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KEYS TO CLIMATE ACTION

CHAPTER 4: MANAGING CLIMATE CHANGE—A STRATEGY FOR INDIA

MONTEK SINGH AHLUWALIA
UTKARSH PATEL

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AUTHORS

Montek Singh Ahluwalia, Distinguished Fellow, Center for Social and Economic Progress; former Deputy Chairman, Planning Commission of India

Utkarsh Patel, Associate Fellow, Center for Social and Economic Progress

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Introduction

The COP26 Summit in Glasgow represented a breakthrough because developing countries, for the first time ever, agreed to reduce the level of carbon emissions to net zero by various dates around mid-century. India, along with many other developing countries, had traditionally argued that global warming is occurring due to the accumulation of greenhouse gases (GHGs) in the atmosphere, which is mainly due to the activities of developed countries as they industrialized. Since India had contributed little to the stock of GHGs, and also had a very low energy consumption per capita, imposing emissions reduction obligations on India was seen to be unfair and inconsistent with its development goals.

This position changed because of the recognition that technological advancements have made it possible to meet the energy requirements of development using renewable sources of energy, which do not emit GHGs. Prime Minister Modi announced that India would achieve net zero emissions by 2070. Most advanced countries, and also some developing countries like South Africa and Vietnam, announced 2050 as their target net zero date. China, Russia, Saudi Arabia, Indonesia, Nigeria, and others committed to reach net zero by 2060.

This chapter examines the challenges India will face in implementing its new commitment. Section 1 summarizes India's COP26 targets and outlines the broad strategy we must follow to achieve them. Sections 2 to 5 focus on what can be done to reduce emissions in sectors which account for almost all of the country's carbon dioxide (CO_2) emissions. Section 6 discusses afforestation and carbon capture, utilization, and storage (CCUS) as ways of dealing with residual emissions. Section 7 presents an assessment of the likely investment requirements of this transition. Section 8 presents the main conclusions.

India's COP26 targets

India's emissions reduction targets announced at COP26 consisted of a longer-term target of reaching net zero by 2070 and some interim targets for 2030, which are as follows:

1. Emissions intensity of GDP to be reduced by more than 45 percent by 2030, compared to the 2005 level, up from the Paris target of 33–35 percent.[1]
2. The share of non-fossil fuel-based electricity generation capacity will be raised to 50 percent by 2030, up from the earlier target of 40 percent. This is based on the target of 450 GW of renewable energy (RE) capacity, predominantly solar and wind, by 2030.
3. The afforestation target of creating 2.5–3 Gt-CO_2 equivalent additional forest sink by 2030, that was part of India's Paris nationally determined contributions (NDCs), was not explicitly mentioned, but remains in force.

The target for reducing emissions intensity is likely to be achieved but, of course, reducing emissions intensity will not necessarily lead to a reduction in absolute emissions. Since GDP in 2030 is likely to be 4.5 times what it was in 2005, a 45 percent reduction in emissions intensity would still leave absolute emissions almost 2.5 times the level in 2005, or about 33 percent above the 2020 level (GCP, 2022). The fact that India's emissions are projected to rise over the near future should not cause any surprise because India's per capita energy consumption is currently very low—only a sixth of the average of Organisation for Economic Co-operation and Development (OECD) countries (BP, 2021). India needs to achieve growth of 7–8 percent per annum in its GDP over the next 10 years, to meet legitimate expectations of higher income levels, and this is bound to involve growth in total energy consumption.

India's strategy for decarbonization reconciles growth in energy consumption, with a reduction and ultimately elimination of CO_2 emissions, through a combination of demand-side and supply-side actions on energy. On the demand side the strategy relies on:

(i) increasing energy efficiency through adoption of energy-saving technologies, combined with lifestyle changes, which will moderate the growth of energy demand for any given growth of income; and
(ii) shifting from direct use of fossil fuels to electricity as the final energy source wherever possible. Electrification of transport is the most obvious possibility which saves on use of petrol and diesel.

Action in these demand side areas will be combined with supply-side actions such as:

[1] Emissions intensity of GDP is greenhouse gas emissions (generally CO2 emissions) per unit of GDP.

(iii) shifting away from electricity generation using fossil fuels (mainly coal, and also gas) to electricity from RE (mainly solar and wind)—this transformation on the supply-side is critical for reducing emissions from other demand-side sectors such as transport; and
(iv) developing green hydrogen (H_2) as a substitute for fossil fuels in hard to decarbonize areas.

The above actions must be accompanied by:

(v) expanding forest area to increase natural carbon sinks; and, finally,
(vi) developing CO_2 capture and sequestration techniques to make them commercially viable to offset emissions from residual use of fossil fuel that may remain.

These transformations involve many difficult steps but there is recognition, at least in official circles, that these steps are in India's interest because the country would be among the worst sufferers of climate change. IPCC (2022a) estimates that impacts of unabated climate change would lead to extreme weather events causing large-scale displacement of people and loss of infrastructure, reduced labor productivity owing to heat stress, and lower agriculture yield from water scarcity and heatwaves. The report places India, second only to China, in the list of countries with the highest expected loss of GDP due to sea-level rise by 2080 (IPCC, 2022a). Climate change will also deepen inequality as those employed in primary and secondary sectors would suffer disproportionately higher income losses (Aggarwal, 2021; Ortiz-Bobea et al., 2021).

In the sections that follow, we discuss what can be done along these lines to decarbonize the major sectors which account for almost all of the country's CO2 emissions,[2] viz: Power generation (50 percent of emissions in 2019), industries and manufacturing (30 percent), transport (13 percent), and buildings and appliances (5 percent).[3]

Our analysis shows that success will not depend on one or two "magic bullets." It will require multiple interventions in different areas, many of which are mutually reinforcing and therefore need to be coordinated. The private sector has a crucial role to play in the transition, and the incentive structure therefore must be supportive of the sector. However, government will also have to intervene actively in many areas through increased public investment, improved regulation of the electricity market, rationalizing energy subsidies, providing an environment conducive to private action in managing climate change, and possibly also moving toward some form of taxation of carbon.

Since it is not possible to define all the details of a strategy spanning the full period of the transition, we argue the case for proceeding on the basis of a sequence of 10-year plans. The first of these, spanning the first 10 years, should define granular targets for the period in each of

[2] CO_2 accounts for about 72 percent of all the greenhouse gases (GHGs) emitted in India.
[3] Source: CAIT Historical GHG Emissions. 2022. https://www.climatewatchdata.org/ghg-emissions

the major areas which contribute to emissions. The responsibility for achieving these targets can then be assigned to relevant bodies, and progress regularly monitored and targets adjusted as necessary. The national 10-year plan could be complemented by states announcing state-specific plans for the 10-year period indicating their respective targets. This exercise can be repeated for the subsequent 10 years, taking on board the lessons from the first phase.

In addition to steps aimed at mitigation, it is also necessary to take steps aimed at adaptation to the climate change that has occurred and will continue, even on optimistic assumptions. These changes include increased frequency and severity of extreme weather events such as heat waves, droughts, and floods which could disrupt agriculture and lead to food and water shortages; decline in labor productivity which could lower household incomes; rising sea levels which could lead to coastal flooding in low lying regions, displacing millions of inhabitants; and loss of biodiversity and ecosystems which could negatively impact livelihoods of many people.

These impacts could lead to widespread economic, social, and political instability and it is therefore crucial for us to take proactive steps to adapt to climate change by investing in building climate resiliency.

Decarbonizing the electricity sector

The most important element of the strategy consists of shifting from fossil fuel-based electricity generation to electricity from non-emitting/renewable sources. This is important because the power generation sector accounts for about half of the total CO_2 emissions in the economy and therefore has the largest potential for reducing emissions. Furthermore, decarbonizing other sectors will involve switching from direct use of fossil fuels to electricity as the final energy source (e.g., in transport). This process of electrification will greatly increase the share of electricity as the major energy carrier, making decarbonization of electricity that much more important.

The scope for delinking electricity generation from CO_2 emissions on a large scale lies primarily in expanding capacity in solar and wind power. This is the area where technology has evolved rapidly in the past two decades, making electricity generation from these sources much more economical. This is explicitly recognized in the government's strategy for setting up 280 GW of solar (rooftop plus utility scale) and 140 GW of wind (onshore and offshore) by 2030 as part of the 450 GW RE target.

The other sources for generating electricity without GHG emissions are hydropower, nuclear power, and biomass. India currently has about 47 GW of hydropower capacity, but geophysical factors and environmental and social concerns make significant expansion unlikely (NPP, 2023). Similarly, there is about 10.2 GW of biomass-based capacity, again with very limited scope of expansion due to logistical reasons. Nuclear capacity is currently only 6.8 GW, with another 6.7 GW under construction (ibid.). This is an area where significant expansion should be possible if India can make progress in disposal of nuclear waste and alleviate local concerns regarding safety of nuclear plants.

Small modular nuclear reactors, which are under development in many advanced countries, may be a feasible way of expanding nuclear power, with much less resistance on account of safety concerns. Since atomic power remains reserved for the public sector, the plants would have to be set up and operated by one of the public sector companies. NTPC Ltd. (formerly known as National Thermal Power Corporation) could use its existing locations, where coal-based plants will be phased out as part of the energy transition, to install new small modular nuclear reactors in a cost-effective manner, making use of existing power generation and evacuation infrastructure.

