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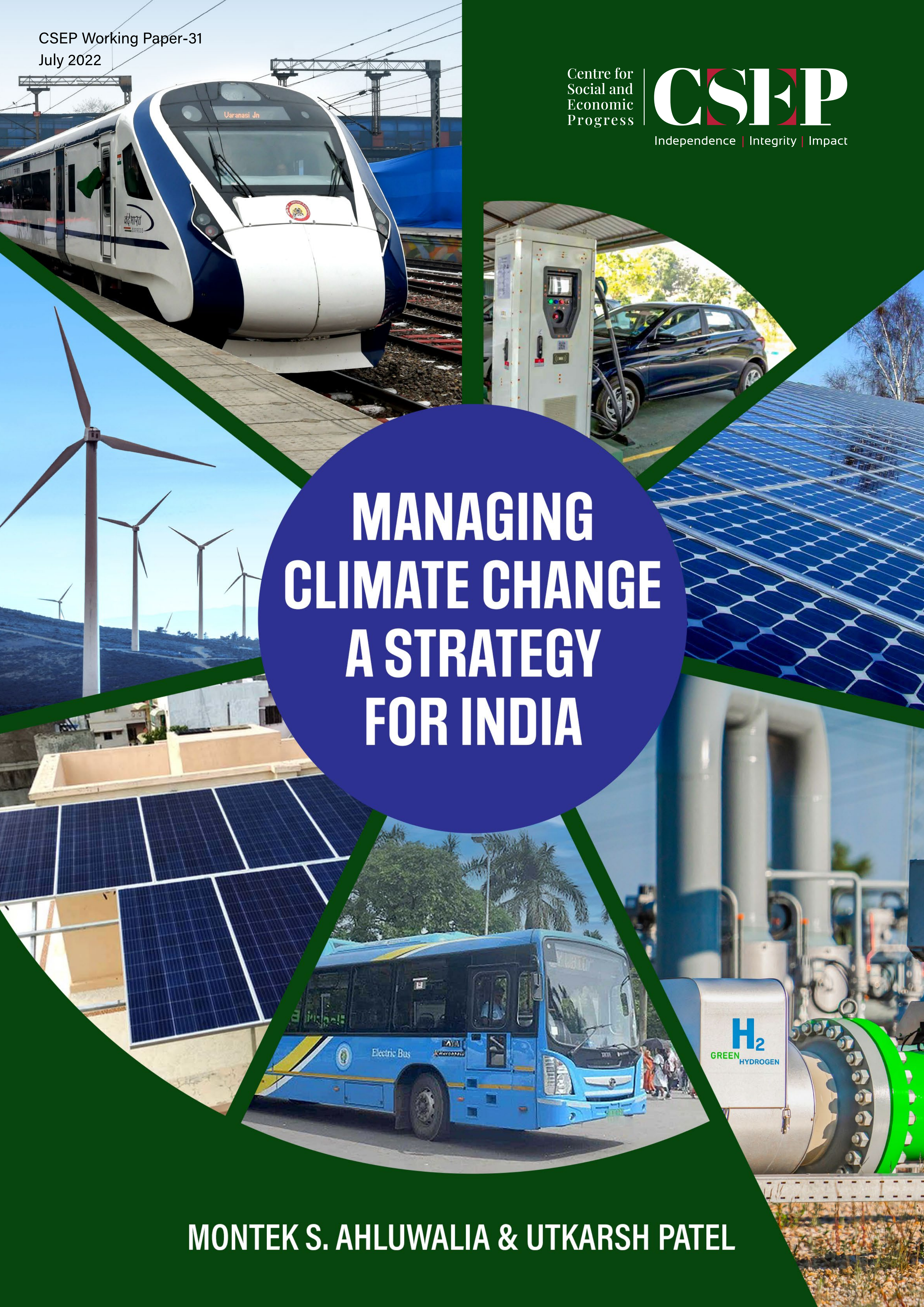

MANAGING CLIMATE CHANGE A STRATEGY FOR INDIA

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Designed by Mukesh Rawat

MANAGING CLIMATE CHANGE A STRATEGY FOR INDIA*

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At the COP26 Summit in Glasgow, in a major breakthrough, the developing countries, for the first time ever, undertook to reduce the level of carbon emissions to net zero by various dates around mid-century. The new position reflected an acknowledgment of the seriousness of the problem of global warming and also of the opportunities presented by new technology.

