicles, or indirectly though energy efficiency within a particular technology, e.g., if some EV batteries are more efficient than others. LED vs incandescent light bulbs are another example. Appliance and building energy standards are other cases where price incentives do not operate at the right margin.

allocations, such as through an auction mechanism, effectively reduces the possibility of windfall profits from subsequent trading, and generate government revenue that can be earmarked for climate action. In contrast to a domestic ETS, because India is a low-intensity carbon emitter, Gambhir, et al. (2014) argue that an equitably-designed international system of trading carbon credits could actually allow India to generate revenue for climate action.[35]

Finally, it is worth noting the general importance of digital infrastructure. A new, more complex power grid will require a new digital infrastructure as well. The rapid growth of the use of smart phones in India can obscure the fact that much of the population has more limited access to high quality, affordable broadband internet access, which would allow more use of remote knowledge work and education services, and reduce transportation demand. In turn, a robust electricity generation, transmission and distribution infrastructure is essential as a foundation for this digital infrastructure.[36] At the same time, the increased demand for digital technology, in processing, transmitting and storing information, will increase the demand for electricity disproportionately to growth, and reinforce the importance of decarbonizing generation.

Financing the Green Transition

India has a little over one sixth of the world's population, but contributed just 7-8 percent of global CO_2 emissions in 2021.[37] Its cumulative emissions are proportionately even lower, compared to its population. The country's relatively low GDP per capita compared to other large contributors to greenhouse gas emissions means that it is less well positioned to finance a green transition. Arguments for climate justice or fairness (Tongia, 2021; Ahluwalia and Patel, 2022) suggest that countries which have contributed more to the current accumulation of greenhouse gases should take greater responsibility for fixing the problem. However, using this reasoning to favor a slower green transition for India, until it has grown enough to generate more resources for the transition, is not the only possibility.

Since the problem is global, India's policymakers can aim for a faster transition (reaching net-zero in 2050 rather than its COP26 commitment of 2070), and make a case to advanced countries and multilateral institutions for financial support.[38] Aside from this possibility, there can also be an independent case for acceleration as intertemporally optimal. In particular, a business as usual

[35] The European Union's Carbon Border Adjustment Mechanism (CBAM), which is being introduced over the next two years as of this writing, is designed to equalize the carbon price for exporters to the EU with that borne by domestic firms. The CBAM forces the issue of tackling carbon pricing on to EMDEs, in a manner that is theoretically efficiency enhancing but not necessarily equitable. The kind of mechanism proposed by Gambhir, et al. (2014) could remedy some of this inequity, as could lump sum transfers to EMDEs.

[36] Other issues that we have not tackled here for reasons of scope are international cooperation, greenness of global value chains as India attempts to integrate into them as part of its development strategy, and energy security as it relates to fossil fuels and to resources used in technologies such as solar panels and lithium-ion batteries.

[37] See https://globalcarbonatlas.org/emissions/carbon-emissions/.

[38] The mechanism suggested by Gambhir, et al. (2014), of internationally allocated and traded carbon permits, could be one way to implement such transfers. Political decision making would determine initial allocations, not the resulting transfers.

approach to economic growth now can make it more difficult to switch later, rather than making greater upfront investments in the green transition. This thinking can be seen in the NEP (2023), which announced the postponement of new coal-fired power plants, in favor of storage technology investments that would increase the productive capacity of renewables-based power plants. Rapid investment in areas where long run changes are necessary, such as solar power for generation and various kinds of green infrastructure, can take advantage of dynamic economies of scale, through learning by doing.[39]

The challenge is to estimate the incremental costs of green investment in infrastructure and other areas, versus the best alternative. If new power generation from solar and wind is cost competitive with coal, as suggested by recent estimates, then the incremental cost of making future growth greener might be relatively small, or even negligible. However, if existing coal-based power plants have to be retrofitted for carbon capture, the additional costs of going green could be more substantial.[40]

An earlier IPCC special report (IPCC, 2018, based on McCollum et al., 2018) estimated the incremental annual energy investment costs for India to make the green transition at $82 to $135 billion, for the period 2016 to 2050.[41] These figures represent 2.7 percent to 4.5 percent of current GDP, but allowing for growth reduces the average over the whole period to below 2 percent. To put these numbers in perspective, India's tax-to-GDP ratio for the national and state governments combined is only about 18 percent, so that the incremental investment needs for India's transition to green energy cannot simply be financed by additional public expenditure.[42] But sufficient improvements in energy markets and pricing to provide adequate returns on capital could make domestic and global private investors a possible source for much of this funding.