India has made good progress in expanding RE capacity thus far and the installed capacity has expanded from only 6 GW in 2005 to about 121 GW by the end of 2022 (ibid.). Most of the expansion has been through private sector investment, led by ReNew Power, Greenko, Adani Green, and Tata Power (Jaiswal and Gadre, 2022). The private sector's involvement augurs well for the future since resources with the public sector are limited and the private sector is expected to play a major role in the expansion of RE capacity. However, while the expansion thus far has been impressive, the rate of annual capacity addition in the last four years has averaged about 11 GW per year (NPP, 2023). It will have to increase to 38 GW for the next 8 years to meet the 2030 target.

The structural obstacles that need to be addressed to ensure a faster pace of capacity expansion in future are discussed below.

The problem of intermittency

Both solar and wind electricity are characterized by intermittency of supply, which creates problems of grid management because the supply and demand of electricity must always be balanced. This has not been a serious problem thus far because RE currently accounts for only about 11 percent of total electricity supply, and at this level it is possible to counter imbalances by ramping up supply from the conventional modes of generation when needed (CEA, 2022). However, as RE sources account for about a third of the total electricity supplied in 2030, as the new targets imply, balancing will become more difficult (ibid.). These problems will only increase in future when the share of RE will rise to over 70 percent by 2070 as projected by Chaturvedi and Malyan (2022).

Intermittency can be handled in several ways, and these are summarized in box 4.1. In practice, a mix of all these solutions is likely to be deployed. The most promising are: (i) pairing RE generation with gas-based power plants, to begin with; (ii) pumped-hydro storage where possible, using RE electricity in peak hours and generating hydroelectricity when needed; and finally (iii) use of grid-scale battery storage.

Each of these methods entails additional costs, and that will increase the cost of getting a balanced supply of RE. The pace at which we can shift to RE depends critically upon its cost competitiveness.

Cost competitiveness of solar and wind electricity

The good news on competitiveness of RE is that the unit cost of solar power has fallen by 88 percent in the past 10 years and that of wind power by over 60 percent (IRENA, 2021; IRENA, 2022), due to a combination of technological improvements and economies of scale in manufacturing solar panels. This has made solar and wind electricity competitive with electricity from new coal-based plants if we look only at unit costs for RE as available, i.e., accepting intermittent supply and ignoring the cost of backing down supply from contracted plants. Cost on account of backing down arises because current regulations in India compel discoms to take up RE supplies whenever they are available. This could involve backing down supply from contracted conventional power plants, in which case the fixed cost component of the electricity still has to be paid to the conventional power generators.

Box 4.1: Balancing intermittent supplies

The following are the major ways of handling the intermittency of supply from RE sources.

1. Optimizing solar to wind capacity ratio can moderate the variation in total supply, since wind can complement solar generation during evenings, although the costs would be a little higher.

2. Offshore wind power tends to be more consistent than onshore wind, and offshore wind capacity expansion would therefore be a more stable source of RE. However, it is three to four times costlier (IRENA, 2021).

3. Excess RE available in peak hours can be used to recharge water reservoirs, which can be used to generate power during the off-peak period. India currently has about 4.8 GW of pumped-hydro storage facilities able to operate in recharging mode, and several more are under construction/ consideration.

4. RE generation could be paired with gas-based power plants, which can generate power in off-peak periods. Natural gas power plants generate much less CO2 than coal power plants. Emissions can be further lowered by blending natural gas with biogas, or green H_2.

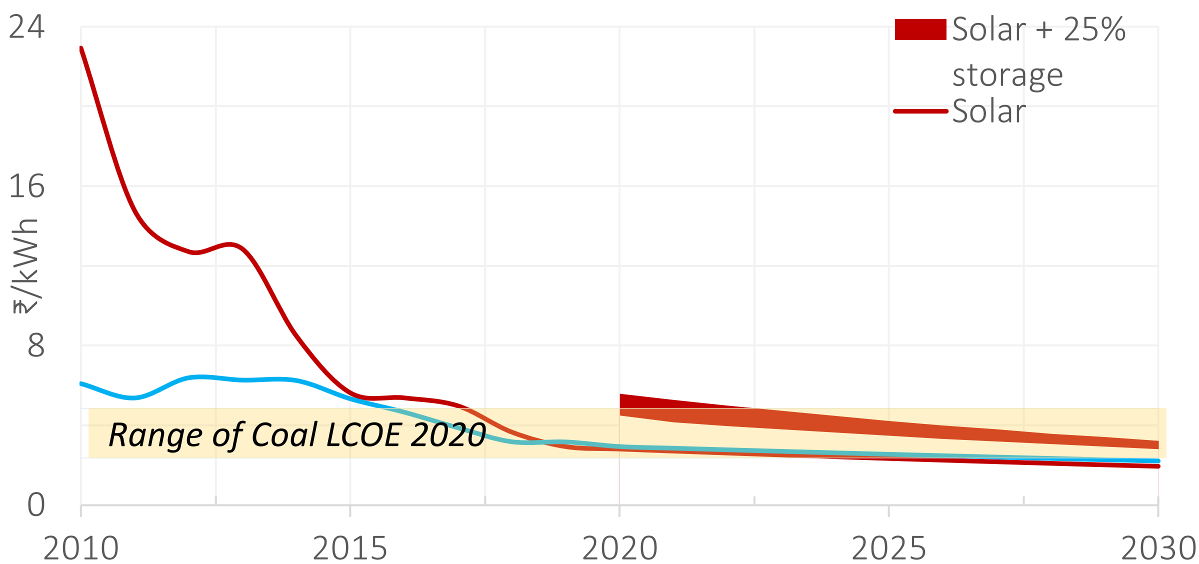
5. Batteries can store electricity during peak hours, for use during off-peak periods. Battery storage is also quick to respond to demand-side changes, but grid-scale storage has only just begun and costs are still high.

6. Inducting small modular nuclear plants (under 300 MWe) which can be ramped up and down to offset intermittency is another possible solution.

7. Intermittency can also be handled by shifting the time pattern of demand to align better with supply. Generation during solar peak hours is already being used to meet the agricultural load in many states of India where segregated feeders for agriculture users are available. Non-agriculture demand for electricity can be aligned more closely with supply availability, by more aggressive use of time-of-day pricing.

As shown in figure 4.1, if the cost of battery storage is added to even out supply, solar electricity (and also wind) is not yet competitive. Falling costs of battery storage may change the picture in future, but for the present obtaining a balanced electricity supply from RE is expensive compared to coal power plants.

Figure 4.1: Levelized cost of electricity (LCOE) from utility scale solar photo-voltaic (PV) and onshore wind power plants in India



Source: IRENA (2021), Bloomberg (2021), Cole et al. (2021), and authors' projections.

In practice, offtake of RE power has been insulated from its cost because the central government has imposed a renewable purchase obligation (RPO) on discoms and large industrial consumers with captive power generation to source a certain amount of power from RE generators. The RPO is currently set at 24.6 percent (including power from large hydro) and this is intended to increase to 43.3 percent by 2030.[4] However, the higher RPO requirement would make balancing the grid with existing methods difficult. It would require grid-scale batteries to store RE and stabilize the supply. Tongia (2022) finds that in 2030 a battery storage system would reduce curtailment of electricity from 450 GW of RE capacity during peak generation hours and would serve as a cost-effective source of power to supply during the periods of high demand, compared to peaking thermal power plants.

Financial weakness of the distribution sector is a major problem

The biggest impediment to significant expansion of electricity generation is the financial condition of the distribution sector (discoms). Most discoms in India are owned by state governments. They buy power from generators at prices regulated by independent state

[4] See order dated July 22, 2022 of the Ministry of Power (India). Available at https://powermin.gov.in/.

regulators and are monopoly sellers to consumers within the state at tariffs also regulated by the same regulators.

The tariffs charged to consumers are supposed to cover the approved costs of generation and transmission, and also provide a suitable return on capital, assuming expected levels of operational efficiency. There is no reason therefore for discoms to make losses as long as they achieve the prescribed operating efficiency levels. In fact, almost all state-owned discoms make large losses. Four separate reform programs have been implemented over the past two decades to remedy the problem, but they have had little success. Most discoms continue to make large losses and suffer from severe financial stress.

If the financial condition of discoms does not improve, we cannot expect to see large investments in generation from private investors (and lenders) because they will perceive high likelihood of default on payments due. It must be emphasized that the problem does not arise because of the need to make a transition to RE. It would arise whether the expansion is in conventional generation or in RE, although it is magnified in the case of RE because the volume of capital investment required upfront is much larger.

The financial weakness of the discoms is also impeding the expansion of rooftop solar capacity because the discoms do not allow net metering wherein a rooftop solar generator would effectively save from having to buy all the electricity needed from the grid. Rooftop generators only receive a feed-in tariff that is lower than the tariff charged for grid electricity. Discoms clearly do not want to lose demand from customers who are charged higher tariffs (industrial and commercial consumers) which helps to cross-subsidize others, but the low feed-in tariffs discourage full exploitation of rooftop solar potential. A similar problem arises in the case of captive generation of wind power by industrial consumers. As a result, although the target for solar rooftop installations by 2022 was 40 GW (as part of the 175 GW target), the actual achievement has been only 12 GW in 2021.[5]

Restoring the financial health of the discoms should clearly have the highest priority for policy. One reason why the problem arises is because the discoms are in the public sector which often limits the ability of those who manage the system to take steps to increase operational efficiency. Privatization is often recommended as the best way of solving the problem. It would certainly help, but there are also several other problems which need to be tackled.

One of these is the tendency of state governments to interfere politically to keep tariffs low. This is easily done when the discoms are state owned because the state governments can simply instruct the discoms to not ask the regulator for tariff increases by asserting that they

[5] Business Standard, India's power crisis deepens as policy issues eclipse rooftop solar, June 8, 2022.

will make large efficiency improvements. However, even if distribution is privatized one cannot rule out political intervention in the form of pressure on regulators to limit tariff increases.