The seriousness had been highlighted by the Inter-governmental Panel on Climate Change (IPCC), which warned that if nothing was done, global warming was likely to reach at least +2.8°C by the end of the century and this would have very negative effects on all countries, with the developing countries being the worst affected (IPCC, 2021; 2022a). Meanwhile, developments in technology presented new opportunities making it possible to meet the energy demand from renewables, thus effectively decoupling emissions and economic growth. Both factors were important in influencing India's position at COP26.

Most advanced countries, and also some developing countries like South Africa, Vietnam, Thailand, etc. announced 2050 as their target net zero date. China, Russia, Saudi Arabia, Indonesia, Nigeria and others committed to reach net zero by 2060. India committed to reach net zero by 2070.

This paper examines the challenges India will face in implementing its new commitment. Section I summarises India's COP26 targets and outlines the broad strategy we must follow to achieve them. Sections II to V focus on what can be done to reduce emissions in sectors which account for almost all of the country's carbon dioxide (CO2) emissions. Section VI discusses afforestation and carbon capture, utilisation and storage (CCUS) as ways of dealing with residual emissions. Section VII presents an assessment of the likely investment requirements of this transition. Section VIII presents the main conclusions.

I. India's COP26 Targets

India's targets on emissions reduction consist 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[1] to be reduced by more than 45% by 2030, compared to the 2005 level, up from the Paris target of 33-35%;
2. The share of non-fossil fuel-based electricity generation capacity will be raised to 50% by 2030, up from the earlier target of 40%. 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-CO2 equivalent additional forest sink by 2030, that was part of India's Paris 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 the GDP in 2030 is likely to be 4.5 times what it was in 2005, a 45% reduction in emissions intensity would still leave absolute emissions almost 2.5 times the level in 2005, or about 33% above the 2020 level. 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 OECD[2] countries. India needs to achieve growth of 7-8% per annum in its GDP over the next ten years, to meet legitimate expectations of higher income levels, and this is bound to involve growth in total energy consumption.

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

[2] Organisation for Economic Co-operation and Development.

India's strategy for decarbonisation reconciles growth in energy consumption, with a reduction and ultimately elimination of CO2 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:

(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;

(iv) developing green hydrogen (H2) as a substitute for fossil fuels in hard to decarbonise areas.

The above actions must be accompanied by:

(v) expanding forest area to increase natural carbon sinks; and finally,

(vi) developing CO2 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 labour 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 of 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 decarbonise the major sectors which account for almost all of the country's carbon dioxide (CO2) emissions,[3] viz: power generation (50% of emissions in 2019), industries (32%), transport (13%), and buildings and appliances (5%).[4]

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, rationalising energy subsidies, providing an environment conducive to private action in managing climate change and possibly also moving towards 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 ten-year plans. The first of these, spanning the first ten years, should define granular targets for the period in each of 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.

[3] CO2 accounts for about 72% of all the greenhouse gases (GHGs) emitted in India.
[4] Source: CAIT Historical GHG Emissions. 2022. https://www.climatewatchdata.org/ghg-emissions

The national ten-year plan could be complemented by states announcing state-specific plans for the ten-year period indicating their respective targets. This exercise can be repeated for the subsequent ten years, taking on board the lessons from the first phase.

II. Decarbonising 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 CO2 emissions in the economy and therefore has the largest potential for reducing emissions. Furthermore, decarbonising 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 decarbonisation of electricity that much more important.

The real scope for delinking electricity generation from CO2 emissions on a large scale lies in expanding capacity in solar and wind power. This is an area where technology has evolved rapidly, making electricity generation from these sources much more economical, and this is explicitly recognised 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 hydro power, nuclear power, and biomass. India currently has about 51.6 GW of hydropower (including small hydro) capacity, but geophysical factors and environmental and social concerns make significant expansion unlikely. 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. This is an area where significant expansion should be possible if we 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 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.

Expansion of RE capacity has done well and India has made good progress in expanding RE capacity. The installed capacity has expanded from only 6 GW in 2005 to about 114 GW by July 2022. Most of the expansion has been through private sector investment, led by ReNew Power, Greenko, Adani Green and Tata Power. 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 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. It will have to increase to 38 GW for the next eight 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.