Starting from a different angle, Bhattacharya et al. (2022) focus explicitly on the size of a "big investment push" for emerging markets and developing economies (EMDEs). Their scope is much broader than just investments in energy, but in some ways, it is too broad. To illustrate, their estimate for the needed aggregate spending in 2025 for all EMDEs (except China) is $3.7 trillion (Table S1). However, $2 trillion of this is for human capital investments. It is not immediately clear how much, and why, any of this is incremental to a greener growth path. One fourth of the remaining $1.7 trillion is associated with two spending categories, adaptation and resilience, and the restoration and protection of natural capital. The latter is clearly an important aspect of an emission reduction strategy. For the moment, if one focuses on the remaining $1.16

[39] For a clear discussion of these issues, see Solow (1997).

[40] In either case, one can re-emphasize the benefits of pollution reduction, which might not show up in conventional GDP calculations, since increased health expenditures appear as a positive contributor to measured economic activity.

[41] These numbers are different from what is reported in Ahluwalia and Patel (2021). They are calculated directly from Table 1 in McCollum et al. (2018), by taking the difference of the 2° and 1.5° scenarios relative to the baseline. It should be noted that the confidence intervals for these estimates of funding requirements are extremely wide.

[42] Close to 20 percent of government tax revenues come from fossil fuels (Bhandari and Dwivedi, 2022), so decarbonization will have to be accompanied by a shift in the tax structure to compensate for lost tax revenue as fossil fuels are replaced, possibly including carbon taxes elsewhere, or simply a broader direct tax base as the economy grows.

trillion, that is the estimated cost of sustainable infrastructure and an accelerated energy transition. India's GDP is just under 20 percent of the EMDE-minus-China total, so if one prorates the expenditure, it would be close to $220 billion, or about 5.5 percent of GDP. Similar financing needs or targets can be found in more recent documents (IEG, 2023a; IEG, 2023b; IHLEG, 2023), which provide an estimate of $1.8 trillion a year for EMDE climate finance by 2030, again excluding China.[43] A similar calculation for India's share of this financing requirement depends on assumptions about the growth rate, but would be about 6 percent of 2030 GDP.

We get a slightly different picture if we start from the bottom up. The NEP (2023) estimates that 40 GW in capacity will be added annually, on average, over the next five years, most of it being solar power (Tables 5.3 and 5.7).[44] Using their capital expenditure figures (p. 5.29), the implied total annual capital expenditure in this plan is $50 billion. This figure does not take account of transmission infrastructure and land acquisition costs, but even doubling that $50 billion gives less than half the number derived from the Bhattacharya et al. (2022) global calculations. Again, those are not restricted to electric power capacity, and could include things like infrastructure for a shift to electric transportation, but IEA (2021a) estimates suggest that is relatively small compared to the cost of increasing power generation capacity. Finally, the NEP figures reflect investment required for economic growth, not the incremental investment for green vs non-green growth. None of this is meant to minimize the size of the challenge. However, it may be that the most severe constraints are not in the size of the investments required, but in the sources of financing, and the human capital needed for design and implementation of all the new infrastructure. It is also possible that the NEP calculations are overoptimistic, since cost overruns are typical. Even then, the $220 billion figure for *incremental* costs of sustainable infrastructure may be somewhat on the high side.[45]

Yet another set of estimates is provided by Gupta et al. (2022). They have breakdowns by components of the economy, such as power, transportation, industry and agriculture, but we can begin with the aggregate figures. The estimates are presented by decade, and cumulatively, for 2020 to 2050. The numbers reported for green investment are $7.2 trillion for the LoS scenario, and an additional $4.9 trillion for the accelerated scenario, or $12.1 trillion in total (Exhibit T).[46] None of these figures use any present value discounting, however, though they are adjusted for inflation. If we take the $1.6 trillion figure for the accelerated scenario covering 2020-2030, a simple average is $160 billion annually (Exhibit E), covering all aspects of the green transition,

[43] IEG (2023a, b) was formed by the G20 under India's Presidency, with its main goal being a plan for reforming multilateral development banks (MDB) to advance a broad agenda, of which dealing with climate change is only one component. IHLEG (2023) was initiated by the COP26 and COP27 Presidencies, essentially as a follow-up to Bhattacharya, et al. (2022).
[44] As we discuss in the conclusion, actual capacity addition has been much lower.
[45] An alternative interpretation of the calculations in Table S1 of Bhattacharya et al. (2022) is that the incremental expenditure for a green transition is the difference between 2025 and 2019, which is $430 billion for sustainable infrastructure. Prorating this for India yields a figure of $80 billion as an incremental investment. This is much more in line with the bottom-up calculations based on the NEP.
[46] 70 percent of this total would be required for power and transportation.