The Electricity Act (2003) allows the government to force discoms to charge lower than prescribed tariffs for certain categories of consumers, such as farmers and low-income households, provided the difference is offset by an explicit subsidy from the state budget. If these subsidies were regularly paid it would not affect the financial condition of the discoms but in fact, the subsidy amounts provided in the budget are often inadequate and, in any case, not always paid on time.

Yet another problem is that state governments and their entities often default on paying electricity bills, which show up as large and rising levels of receivables in the books of the discoms (Tyagi, N., and Tongia, R., *forthcoming*). All this adds up to most discoms facing serious cash-flow problems, which in turn leads to delayed payments to their contracted suppliers. Successive governments have tried to solve the problem by a "one-time" resolution of accumulated debt of the discoms, combined with proposed reforms intended to prevent the problem recurring over time, but none of the schemes were successful.[6] There are many different estimates of the financial losses made by the discoms which vary in how they treat different components. In a recent assessment, Tongia and Tyagi (*forthcoming*) have estimated the annual gross losses, before subsidies and other support, at over ₹2.3 trillion for 2019–2020, which is about 1.2 percent of the GDP.[7]

The root cause of the problem is obviously competitive populism. State politicians find it tempting to offer a lower price of electricity in the hope of getting votes. This works because the voters do not appreciate that such immediate benefits only come at the cost of a weakened power system and poorer quality of supply. Offsetting low prices for some consumers by overcharging commercial and industrial consumers would protect the financial position of the discoms, but it is no solution since it only reduces the competitiveness of these enterprises and leads to slower growth in incomes and employment.

Since the problem originates in competitive populism, one can expect that it will improve only when voters realize the damage this causes to the quality and reliability of electricity supply and see through the innate drawbacks of competitive populism. However, this will require very extensive education of the public and a change of political culture, and that will take time.

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[6] For example, the Ujjwal DISCOM Assurance Yojana (UDAY) scheme of 2015.

[7] Tyagi and Tongia (forthcoming) define gross losses as costs minus revenues from consumers or other operations, and thus excludes subsidies paid by states, which were ₹0.90 trillion. Addition state subsidies paid and also other support like grants into revenues, the all-India losses were still ₹0.86 trillion, or 0.45 percent of GDP.

The time taken by a longer-term solution necessitates adoption of special risk-mitigation measures to encourage private investment in RE. An example of such a measure is the tripartite agreement between a state government, the union Ministry of Power (MoP), and the Reserve Bank of India (RBI). Under this agreement, RE generators, with power purchase agreements (PPA) tied up through the Solar Energy Corporation of India, if not paid in time, can receive the payment from the RBI, which debits the account it has of the respective state government.

These arrangements can be criticized on the grounds that they only shift the risk to the state government. However, there is reason to believe that the risk is also reduced because state governments entering such arrangements will act in a more responsible and investor-friendly manner. The presence of a central government agency as an intermediary between the discoms and the state government on the one side and private generators on the other is expected to discourage state governments from attempting to cancel or renegotiate PPAs signed earlier, which has happened in the past.[8,9]

Privatization of discoms also needs to be considered. State governments may find it difficult to privatize the whole distribution system, but they may find it easier to privatize parts of it. If these privatized segments produce better result—as they have in many cases—it will put competitive pressure on the rest of the publicly owned system and in due course would weaken the resistance to relying on private management.

The Electricity Amendment (2022) Bill, recently introduced in Parliament, contains three provisions that may help improve the situation. One opens up the state-owned distribution network to private access allowing private companies to apply for a distribution license with a suitable network-usage charge, and compete with the incumbent discom. This introduces the possibility of private sector competition without privatizing existing public sector discoms. Another provision empowers the National Load Dispatch Centre to cease electricity supply to discoms that fail to maintain adequate payment security in favor of their contracted power generators. Lastly, the bill forces the regulator to revise tariffs regularly, and fix the maximum and minimum tariffs. The success of this initiative will depend upon the final version of the Bill as passed by the Parliament and, even more importantly, on its implementation in practice. It is clearly too early to pronounce.

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[8] Governments of Andhra Pradesh, Uttar Pradesh, Rajasthan, Gujarat, Punjab, and Madhya Pradesh have cancelled contracts or re-opened bids in anticipation of securing lower power tariffs from RE producers (Financial Express, Don't renege on PPAs; Room for renegotiation may be created, but with penalties, Nov 9, 2021).

[9] In March 2022, the High Court of Andhra Pradesh ruled that executed power contracts cannot be unilaterally renegotiated and ordered the discom to clear the dues it owes to the concerned RE generators (Economic Times, Andhra Pradesh high court's order reinforcing PPA sanctity, positive for renewable firms, Mar 16, 2022).

Creation of a transmission infrastructure

Although the major burden of setting up RE generation capacity will fall on the private sector, the government/public sector will also have to play a major role in creation of transmission infrastructure. Since RE generation capacity will be concentrated in the southern and the western parts of India, surplus electricity generated from these areas will need to be transported to the rest of the country. This calls for an ambitious effort to strengthen the transmission grid keeping in mind the temporal and spatial aspects of RE generation.

Building transmission infrastructure in India could also, in principle, be entrusted to the private sector, but it often runs into problems of land acquisition and environmental clearances, which the public sector is better equipped to handle. An appropriate strategy would therefore be for the Power Grid Corporation—a central government undertaking—to take on this task. As the new transmission lines become operational and start earning revenues, they could be privatized to raise capital for further investments.

Transmission and distribution companies can also take up the task of building some electricity storage capacity near generation sites. Such investment will avoid the need to install transmission and transformation capacity to deal with peak generation periods, which would be under-utilized during non-peak generation times.

Reforming the electricity market for RE

Increased intermittency and decentralized electricity generation from a steadily rising share of RE will call for more sophisticated electricity markets and contracts. Increased intermittency means discoms would have to rely more on short-term markets to buy additional power to deal with situations where supply falls, and also to sell excess power in case of oversupply.

Electricity exchanges in India[10] do allow short-term contracts covering the real-time market (power delivery in an hour), day-ahead market (delivery on the next day), and the term-ahead market (delivery in 3 hours to 11 days) but much more market-based innovation will be needed. In 2020, the exchanges launched a green term-ahead market to enable bulk electricity buyers (discoms and consumers above 1 MW) to procure RE on a short-term basis from sellers (including discoms with surplus RE), who earlier could only trade through long-term PPAs. This is expected to reduce curtailment rates in RE-rich states by facilitating the sale of surplus RE to RE-deficient states or other large consumers. As potential producers of green H_2 look to secure RE supply to operate electrolyzers, large RE producers may want to sign long-term contracts with financially viable entities. Expanding the market to include conventional generators will allow creation of competitive wholesale electricity markets and better price discovery.

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[10] India Energy Exchange Ltd., Power Exchange India Ltd., and newly launched Hindustan Power Exchange Ltd.

Case for carbon taxation

The introduction of carbon taxation will internalize the social costs of CO_2 emissions from burning coal and raise the price of coal-based electricity. This will create a market-based incentive for discoms to shift to RE, making the present system of RE purchase obligations imposed on discoms unnecessary. The top-down system of purchase obligations has worked thus far—though there have been reports of non-compliance[11]—because the RE volumes involved have been fairly low. But once RE sources dominate the electricity mix, the idea of directing the electricity purchasers to source a fixed share of RE could run into problems. States are likely to complain of unfair treatment if they have to pay for transmission charges to source RE from other states.

This problem would not arise if all the discoms and large consumers procure power from a common market in which the price of conventional power includes carbon taxes whose imposition is constitutionally entirely within the purview of the center. The revenues from the tax can be distributed among the center and the states to reduce resistance from the states.

Carbon taxation can not only help to accelerate a market-based transition to RE, it can also generate much needed revenues to help finance other elements of the climate management plan including providing support to those adversely affected. Since collections from fossil fuels taxation, which contribute disproportionately to the central and state government revenues, will decline as the fuels are phased out, it is important for the government to plan for this decline and restructure the tax system by offsetting tax resources from other parts of the expanding economy (Bhandari and Dwivedi, 2022)

The case for economy-wide carbon taxation in India will be greatly strengthened if other countries introduce such taxes and then levy border adjustment taxes on imports of goods from countries that do not have such a system. The EU has announced it will impose such taxes on imports of certain carbon intensive goods from 2026. If this happens, it makes sense for us to introduce a suitable system of carbon taxation that would exempt our exports from imposition of such duties.[12] The Parliament of India has recently passed an act[13] to implement a domestic

[11] Economic Times, Delhi's power discoms penalised by DERC for defaulting on green power obligations, Oct 6, 2019.

[12] Keen, Parry, and Roaf (2021) estimate that a tax of $50 per tonne-CO2 in 2030 would increase the unit costs of iron and steel, in India by 25–30 percent, in China by 12–15 percent, and in the EU and United State by under 10 percent. A progressive tax which is lower for low-income countries as proposed by Parry, Black, and Roaf (2021) would be much less damaging to our competitiveness.

[13] The Energy Conservation (Amendment) Act, 2022;
https://egazette.nic.in/WriteReadData/2022/241246.pdf

carbon market[14] for restricting carbon emissions from large industries in the country. The relative merits of a cap-and-trade system versus a carbon tax need to be carefully examined.