(i) The Problem of Intermittency

Both solar and wind electricity are characterised 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% 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. However, as RE sources account for close to a third of the total electricity supplied in 2030, as the new targets imply, balancing will become more difficult (CEA, 2020). These problems will only increase in future when the share of RE will rise to over 70% by 2070 as projected by Chaturvedi and Malyan (2022).

Intermittency can be handled in several ways, and these are summarised in Box 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.

BOX 1: Balancing Intermittent Supplies

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

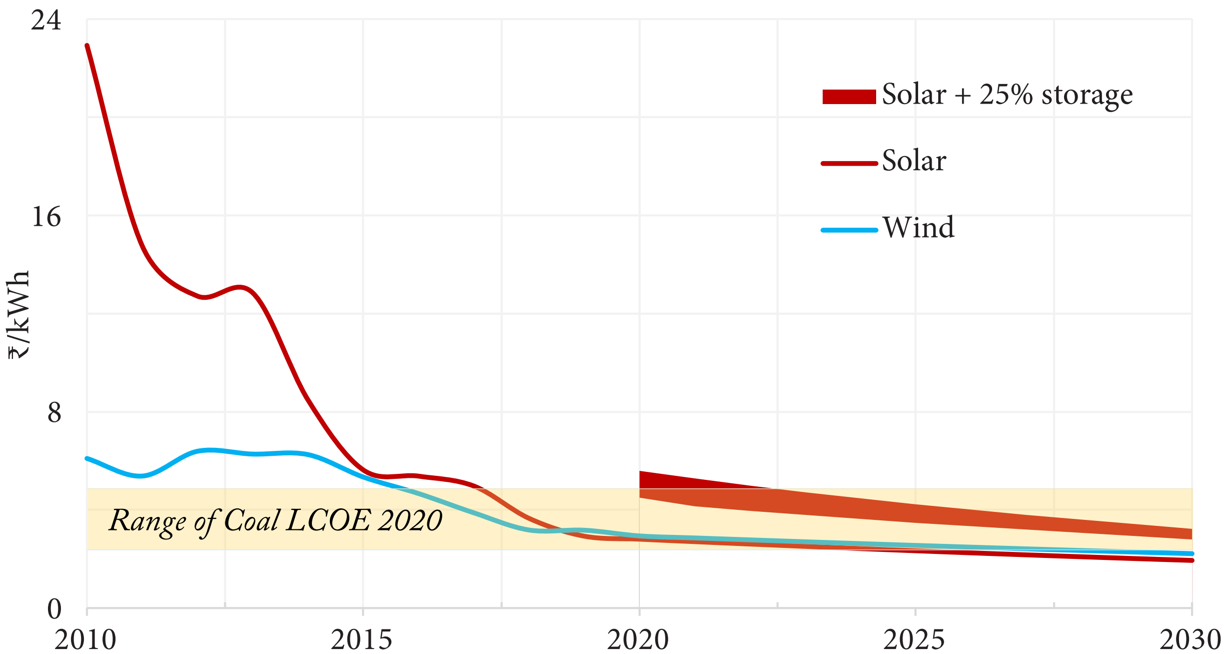
1. Optimising solar to wind capacity ratio can moderate the variation in total supply, since wind can complement solar generation during evenings, although the costs would be a little higher.
2. Offshore wind power tends to be more consistent than onshore wind, and offshore wind capacity expansion would therefore be a more stable source of RE. However, it is three to four times costlier.
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 H2.
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.

(ii) Cost Competitiveness of Solar and Wind Electricity

The good news on competitiveness of RE that the unit cost of solar power has fallen by 88% in the past 10 years and that of wind power by 52%, 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.

As shown in Figure 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 1: Levelised 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 the cost competitiveness of RE, compared to conventional power, will not affect its demand 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% (including power from large hydro) and this is intended to increase to 43.3% by 2030.[5] The higher RPO requirement would make balancing the grid with existing methods difficult. It would require grid-scale batteries to store RE and stabilise 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.

[5] See order dated 22nd Jul 2022 of the Ministry of Power (India). Available at https://powermin.gov.in/

(iii) 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 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 programmes 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 emphasised 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-subsidise 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.[6]

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

The law 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.

[6] Business Standard; June 8, 2022.

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.[7] 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 2019-20, which is about 1.2% of the GDP.[8]

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, and 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 leave the finances of the discoms unimpaired, 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 realise the damage this causes to the quality and reliability of electricity supply and see through the innate drawbacks of competitive populism. This will require very extensive education of the public and a change of political culture. That will take time.