including an energy transition as well as other actions such as greater recycling of materials. This number is higher than the McCollum estimates, but not out of line with them, especially if the difference in base year for the dollars is accounted for. The Gupta et al. (2022) figure represents just over 4 percent of GDP in the current decade, but that percentage is estimated to be higher in the subsequent two decades, so that their estimated average financing requirement for three decades is close to 6 percent of GDP. On the other hand, based on a range of India-specific estimates, Ahluwalia and Patel (2024) posit a current incremental investment need of 1.5 to 2 percent a year, which is much more feasible, and in line with the bottom-up estimates presented here.[47]

We can go on to embed these investment numbers in a growth context. Suppose that, in the absence of climate change, the incremental capital-output ratio (ICOR) was 5, and so a growth rate of 6 percent would require an investment rate of 30 percent of GDP. Presumably, the assumption is that such a growth model is no longer feasible, since it is unsustainable. Instead, growth will have to be more capital intensive, and achieving long-run growth of 6 percent will now require an ICOR of 6, and an investment rate of 36 percent, or 6 percent more of GDP, as in the Gupta, et al. (2022) calculations.[48] The challenge is how to finance this higher investment rate.

Bhattacharya et al. (2022) and its successor, IHLEG (2023) estimate that half of the incremental financing could come from domestic resource mobilization (their Figure S1), including improvements in tax systems, carbon pricing, and removal of fossil fuel subsidies, though they do not explore the political economy and institutional capacity questions of how this will all be done. One third of the incremental investment would come from the private sector, which would presumably invest in projects where they can earn a competitive rate of return. This is plausible, provided there are mechanisms for risk sharing and insurance.[49] Because of elevated and novel risks, one of the greatest uncertainties going forward will be the working of global insurance markets (Litterman, 2023).

Finally, the remaining one-sixth of the incremental investment would come from various multilateral and bilateral sources of finance, concessional as well as non-concessional. This proportion, which includes sources beyond MDBs, is lower than the MDB target in IEG (2023a, 2023b), but perhaps more realistic. All these sources of finance can often be important complements to domestic resources and private sector investment, so the domains of application of the three sources of finance are not mutually exclusive. In particular, the conceptualization of these public institutional sources of climate finance for MDBs is that they can act as lead

[47] Ahluwalia and Patel (2024) also note that the external component of this incremental investment would not have a major effect on the current account, and therefore not threaten macroeconomic stability.

[48] These figures can also be used to do some simple welfare calculations. In a two-period framework with logarithmic utility, the extra 6 percent of green investment would be welfare-increasing if the probability of a 10 percent reduction in GDP without that investment is above 50 percent.

[49] In some areas of investment, such as carbon capture associated with retrofitting of coal plants, private and international investment could be deterred by political risks (Tongia, 2021; Malyan and Chaturvedi, 2021), and government backstopping may be required. Overall, there will be an increase in uncertainty due to climate change itself, as well as the rapid deployment of newer technologies.

investors, possibly bring down risks for private investors, or at least providing positive signals based on their willingness to invest.[50]

In contrast to the global analysis of Bhattacharya, et al. (2022) and IHLEG (2023), the discussion in Gupta, et al. (2022) provides a detailed discussion of the role that the Indian financial sector, particularly banks, can play. In doing so, they also refer to the European Central Bank's guidelines and proactive stance for nudging banks in its jurisdiction toward climate finance actions. However, the Indian banking sector, and even the nonbank finance sector, have shown persistent weakness in their operational capacities, particularly in the case of public sector banks, and large, long-gestation infrastructure projects. It may be the case that technologies such as solar plants will become routine, but issues of pricing, contract enforcement, risk assessment, land acquisition, political interference and more may continue to plague the Indian financial sector. Its weaknesses have hindered economic development, even without the added need to step up investment in the context of a major structural transformation of the economy.