An IMF Staff Paper (Parry, Black, and Roaf, 2021) has proposed imposition of a graded tax on CO_2 ranging from $25/tonne-$CO_2$ for India, $50 for China, and $75 for the United State and the EU. If India were to levy a tax at the level recommended by the IMF paper on all fossil fuels, the price of petrol and diesel paid by the consumers need not be affected since these fuels are already highly taxed and the proposed tax could simply be subsumed within the existing taxes. However, the price of coal would increase substantially since the cess on coal at present is only ₹400/tonne[15], which amounts to $3.5/tonne-$CO_2$. This would significantly raise the cost of coal-based electricity and promote the shift to RE.

Phasing out coal-based power

Phasing out coal-based power is high on the international agenda for decarbonization. India's net zero commitment implies that coal-based power will be phased out over the coming decades, but India has not made any specific commitment on this issue. This is understandable since coal accounts for 70 percent of power generation at present (CEA, 2022) and a large proportion of our conventional power generation capacity is relatively new, with a long remaining life (GEM, 2022).[16]

Nevertheless, a strong case can be made for planning a phase out of old and inefficient coal-based power plants. Ganesan and Narayanaswamy (2021) suggest that about 50 GW of coal capacity in India can be considered for early retirement provided supportive finance is available. The MoP has recently announced phasing down of 81 units of coal power plants to 40–55 percent of their capacity, to replace 58 billion units of thermal electricity with approximately 30 GW of solar power by 2025–2026.[17]

Since the benefits of early retirement of coal-based power accrue both to the country and the global community, there is a case for incentivizing the process by provision of international concessional financing. South Africa has committed to an accelerated coal phase out, based on

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[14]Carbon markets refer to cap-and-trade systems which put a limit to the amount of CO2 that can be emitted by an entity. Those who can reduce carbon emission below the mandated level get "carbon credits" which they sell to those exceeding the cap, effectively subsidising the expenditure incurred on reducing emissions to earn carbon credits. The relative size of the cap on emissions imposed on different industries is a critical determinant of the net tax and subsidy effect.

[15] Times Now, Clean energy cess-tax on coal, Nov 19, 2020.

[16] The RE-capacity target of 450 GW by 2030 will reduce this share to 55 percent, but since the total electricity generation is expected to increase from 1.5 trillion units to 2.5 trillion units, the absolute amount of coal-based electricity in 2030 will be 30 percent higher than current levels (CEA, 2022).

[17] See letter dated May 26, 2022 of the Ministry of Power (India). Available at https://powermin.gov.in/sites/default/files/Trajectory_for_replacement_of_Thermal_Energy_with_about_58000MU_30%2C000MW_of_RE_by_2025_26.pdf

an international program providing $8.5 billion in assistance in the first phase.[18] However, South Africa's coal plants are much older, with much less remaining life. A similar effort in India would entail much larger economic loss and require a correspondingly larger volume of concessional financing to justify.

Apart from phasing out old plants, there is a strong case for announcing that no new coal-based plants will be built except those which are already under construction. Since coal plants have a life of around 40 years, any plant that starts operation in 2030 will not reach the end of its life until 2070. There is hence little point in investing in coal-based plants, especially if cleaner power is expected to be feasible well before then. The governments of Gujarat, Maharashtra, Karnataka, and Chhattisgarh have announced that they will not fund any new coal power plant in their respective states. The central government could also consider announcing the same.

Phasing out coal-based power involves some potentially disruptive structural changes. The coal sector directly employs nearly 1.2 million people (CIF, 2021) and, although initially phasing out coal-based power will lead only to a decline in coal imports, this will be followed in due course by a decline in domestic coal mining, with a loss of employment and incomes in these states. There will be an offsetting expansion in employment and income generation from the expansion of businesses associated with RE, but this expansion will take place in RE-producing states and not in coal-mining states. Coal-mining states will lose royalty from coal production,[19] and since these states happen to be relatively poor, this will call for some compensatory action, probably through additional central government transfers.

Fortunately, we have time since this transition will stretch over the next two to three decades. However, work should begin now on spelling out a plan for safeguarding livelihoods of the vulnerable population through reskilling and generating new employment. As part of the transition, Coal India Limited (CIL) is reported to be considering diversifying into mining other minerals and expanding in the RE sector. It could similarly also look into green H2 production. CIL needs to plan forty years ahead and consider how it will reinvent itself.

Building a production base for RE

The transition to net zero implies that total RE capacity will have to reach around 7400–8400 GW by 2070 (Chaturvedi and Malyan, 2022). This will create large demand for solar PV modules, wind turbines,[20] and batteries. It is logical to try to capitalize on this opportunity and build an

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[18] The Just Transition Partnership announced at COP26 comprises South Africa, France, Germany, the UK, the U.S., and the EU.

[19] See for further reference Bhandari and Dwivedi (2022).

[20] India has a good domestic manufacturing base for wind turbines with many large international manufacturers having production bases in the country.

efficient domestic industrial base to cater to this demand and hopefully also exploit the global market, since other countries will be going through the same transition.

The central government has announced a production-linked incentive (PLI)[21] scheme for establishing domestic manufacturing capacity in the solar-PV area—covering polysilicon wafers, solar cells, and modules. The scheme includes increased import duties on the import of solar cells and modules. Current plans imply increasing the annual manufacturing capacity of solar cells from 4 GW to 18 GW by 2023–2024, and of PV modules from 18 GW to 36 GW over the same period.[22] By way of comparison, solar cell manufacturing capacity in China in 2021 was 350 GW (85 percent of global capacity) and PV module capacity was 345[23] GW (75 percent of global capacity) (Bloomberg, 2021; IEA, 2022).

The government has recently concluded the bidding process for the allotment of $2.4 billion in PLIs to four companies[24] over five years to set up combined 50 gigawatt-hours of battery manufacturing capacity in India. The scheme requires 25 percent localization of the battery manufacturing process, including the cell and other components, within the first two years of commissioning, rising to 60 percent within five years. Similar incentives are being planned to establish manufacturing capacity for H_2 electrolyzers and fuel cells in India.

While it is logical to try and build domestic manufacturing capacity to meet our needs, it is important to avoid repeating the mistakes of the import-substitution approach of the 1970s, when domestic production was favored irrespective of costs or quality. A case can be made for modest import duties, but these should ideally be phased down over a period. High import duties to protect domestic production of equipment that goes into renewable power generation will raise the costs for users, hurting the country's global competitiveness. This is already being felt in the solar sector, where higher import duties on panels and modules have raised the cost of generation from new solar capacity. Particular attention should be paid to avoiding a situation where producers first claim the benefit of a capital subsidy under the PLI scheme and then start lobbying for higher duty protection.

The government has indicated that our ambition should be to make India a global manufacturing hub for these new products, and has encouraged partnerships with leading international companies. The trade policy required for this objective has to be carefully

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[21] The Government of India introduced PLI schemes in 2020 to promote and scale up the domestic industrial base in the country. The schemes aim at creating large manufacturing capacity for 14 identified sectors (including automotive components, electronics, pharmaceuticals, textile, steel, etc.), increase the share of exports and generate employment. It takes the form of a subsidy on additional production compared to a defined baseline.

[22] PV Magazine India, India's PV module production capacity could hit 36GW by 2023, March 15, 2022.

[23] S&P Global, India's solar power prospects compromised by steep import duty, commodity hikes, April 01, 2022

[24] Rajesh Exports, Hyundai Global Motors, Ola Electric Mobility, and Reliance New Energy Solar.

designed, recognizing the importance of openness to innovation via access to imported inputs at low duty rates. Domestic R&D efforts by the industry should also be encouraged.

Land requirement for RE expansion

Solar capacity on the scale needed will require large tracts of land. According to van de Ven et al. (2021) if half of the total electricity needed in 2050 has to be through solar power, it would require 23,800 sq. km of land, which is approximately 0.8 percent of India's territory, or roughly half the area of Punjab.[25] It will not be possible for private developers to acquire land on this scale through their own efforts. State governments would need to be proactive, perhaps acquiring the land with appropriate compensation or payment of leasing charges to landowners, and passing it on to private solar power developers on a fixed/long-term lease basis. The way this is done needs to be determined transparently to avoid the usual accusations of cronyism and favoritism.

There is a large fleet of very low-capacity, old wind turbines in southern India, nearing their end of life (Boopathi et al., 2021). These may be considered for accelerated replacement, with taller and more powerful turbines with adequate upgradation of evacuation lines and ecological considerations.[26] A policy framework for repowering old wind farms, including measures for disposal of old turbine blades, could make the replacement process easier. Development of offshore wind, although costlier than onshore wind, should also be accelerated which would ease some pressure off land, given India’s long coastline and good offshore wind potential.

Diversion of land for RE capacity will raise fears about the impact on agricultural production and food security. These should not be exaggerated because initially, wasteland or land with very low agricultural productivity would be diverted. More importantly, land productivity in India is much less than other East Asian countries[27] and improved land productivity is the way to counter the adverse impact on agriculture and food production. This calls for changes in agricultural practices, including better water management, crop diversification, improved seeds and other modern agricultural techniques. As part of this transformation, we must also actively pursue reduction in methane emissions from this sector. A comprehensive analysis of these issues is beyond the scope of this chapter, but it illustrates the extent to which management of climate change requires a “whole-of-the-economy” approach, with close collaboration with state governments.

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[25] This area excludes rooftop PV installations, which would amount to 5.7 percent of total solar generation. The estimate assumes that solar modules will have 24 percent conversion efficiency. In land area per unit electricity generated terms this means 7.5 km^2 per billion units.

[26] Sometimes it may not be possible to increase the hub height of wind turbines if it affects the movement of migrating birds.

[27] Indian Express, Market incentives, direct income support for farmers are far more effective in increasing agricultural productivity, Oct 31, 2019.