On the one hand, the numbers in all of these calculations of incremental investment are not beyond the scope of financial markets and public resource mobilization. Rapid policy actions and front-loading investment can potentially reduce risks, or their rate of increase, and prevent risk premia from pushing costs of private financing so high that it deters investment. There are two types of risk for borrowers, physical risk and transition risk. Taking action earlier can potentially reduce both sources of risk, for private as well as sovereign borrowers. Government policies that seek to accelerate a green transition might increase short-term transition risks, but reduce them in the long run, as well as short-term and long-term physical risks.[51] One challenge for this acceleration is the risk of fiscal unsustainability, as pointed out in Pisani-Ferry (2023) and Natarajan and Nageswaran (2023).[52] The accumulation of government debt globally has begun to reverse the low interest rate environment that was noted hopefully in Stern (2022), which makes borrowing costlier than in the recent past, and this adds to the challenge.

Conclusion

This chapter has considered the nature and feasibility of a green transition for India, as part of its development trajectory. The argument has implicitly and explicitly been built on an acceptance of the desirability of an accelerated transition, defined as a target of net-zero emissions by 2050. We have also not given weight to fairness or climate justice as reasons for a slower transition.

[50] Note that the breakdown used by Bhattacharya, et al. (2022) includes their category of human capital, and it is possible that category would need to rely disproportionately on domestic resource mobilization.
[51] Credit-rating agencies are already analyzing such risks and their implications for required yields, e.g., MSCI (2023).
[52] Natarajan and Nageswaran (2023) frame Pisani-Ferry's concern with the simultaneous challenge of achieving net zero targets, preserving fiscal sustainability, and maintaining competitiveness as a new "impossible trinity." I am grateful to Shoumitro Chatterjee for this reference, and for emphasizing this challenge. In the case, of India, as discussed earlier in the chapter, while fiscal sustainability and competitiveness are not automatic, higher growth rates than in Europe, potentially higher investment rates than the current level, and the scope for significant greenfield investment, rather than replacing or retrofitting existing infrastructure and other physical capital are all relative positives.

Evidence from several recent global and India-specific studies has been compared and assessed in developing the perspectives presented here.

The shape of India's green transition requires a strong prioritization of electrification through the rapid growth of electric power capacity through solar and wind power. Renewables-based electric power also provides the foundations for the electrification of the transportation sector. Other aspects of the green transition include the possible roles of hydrogen and of carbon capture and storage, changes in production methods in agriculture and industry, and energy efficiency in building design and construction.

Next, the chapter considered various aspects of the policies and institutions that would affect or play a role in shaping the green transition. The issues considered included managing the transition away from coal, including the benefits of pollution reduction and how to handle the negative impacts on subsets of the population, upgrading of the electric power grid and general reform of the power sector, appropriate target carbon prices, and how taxes and standard setting can play roles in aligning incentives with the goal of emission reduction. The chapter also considered agricultural sector reforms, and broader issues of institutional capacity and political economy.

Finally, the chapter discussed the magnitude of incremental investments needed for an accelerated green transition, comparing estimates based on global calculations, India-specific estimates, and bottom-up estimates from India's latest national electricity plan. It also discussed sources of finance, including choices between public vs private, and domestic vs international, Finally, it considered potential barriers in terms of institutional capacity, higher risks and risk premia, and the functioning of insurance markets.

The essential message of the chapter is that an accelerated green transition for India is both desirable and feasible, and it can be achieved with the right strategic focus, especially in the key sectors of electric power generation and transportation. The amounts of funds needed for incremental investment are quite feasible to access, especially if actions are taken before risks worsen. Many of the institutional barriers to a green transition are similar to those that hinder economic development, so there is no conflict between pursuing the two goals. Indeed, there is no long run alternative to green growth, and India can serve as a role model and leader for all developing countries in achieving a globally coordinated reduction of greenhouse gas emissions.

However, to end on a cautionary note, recognizing the feasibility and optimality of a more rapid green transition does not ensure its implementation. Institutional barriers remain substantial, and there is considerable inertia in government action. For example, despite the clear analysis and targets in NEP (2023), additions to renewables capacity were well short of the targets for the last year. In another example, the adoption of electric vehicles, switching of domestic production, and the building of new infrastructure for electric vehicles have barely begun in India, whereas China has rapidly become a major global producer, with one or more domestic manufacturers transforming its production capabilities away from conventional automobiles. While battery storage technology has received investment, there is no significant move to create and scale up a domestic solar panel industry although domestic and global demand are guaranteed to grow exponentially. Perhaps this inertia should not be surprising in an economy where the share of manufacturing has been surprisingly stagnant, even after decades of policy reforms meant to give businesses more space to thrive. In addition to the central government, many subnational governments have also struggled individually with implementing policies effectively, and their competing interests present further challenges for the center. All these factors remind us that feasible and optimal policies may still fail to become realities.

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