Decarbonizing industries

The industries and manufacturing sector accounts for nearly a third of India's CO_2 emissions, and about half of this comes from steelmaking, oil refining and solid-fuel transformation,[28] and cement production. The rest is emitted from mining and quarrying, brick manufacturing, pulp and paper, fertilizers, textiles and petrochemicals, and other non-specific industries.[29]

Where industries use fossil fuels to generate heat, it is technically possible to switch to electricity using electric arc furnaces albeit at higher cost. However, industries such as steel, fertilizers, petrochemicals, and cement production also use fossil fuels and other materials as feedstock in chemical processes. These are the "hard-to-abate" areas, where electrification cannot help. However, green H_2, (i.e., H_2 produced through electrolysis using RE) may be a solution in some areas.

Green H_2 can be used as a substitute for coking coal for iron-ore reduction in steelmaking. In fertilizer production, it can replace natural gas to make ammonia. Oil refineries need H_2 to de-sulfurize petrol and diesel. This is done at present with gray H2 from natural gas, which emits CO_2. Switching to green H_2 would eliminate these emissions. The only problem at present is that the cost of producing green H_2 is very high.

India's H_2 demand is expected to double over the next 10 years, and the government has targeted production of 5 million tonnes (mt) green H_2 by 2030. This is half the level targeted by the EU.[30] Large industrial consumers of H_2 are being pushed statutorily to use green H_2 for part of their needs. For example, fertilizer producers and oil refiners are required to meet 5 percent and 10 percent of their respective H_2 demands from green H_2 from 2023 onward, to be raised to 20 percent and 25 percent, respectively, by 2028. This forces the users to bear the higher cost of green hydrogen while giving them an incentive to try and reduce costs. The same effect would be achieved if carbon taxes were introduced making fossil fuels more expensive. The government clearly feels that while imposition of taxes may be resented, enforcement of compulsory obligations is less so, although they have the same effect on costs. This is obviously an area where inter-ministerial coordination is essential. Purchase obligations can be enforced by the MoP itself whereas carbon taxation falls under the ambit of Ministry of Finance.

Several public and private corporations in India, e.g., Indian Oil, Gas Authority of India Ltd., Adani Group, Greenko, L&T, etc., have announced large investments toward developing green H_2 production capacity. Although these are at present only public announcements, they reflect the

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[28] For instance, converting coal to coke.

[29] Based on estimates by climatetrace.org

[30] REPower EU plan of the European Commission (May 2022). Available at https://ec.europa.eu/

fact that corporations are thinking actively of the part they can play in the green transition. The cost of producing green H_2 is around $5–6/kg at present and is projected to fall to less than half of that level by 2030. To support this, inter-state electricity transmission charges for green H_2 producers have been waived. However, more basic advances in technology and economies of scale will be needed to reduce costs. Reliance Industries, which is expanding into renewables and green H_2 areas, has announced an ambitious target of bringing down the cost of green H_2 production to $1/kg by 2030.

Cement manufacturing relies on coal for heat and on the use of limestone as raw material, both releasing CO_2 in the process. India is the second-largest producer and consumer of cement in the world and although some Indian cement manufacturing units are among the most CO_2-efficient in the world, they contribute significantly to the total CO_2 emissions of the country. According to IPCC (2022b), CCUS, through the reverse-calcination process, could be a feasible solution to decarbonize this industry as the costs become favorable. Dalmia Cements of India has committed to becoming carbon negative by 2040 by utilizing CCUS, and similarly, ACC (Cements) Ltd. has announced that it will reduce the CO_2 intensity of its cement operations by 21.3 percent by 2030 over 2018 levels.

Decarbonizing transport

The transport sector includes railways, road transport, aviation, and inland shipping. The sector depends heavily on fossil fuels (petrol, diesel, aviation turbine fuel, bunker fuel, and natural gas) and accounts for about 13 percent of India's CO_2 emissions.[31] It is now technologically possible to avoid emissions by electrifying most of these areas, but not yet all.

Railway electrification

Indian Railways (IR), currently the fourth-largest rail network in the world, relies on both electric and diesel traction. It has long been engaged in electrifying its tracks and the entire broad-gauge network is expected to be electrified by the end of 2023.

Full electrification of the network does not mean electrification of all traction because IR has a large fleet of diesel locomotives with a substantial remaining life. Over a third of its trains (both passenger and freight) are currently hauled by diesel locomotives.[32] The IR should put in place a plan for an accelerated shift to full electric traction over this decade based on reasonable assumptions.

Much will depend on how quickly diesel locomotives can be phased out. It is possible to convert diesel locomotives to run on overhead electric power, and this is being attempted at IR's Diesel Locomotive Works unit in Uttar Pradesh. GE Transportation, a U.S. company, currently has a factory in Bihar manufacturing high-powered diesel locomotives for freight hauling. The unit was set up in partnership with IR, based on assured purchase of locomotives up to 2028. The IR should explore the possibility of persuading GE to convert this facility into an electric locomotive facility, with an extended offer to purchase electric locomotives.

Reversing the long-standing trend of shifting of general freight cargo movement from railways to roads is a low hanging fruit to save emissions. This would be the case even if IR remained dependent on fossil fuels because railways are more energy efficient than road transport on a per metric ton-km basis. In fact, the reduction in emissions will be much larger because IR will become fully electric long before road-freight transport graduates from using internal combustion engines (ICEs). Completion of the dedicated freight corridors currently under construction and their further expansion will allow faster transport of goods between the major manufacturing centers, cities, and seaports.

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[31] International shipping by convention is not part of country's CO_2 emissions inventory.

[32] Economic Times, 37 percent of trains in India being hauled by diesel locomotives, rest by electric engines, Dec 10, 2021.

A policy issue in this context is whether IR should try to deal directly with consumers on an exclusive basis or rely on customer-facing logistics companies to mobilize road transporters to provide door-to-door services, while using rail movement over longer distances. Seamless multi-modal traffic movement, together with real-time tracking of cargo, can help in bringing about the shift. However, for this to be fully exploited, the terms on which railway freight movement capacity can be booked by logistics companies need to be carefully worked out. Standardizing handling and storage structures across road and rail freight, for example, would help in faster loading/unloading. Gaining share in general freight cargo is particularly important since coal traffic, which is a major source of revenue for the railways at present, will gradually decline as coal power plants are phased down.

Electrification of the railway network also opens the possibility of an assured offtake of RE by IR, through contract arrangement with private-sector generators. This could also involve installing solar PV panels on the large tracts of land owned by IR and also on the roofs of its building assets (e.g., stations).

The IR has announced a target of becoming net zero by 2030. This would have a very large contribution to mitigation and achieving this target would bolster confidence in what is otherwise a challenging journey. Credibility of the target would be greatly increased by announcing progress on the issues listed above in granular detail.

Electrifying road transport

Electric vehicles (EVs) are gaining popularity in advanced countries and are making an entry in India also. Different models of two-, three-, and four-wheeler EVs are being introduced by domestic and international manufacturers in passenger and light commercial vehicles (LCV) segments. Electric buses are also being produced and inducted into some municipal public-transport fleets (e.g., Delhi, Mumbai, Chennai, Bengaluru, Indore, etc.). However, it is early days yet, and EVs at present account for only about5 percent of the total automobile sales in the country by number, dominated by two- and three-wheelers (MORTH, 2023). This is comparable to Indonesia or Brazil, but much lower than the 15 percent achieved in China.

The pace at which road transport is electrified will depend largely on the private sector, but it cannot be achieved by leaving everything to market forces. There is a need for active government intervention at different levels. The main areas for action, and the status on these in India, are listed below.

Price signals

Prices are clearly important in determining consumer choice and from that perspective the high petrol and diesel prices in India—reflecting traditionally high taxes on petroleum products—create the right price incentive to encourage a shift to EVs. However, the capital cost of an EV is much higher than that of an ICE vehicle, so additional measures may be needed if consumers are expected to switch on a large scale.

Government purchase of vehicles

It is essential to promote the idea that EVs reflect a more sustainable mode of personal transport. The central and state governments could send a strong signal by announcing that all future purchases of vehicles by the government and the public sector will be of EVs. The government of Andhra Pradesh has taken a step in this direction and is procuring 25,000 electric two-wheelers for its employees. Similarly, the city corporation of Navi Mumbai has also announced procurement of EVs for its officials.[33] Inevitably, the pace at which this can be done will be constrained by state- and city-level public finances.

Promoting EVs for taxis

Once EVs are in sufficient supply, taxi licenses could be restricted to EVs only from a specified date in the future. To incentivize the switch, the fee for such licenses could be substantially lowered. This is something that would have to be done at the sub-national level, after consulting with relevant stakeholders. Special programs for extending credit to taxi operators to pay for the costlier vehicles would help and this is something that can only be done by the central government.

Establishing an EV-charging network

The pace of expansion of EVs will depend critically upon the establishment of an EV-charging infrastructure to ameliorate "range anxiety." Mandating standard chargers across EV-models[34] has helped to scale up the charging network to over 5,000 public charging stations across India by the end of 2022.[35] However, this is a bare start and needs to expand much more. Private-sector players are leading in this area, with major expansion plans.[36] Public-sector oil marketing companies that run fuel stations can foray into this space by setting up such charging points within their premises. The discoms could also fit plug-in paid chargers on lamp posts in cities, as is being done in many cities in advanced countries. This should be a top priority for the large cities. As the fleet of EVs expand, the demand for electricity on this count will increase sharply

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[33] The central government, with its undertaking, Energy Efficiency Services Ltd. (EESL) had floated a tender for 10,000 EVs in 2017, for use by its officials. Owing to poor performance and therefore low acceptance, only 2,000 vehicles were acquired (Mercon India, EESL Scraps its Tender for 10,000 EVs Due to Non-Availability of Chargers, Jul 13, 2018).

[34] See letter dated Jan 14, 2022 of the Ministry of Power (India). Available at https://powermin.gov.in/

[35] Livemint, Tata Power to set up 25000 EV charging points across India, Dec 7, 2022.

[36] Tata Power, for example, announced in January 2023 to set up 25,000 EV charging points across the country over the next 5 years. (Livemint, January 6, 2023).

and there is a case for calibrating electricity tariffs for EVs to reflect intraday variations in RE supply.

Battery swapping

Battery swapping is an alternative to developing charging infrastructure. In fact, reliance upon a “battery-as-a-service” model can reduce the upfront cost of EV ownership. NITI Aayog has put out a draft National Battery Swapping Policy aimed at creating a battery-swapping framework.[37] The draft has proposed extending the existing fiscal incentives on regular EVs to EVs with swappable-batteries. China has established 1,400 operational swapping stations as of March 2022, with a target of 24,000 by 2025. Battery-swapping stations need much less urban land compared to charging stations, which require temporary parking space. They also allow flexibility in charging times so that maximum electricity demand can be synchronized with peak solar hours.

Restructuring manufacturing capacity in the automotive sector

India has a large automotive manufacturing base, and it is necessary to consider to how to accelerate the transition to EVs. While the two-wheeler segment, which is dominated by Indian players, has already made some progress, the four-wheeler and LCV segment is yet to pick up.

A simple early step, to incentivize the sector to accelerate the production of EVs, would be to give a clear policy signal by announcing a date after which sale of ICE vehicles would not be allowed. For the economy to become net zero by 2070, it is reasonable to plan for all passenger transport to become emissions free by 2050. EV sales obviously have to increase to 100 percent, but that must be reached well before the target date for the entire fleet to be EV because even after EVs account for all the sales, there will be many ICE vehicles in the operational fleet of cars for many years. These will be phased out only over a period of say 15 years. This implies that if we want the entire fleet to consist of EVs by 2050, we should perhaps announce 2035 as the terminal year for sale of ICE vehicles. This step can only be taken by the central government, and it should be done after full consultation with all stakeholders to give sufficient notice to manufacturers to plan for the switch.

Restructuring the automobile industry to produce EVs will have implications upstream for the components sector because EVs have far fewer components than ICE vehicles. Since auto component production is dominated by SMEs, they will need to be assisted to restructure themselves to produce the new types of parts, including components for batteries. The SMEs could also shift to recycling end-of-life batteries, due to the labor-intensive nature of the work.

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[37] See draft policy for comments, dated April 20, 2022, prepared by the NITI Aayog (India). Available at https://www.niti.gov.in/

Finally, statutory regulation for this sector needs special attention. EVs need to be safe and there have been cases of batteries of EV two wheelers catching fire spontaneously.[38] We need to establish standards for battery design suited to Indian conditions and for charging and recycling, and also enforcing these standards effectively. This will only be possible with close coordination between industry and the government.

Promoting public transport

Shifting from personal to public transport will make an important contribution to reducing emissions. This would be true even if public transport continued to rely on fossil fuels because it is much more fuel-efficient than personal transport on a per person-km basis. However, the potential reduction in emissions is much greater since public transport can be electrified relatively quickly through supportive government actions.

Metro trains for mass rapid transit are an important means of electrifying urban transport and such metros are currently operating across 13 metropolitan regions in India with ambitious plans to expand the metro rail network within each city and also to cover more cities in future.[39] Expanding the fleet of electric buses is another way of electrifying city transport and several cities have taken steps to order electric buses. Convergence Energy Services Limited (a subsidiary of EESL) is facilitating the procurement, operation, and maintenance of these buses.

A large-scale shift toward public transport requires much more than deploying electric buses and introducing urban metro trains. It calls for action on several fronts to bring about a "system change." Some of the multiple areas where action is needed are summarized in Box 4.2. The state governments and local authorities have to play a major role in this transition.

[38] There have been several reports of two brands of electric two-wheelers catching fire, because of a malfunction in their batteries, perhaps due to overheating in Indian ambient temperatures. This has led to the manufacturers recalling the models. The incidents are being investigated.
[39] Metro Rail Projects in India: Quick Snapshot (n.d.) – metrorailguy.com

Box 4.2: Promoting public transport

The following are some of the measures that can be taken to promote public transport.

1. Behavior change campaigns will be needed to break the perception of personal and social status associated with private car ownership.

2. A good way of encouraging public transport is to take steps to discourage private transport. High parking charges within city areas is a good strategy, as is the introduction of congestion charges. Both can be reduced for EVs to encourage electrification.

3. Disincentives must be accompanied by steps to improve the quality of the public transport experience. This is particularly important if the objective is to encourage individuals normally relying on private transport to use public transport instead.

4. Public transport should be accessible to senior citizens and differently abled people. Women and child commuters also need assurances of greater safety in the last mile from public transport stops to home.

5. Dedicated lanes speed up the movement of buses and can reduce travel times, compared to private cars. This has been successfully introduced in some cities in India (e.g., Ahmedabad, Indore, etc.), but was strongly opposed in some others (e.g., Delhi), where the effort was abandoned.[40]

6. While the quality of public transport must be upgraded, fares should be kept low. Revenues from passenger fares can be supplemented by non-fare revenues from advertising and real estate. Revenues from parking charges and congestion charges mentioned above, can be earmarked to provide cities with a source of revenue to cross-subsidize public transport. Special access on properties along the transport routes can also be considered.

[40] Bloomberg, Why Did Bus Rapid Transit Go Bust in Delhi?, Dec 20, 2016.

Hard to abate areas in transportation

As in industry, electrification is not feasible in several transport applications including heavy freight movement by road, ships, and aircraft. Green H_2 may provide a solution for some of these areas, since it has a much higher energy density by weight, and vehicles running on H_2 can be refueled relatively quickly. Reconversion of green H_2 back into electricity via fuel cells is very energy inefficient because nearly two-thirds of the energy used in producing H_2 is lost in the process with current technology (Sepulveda et al., 2021). Nevertheless, since Li-ion batteries tend to be very heavy, H_2 fuel cell systems may prove to be a viable fossil fuel-free alternative for long-distance freight transport applications because H_2 has a high gravimetric energy density compared to other fuels. H_2 can also be liquefied in the form of ammonia, which, due to its high combustibility and physical stability, is considered a potential alternative to liquified natural gas as an emissions-free fuel for ships. In aviation, synthetic fuels and biofuels are a viable option, but is expensive at the moment.

This is an area of ongoing research and it could take many years for a commercially viable solution to emerge. This is not a high priority area for India in the initial stages, because advanced countries will be investing heavily in these areas. However, we need to keep a close watch on technological developments to experiment and develop some indigenous capacity for a faster roll-out later.

Emissions from expanded urbanization

India has been slow to urbanize, but this is changing and the urban population is projected to increase from about 390 million (or about 31 percent of the population) in 2011, to over 607 million (40 percent of the total) by 2030, and 877 million (53 percent of the total) by 2050 (U.N. Population Division, 2019). An urban growth on this scale, accompanied by an increase in per capita incomes, will lead to an expansion in demand for urban infrastructure and housing, requiring steel and cement in large quantities, and domestic appliances for lighting, refrigeration, and cooling/air conditioning. The latter will raise electricity demand and, since electricity will not become free of fossil fuels for some time, it will generate higher emissions.

The tendency for urban emissions to increase will have to be countered by a sustained push toward higher energy efficiency to promote a less emissions intensive lifestyle.

Energy efficiency of appliances

There is scope for shifting to energy-efficient appliances to reduce energy demand and emissions. The case for energy efficiency remains strong even when all the energy is from renewable sources because greater energy efficiency would keep demand moderated with respect to supply of RE and help keep the costs low.

Energy-efficient lighting

India has made commendable progress in switching from incandescent light bulbs to energy efficient LED bulbs. A government program (UJALA) helped in bringing down the retail price of LED bulbs by 80 percent, from ₹300-350 to ₹70-80 (from $5 to $1) per bulb. Over 370 million LED bulbs have been distributed since 2015, effectively saving 48 billion units of electricity per annum and avoiding 386 mt of CO_2 emissions from electricity generation.[41] Almost all households in India have electric lights, and about two-thirds of them are LED bulbs (Agrawal et al., 2020). This proportion must increase further.

Energy-efficient fans

The UJALA scheme, which was very successful with LED bulbs, has proved disappointing in promoting energy-efficient fans. There are energy efficient ceiling fans in the market which consume about half the electricity used by conventional ceiling fans, but although 90 percent of the households have fans, only 3 percent have energy-efficient ones (Agrawal et al., 2020). This is partly because of lack of knowledge of the implications of energy efficiency, but also because energy efficient fans cost twice as much as conventional ceiling fans, and subsidized electricity

[41] See press release of the Ministry of Power (India) dated Jan 5, 2022. Available at https://www.pib.gov.in/

prices greatly reduce the incentive for households to switch. This illustrates the merit of abolishing the underpricing of electricity through subsidies and substituting it with direct cash transfer to targeted households.

Other appliances

The degree of penetration of other commonly used appliances are: Televisions (72 percent of households), refrigerators (35 percent), washing machines (8 percent), air conditioners (3 percent), and water heaters (3 percent). Interestingly, the penetration of energy efficient models in these appliances is much higher than for ceiling fans: Air conditioners (38 percent of total), refrigerators (34 percent), water heaters (28 percent), and washing machines (23 percent) (Agrawal et al., 2020). An important reason is that these appliances are used by higher-income households, which pay higher tariffs for electricity.

An effective way of pushing for higher levels of energy efficiency is to enforce statutory minimum standards which all products must meet and raise these over time as technology evolves. This would be particularly useful in the case of fans and air conditioners, which consume a great deal of electricity and their use is expected to rise. This can only be done by the central government. The central and the state governments should also mandate high-efficiency appliances for use in government-owned buildings (e.g., offices, schools, and hospitals).

Energy efficient building designs

Energy usage in buildings can be significantly reduced through better building design and use of energy efficient construction materials. The scale of urbanization projected over the next three decades in India, implies that about 70 percent of the buildings are yet to be built. This provides a unique opportunity to leapfrog by adopting building designs which achieve high levels of energy efficiency.

Regulatory mechanisms could enforce LEED/GRIHA/IGBC-codes standards for building design and construction, limit the use of glass facades for commercial building designs, and also promote rainwater harvesting, rooftop solar panels, and construction materials suited to the Indian climate. The regulatory power in this area lies with state governments, but the central government[42] can take the lead in encouraging states to act, and by establishing high standards for its buildings and those of public sector undertakings. The Energy Conservation (Amendment) Act, 2022 passed by the Parliament seeks to expand the coverage of energy

[42] The central government, for example, launched in 2019 the Global Housing Technology Challenge under its flagship urban housing scheme (PM Awas Yojana - Urban) to promote the use of more efficient and sustainable building technologies.

saving standards, which currently apply to commercial buildings, to include large residential buildings.

The corporate sector can also make a major contribution by ensuring that all their new buildings embody the best possible standards. Existing corporate buildings can also be upgraded to meet new standards. Industry associations should play a useful role in pushing for such upgrades.

Emissions from cooking

Cooking fuels in rural Indian households are dominated by biomass, charcoal, and kerosene, with liquefied petroleum gas (LPG) cylinders making a beginning. Although, burning biomass does not add to the problem of CO_2 emissions directly, it has severe health consequences for women and children, and in some cases also encourages forest degradation. The central government, under the Ujjwala scheme, has attempted to provide LPG connections to all households in rural and urban regions, but has had limited success in rural areas, owing to the high cost of LPG cylinder refills and poor access.

Most urban households typically use LPG cylinders or piped natural gas supply, where available, for cooking. It is also possible to rely on electricity for household cooking, using electric stoves—and these are used in a few households at present—but the extent of coverage will depend on whether electricity is more cost-effective than gas, for cooking.

It is also technically possible to blend green H_2 in small amounts with natural gas to reduce the emissions intensity of the fuel. Gas Authority of India Ltd. (through its subsidiary) is conducting a pilot project of supplying H_2-blended natural gas into a part of the domestic gas distribution network in a city in Madhya Pradesh. It has achieved a blend of 2 percent by volume and plans to increase the ratio further. Supplying H_2 in significantly higher ratios would require upgrading the pipelines.

Managing intra-city transportation

The expansion expected in urbanization also provides an opportunity to integrate transport planning with urban development. Spatial planning has been ignored in Indian urbanization, but it can help to maximize walkability and promote a shift from transportation in private vehicles, to public transport. This is easier to do when a greenfield city is being planned but it is also relevant for redevelopment and expansion of existing cities that is bound to take place. The IPCC (2022b) estimates that globally, demand-side measures of infrastructure use—based on compact cities, rational spatial planning, and high public transport usage—can potentially mitigate 30 percent CO_2 emissions by 2050! Developing a 10-year action plan for the 20 biggest metros in the country would be a good first step in elaborating a strategy for decarbonization.

Managing urban waste

The rising amount of solid waste and sewerage generated in cities is a major source of non-CO_2 GHGs. Managing municipal solid waste is a low-hanging fruit with benefits not just in terms of climate change mitigation, but also for health and environment, and resource management.

Afforestation and CCUS

The IPCC (2022b) has recognized that even on favorable assumptions on mitigation action, fossil fuels cannot be completely eliminated, and some residual use will remain in hard-to-abate sectors. The resulting unavoidable CO_2 emissions will have to be dealt with by increasing the stock of forests providing a natural carbon sink, and through CCUS technology.

Afforestation

Expanding the area under forests is an important part of our climate action plan. India committed at Paris to increase the land under forests to create an additional carbon sink of 2.5–3 Gt-CO_2e by 2030, although the base line to determine the "additionality" of the target not specified. The current coverage of forests and trees in the country is 24.6 percent of its total area. The Forest Survey of India (FSI, 2019) estimates that to create a 2.5 Gt-CO_2e equivalent carbon sink, India would require the area under forest and tree cover to increase by 18.7 million hectares, which is 3.4 percent of the country's geographic area. Nearly two thirds of this can be achieved through restoration of impaired and open forests. The FSI (2019) estimates the total cost of meeting the target to be 1.5 percent of the GDP (spread over several years). It is worth noting that this will not only help in sequestering CO_2, it will also have substantial co-benefits including ecological restoration and water management.

Carbon capture use and storage (CCUS)

CCUS refers to techniques of artificially capturing CO_2 either from the atmosphere or from large point-sources such as industries and sequestering it chemically into geological formations for long-term storage. The IPCC (2022b) considers CCUS to be critical to achieving the +1.5°C target. Of the mitigation pathways assessed in the report, 97 pathways that keep global warming below 1.5°C, project deployment of CCUS to capture and store 665 Gt-CO_2 (median value) cumulatively, between now and 2100 (IPCC, 2022b). The Ministry of Petroleum and Natural gas has recently published a draft policy document for CCUS in India, wherein geological sites with 393 Gt-CO_2 sequestration potential have been identified (MoPNG, 2022).

The technology for CCUS is still maturing and it cannot be currently deployed cost effectively at industrial scale. However, advanced countries have a vital interest in this area and are heavily involved in developing the technology.[43] It is reasonable to hope that these efforts will fructify and when they do, the technology will become available to developing countries as well.

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[43] See for reference the Carbon Negative Shot, as part of the U.S. Dept. of Energy's Energy Earthshots Initiative. Link: https://www.energy.gov/fecm/carbon-negative-shot

Investment requirements of the transition

Implementing the strategy discussed in this chapter will involve massive investments in mitigation and adaptation measures. Mitigation related investments include the large investments in RE generation capacity, transmission infrastructure, and battery storage. Apart from the energy sector, there would be additional investment needed in producing the required capital equipment (e.g., solar PV panels and wind turbines) in the country. Similarly, electrification of transport will require investment in the automotive sector to produce EVs instead of ICE vehicles and also in establishing a charging infrastructure. Other elements of the strategy which relate to efforts to reduce emissions from industries, households, and commercial establishments in urban areas, and to promote afforestation will also require additional investment.

There are also unavoidable investments aimed at adaptation. The rise in global temperatures that has taken place, and will continue for a while even under very optimistic assumptions, will increase the number of extreme weather events such as prolonged droughts and heavy floods. Investments will be needed in water conservation and storage methods in rural areas and in developing drought and heat resistant crops. Similarly, urban areas would require investments in expansion of stormwater drainage capacity and in rainwater harvesting and groundwater restoration methods. In addition, building design in urban areas must also be modified to cope with heat stress and to minimize energy needs for cooling. Whereas investments related to mitigation will need to be frontloaded, those related to adaptation are likely to be backloaded.

Several studies have attempted to quantify the additional investment India must plan for in future to mitigate climate change.[44] The estimates emerging from these studies vary widely depending on whether they cover only energy and related sectors, or the energy using sectors as well (e.g. transport, industries, etc.), and the time-period considered along with the underlying GDP growth assumed.

Defining additionality presents some conceptual problems. For example, shifting from coal to renewables for electricity generation will obviously involve a massive investment in setting up new RE capacity, but the “additional” investment is only the excess cost of RE capacity over that of the conventional capacity that would otherwise have had to be added. Admittedly, RE requires more capital per unit of electric-power capacity than coal-based plants, and this would show up as additional investment. But RE also does not require coal as an input, so the capital

[44] See for reference: McCollum et al. (2018), CEEW (2021), IEA (2022), McKinsey (2022), and ASPI (2022).

investment needed to expand production and transportation of coal is saved. Against this, RE requires storage systems to manage intermittency of generation which should be added to total investment requirement.

In chapter 12 of this volume, we provide a detailed analysis of the extent to which the studies have dealt with these factors. For the purpose of this chapter, it is sufficient to note that Bhattacharya et al. (2022) estimate that the additional investments in energy and other sustainable infrastructure, adaptation and resilience, human development and restoration of natural capital needed by all developing countries (excluding China) by 2025 would be about 3.8 percent of their combined GDP or $960 billion per year. The amount is even larger for later years.

This investment should not be viewed as a burden which comes at the cost of growth because the option of proceeding in a business-as-usual fashion without mitigation and adaptation would itself impose costs on growth. It is best seen as a restructuring of investment for moving the economy to a genuinely sustainable and inclusive growth path. However, the scale of the effort needed is clearly very large.

The additional investment needed has to come from the public and private sectors in some combination. Some of the investments, e.g., in transmission infrastructure, agricultural R&D, water management in rural and urban areas will have to come dominantly from the public sector. This will impose a strain on already constrained government finances and efforts will have to be made to create fiscal space to accommodate these investments. For the rest, we should try to ensure that the private sector carries the burden as much as possible. Most of the investment in RE generation capacity should come from the private sector with some coming from existing public sector energy corporations. Almost all the additional investment in areas such as transport, industry, and commercial buildings in urban areas, can come from the private sector, but it will require appropriate encouragement from the government.

Financing the increase in investment will present problems. The U.N. Framework Convention for Climate Change (UNFCCC) explicitly envisaged that developing countries would receive international financial assistance to help meet the demands of both mitigation and adaptation. The climate accords since 2009, reaffirmed by the Paris Agreement of 2015, had promised additional international financial assistance (in some unspecified combination of public and private funds) of $100 billion per year, to be achieved by 2020. This has not been achieved. The Glasgow Pact acknowledges this shortfall and notes that the amount of $100 billion would now be achieved only by 2023. The Pact also called for a substantial increase in the amount of assistance thereafter. The new target for international financial assistance will have to be agreed, as is now under deliberations on the new quantified goal launched at Glasgow. Handling this problem is not a challenge for India alone but for all developing countries and how this could be done is explored in detail in Chapter 12.

What does this imply for India? An important conclusion is that it would be unrealistic to expect large amounts of international support. A substantial part of the investment cost of the transition will have to be borne domestically. However, we can expect additional flows from multilateral development banks (MDBs) to support the transition. These flows could be used to leverage private investment which is otherwise deterred by high-risk perceptions.

The logical forum to push for expanded MDB lending is the G-20. Indonesia chaired the Group in 2022, and India is its current Chair , followed by Brazil in 2024 and South Africa in 2025. This is a unique occasion where four large developing countries will hold the G-20 Chair in succession. They could work together to put expansion of MDB lending in support of climate finance firmly on the global stage.

Conclusions

The picture that emerges from our analysis is that there is considerable scope for reducing the volume of emissions over time through a combination of actions aimed at increasing energy efficiency, switching from direct use of fossil fuel to electricity wherever possible (i.e., electrification), and shifting progressively to RE to meet the electricity demand. Nevertheless, it may not be possible to eliminate all CO_2 emissions and the residual amount has to be handled through expanded afforestation and in due course CCUS. Some of our major conclusions on the feasibility of reaching net zero are summarized below.

The transformation required cannot be achieved by a few strategic interventions or magic bullets. Multiple inter-related interventions will be needed across several sectors: Power generation, industries, transportation, buildings/cities, and forestry. Some of these interventions may appear costly at present but with the whole world focusing on these challenges, it is reasonable to expect that costs will decline in future.

The multiplicity of interventions highlights the need for coordination across different ministries, and also different levels of government (center, states, and rural/urban local bodies) and also the private sector. For example, the Indian Railways is entirely under the control of the central government which is therefore solely responsible for meeting the net zero target for the railways. Electrifying city public transport on the other hand is in the hands of state and local governments. The shift to EVs in personal transport has to be led by the private sector, with government playing an important supportive and regulatory role. Reform of the discoms is critical if private investment is to be attracted into RE generation, and this is entirely in the hands of state governments. However, the central government can help mobilize multilateral funding to help finance the reforms needed. There are also areas which call for cooperation between the center and the states, as for example in setting up tripartite arrangements between the center, the state governments, and the RBI for assuring timely payments to power generators.

It is not possible to prepare a detailed plan for all the elements of the strategy to get to net zero. There are too many uncertainties, including in technological development, which could affect the choices we make in the future. The best way to proceed is to plan for ten years at a time. The central government should consult with relevant stakeholders and outline a well-defined, sector-specific plan for each of the major sectors for the first 10 years, i.e., now until 2032 based on technologies currently available. This plan should have sufficient granularity so that responsibility for implementation of individual elements is clearly assigned and mechanisms are established to reconcile conflicts. The progress of the plan should be regularly reviewed and steps taken to deal with obstacles that may arise. The national plan should be complemented by similar state-specific plans prepared by state governments, with adequate mechanisms for coordination between the two.

Some of the specific targets that could be set for the first 10 years are the following:

i. Since achieving net zero emissions implies elimination of unabated coal-based power plants well before 2070, we could specify a date for peaking the use of coal for power sometime around 2030. This should take into account new capacity currently under construction and some inefficient plants being decommissioned or phased down. All expansion of power capacity after the peaking date would be from other sources.
ii. A date could be set for peak economy-wide CO_2 emissions sometime in the 2030s.
iii. Improving the financial health of discoms is essential to encourage private investment in RE capacity expansion. We are currently going through the fourth round of efforts to improve the financial position of discoms. Targets emerging from this exercise should be publicized as part of our decarbonization strategy. Efforts could also be made to mobilize financing from the MDBs in support of this effort. The states could also be encouraged to set targets for privatizing some parts of the distribution system.
iv. RE is an intermittent source of power and increasing its share in total electricity supply will require innovations in electricity regulation and grid management practices. Central regulators would have to collaborate closely with state regulators in the process. Regulatory changes aimed at improving grid flexibility should be a top priority in the first ten years and a road map for such changes should be announced.
v. Any strategy for decarbonization would be helped by a carbon tax which will send a strong signal to shift from coal-based power to RE and will also raise revenue consistent with the objective that the polluter should pay. Cap-and-trade systems are a substitute for carbon taxes and the recently passed Energy Conservation (Amendment) Act, 2022 makes a provision for introducing such a system. The relative merits of the two should be carefully assessed and a plan put forth accordingly in due time.
vi. Official targets could be set for the growth of green H2 production based on obligatory demand from the industry for meeting a certain percentage of its requirement from green H_2. The relative expectations from the private sector and the public sector should be made public up front.
vii. Indian Railways has announced a target of achieving net zero emissions by 2030. This would require the networks' entire traction to be electric, based on RE or other carbon neutral sources. This implies phasing out of the diesel locomotive fleet or its conversion to electric. The schedule of this transition needs to be spelt out.
viii. Separate targets should be set for increasing the share of EVs in total auto sales for 2-, 3-, and 4-wheelers, by the end of the 10-year period. A target could also be announced for expanding the EV-charging network. The government could also consider announcing the date after which the sale of new internal combustion (IC)-engine vehicles will be banned.
ix. The minimum energy efficiency standards for popular household appliances especially fans, refrigerators, and air conditioners should be reviewed, and new levels set consistent

with current technology, with the provision of raising them periodically as technology advances.

x. State governments should be encouraged to prepare climate action plans for the major cities and rural areas in the state. The plans should have targets for expanding the public transport network and electrifying it through electric buses or metro railways. It should also cover water harvesting facilities.

xi. Finally, we should ensure progress toward our Paris target of afforestation and perhaps even plan to ratchet it up. A bold afforestation program will not only help mitigate CO_2 emissions, it will also help restore water cycle.

A ten-year plan along these lines would help increase public consciousness and generate a public debate on the aspects of a strategy that may seem politically difficult but is necessary to address if progress on climate change is to be made.

Some of the public policy interventions that are necessary for reducing emissions, e.g., eliminating inefficient electricity subsidies for certain classes of consumers, reducing fuel subsidies, introducing appropriate carbon pricing, and privatizing electricity distribution, will pose political problems. Both the central and state governments must make a sustained effort to educate the public on why some of these difficult steps have to be taken. Increase in energy prices is often perceived as anti-poor, but this problem is best handled by protecting the vulnerable sections of the population through direct transfer of cash subsidies. There is no economic case for having low energy prices for all.

The scale of the energy transition envisaged will generate a large domestic demand for products such as solar PV panels, batteries, electrolyzers, wind turbines etc. The scale of this demand justifies pushing for domestic manufacturing of these items, but it is also essential to avoid development of inefficient production capacity behind protectionist walls. Since technologies in this area are evolving rapidly, we must not get locked into outdated high-cost technologies which will compromise the competitiveness of the economy, and also limit our ability to export these products. Industrial-cum-trade policies must be designed to prevent this outcome. Domestic R&D efforts must be actively encouraged to ensure competitiveness.

The large investments required in various sectors cannot be made by the public sector alone although a substantial part will require additional public investment. Since the finances of both the central and state governments are under stress, it is important to ensure the maximum possible private sector involvement. This means policies must be designed to encourage private investment, both domestic and foreign. Private investors from whom investments are expected should be actively involved in the process of designing policies so that their concerns can be suitably addressed. They must also be encouraged to express their concerns frankly.

India’s own requirements call for long-term public international finance (both bilateral plus from the MDBs) to increase to about $30 billion per year, which in turn could help to leverage a greater amount of investment from private sources. The international community has yet to decide on the scale of financial assistance to be promised to developing countries after 2025. The current international environment is not conducive to focusing on this long-term objective, but India's chairmanship of the G-20 in 2023 provides a well-timed opportunity to push for a bold global initiative in this area.

Finally, it is important to note that the actions announced by all nations in COP26 are insufficient to contain global warming to the desired level. The Glasgow Pact therefore called on all Parties to consider taking stronger action, to be announced by COP27. Climate justice requires that the extent to which each country must modify its commitments must be guided by some over-arching criterion of fairness. This issue has never been discussed in any COP thus far, but it can no longer be avoided. We should propose that a reasonable approach would be that each country's future emissions trajectory is such that its share in the remaining global carbon budget is broadly consistent with its population share. This ignores the inequity in the accumulated stock of CO_2 in the atmosphere from the past, but it introduces fairness for future emissions. Fairness requires that the advanced countries should take the lead in announcing tighter transition targets and the others can then follow. If this approach is accepted, the advanced countries would need to tighten their emissions trajectories to reach net zero 5–10 years earlier than currently targeted. China too would have to advance its net zero date to 2050. If an agreement along these lines is reached, India should also consider advancing its net zero date by some years (Ahluwalia and Patel, 2022).

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