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 criticised 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.[9,10]

Privatisation of discoms also needs to be considered. State governments may find it difficult to privatise the whole distribution system, but they may find it easier to privatise parts of it. If these privatised segments produce better results – 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

[7] E.g., the UDAY scheme of 2015.

[8] Tyagi & 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% of GDP.

[9] 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.

[10] 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.

network-usage charge, and compete with the incumbent discom. This introduces private sector competition without privatising existing public sector discoms. Another provision empowers the National Load Despatch Centre to cease electricity supply to discoms that fail to maintain adequate payment security in favour 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.

(iv) Creation of a Transmission Infrastructure

Although the major burden of setting up RE 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 privatised to raise capital for further investments.

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

(v) Reforming the Electricity Market for RE

Increased intermittency and decentralised 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[11] 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 H2 look to secure RE supply to operate electrolysers, 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.

[11] India Energy Exchange Ltd., Power Exchange India Ltd., and recently launched Hindustan Power Exchange Ltd.

(vi) Case for Carbon Taxation

The introduction of carbon taxation will internalise the social costs of CO2 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 – because the RE volumes involved have been fairly low. But once RE sources dominate the electricity mix, the idea of directing the electricity up-takers 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 centre. The revenues from the tax can be distributed among the centre and the states to reduce resistance from the states. A carbon tax would further a market-based economic despatch system for electricity supply[12] with an efficient price-based electricity market that is aligned to emission reduction targets.

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.

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.[13] The Government of India has recently introduced a bill[14] which has been passed in the Lok Sabha (lower house of the Parliament) to implement a domestic cap-and-trade market[15] 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.

A recent IMF Staff Paper (Parry, Black and Roaf, 2021) has proposed imposition of a graded tax on CO2 ranging from $25/tonne-CO2 for India, $50 for China and $75 for the US 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, which amounts to $3.5/tonne-CO2. This would significantly raise the cost of coal-based electricity and promote the shift to RE.

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12 See draft proposal by the Ministry of Power (India) at powermin.gov.in/en/ announcements (Jun 01, 2021) The system is proposed to supersede the prevailing merit-order electricity despatch system. Under the proposed system, electricity from all sources will be traded at electricity exchanges, eliminating the need of PPAs. Such a system would lower electricity procurement costs for discoms as all generators will compete to sell power. This would also reduce RE curtailment as power could be scheduled and dispatched over a larger balancing area.

13 Keen, Parry & 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%, in China by 12–15%, and in the EU and US by under 10%. A progressive tax which is lower for low-income countries as proposed by Parry, Black & Roaf (2021) would be much less damaging to our competitiveness.

14 The Energy Conservation (Amendment) Bill, 2022

15 Cap-and-trade markets amount to a form of carbon taxation which limits the emission of carbon but does not generate net revenue for the government. 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.

(vii) Phasing Out Coal-based Power

Phasing out coal-based power is high on the international agenda for decarbonisation. 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% of power generation at present and a large proportion of our conventional power generation capacity is relatively new, with a long remaining life.[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% of their capacity, to replace 58 billion units of thermal electricity with approximately 30 GW of solar power by 2025–26.[17]

Since the benefits of early retirement accrue to the global community, there is a case for incentivising retirement of functioning coal plants by provision of international concessional financing. South Africa has committed to an accelerated coal phase-out, based on an international programme 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 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 and therefore needs advance preparation. 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. This will lead to both 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 plan forty years ahead and consider how it will reinvent itself.

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[16] The RE-capacity target of 450 GW by 2030 will reduce this share to 55%, 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% higher than current levels.

[17] See letter dated 26th May 2022 of the Ministry of Power (India). Available at https://powermin.gov.in/

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

[19] See for further reference Bhandari & Dwivedi, 2022

(viii) 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 & Malyan, 2022). This will create large demand for solar PV modules, wind turbines,[20] and batteries. It is logical to try to capitalise on this opportunity and build an 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 2023-24, 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 245 GW (85% of global capacity) and PV module capacity was 300 GW (75% 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[23] over five years to set up combined 50 gigawatt-hours (GWh) of battery manufacturing capacity in India. The scheme requires 25% localisation of the battery manufacturing process, including the cell and other components, within the first two years of commissioning, rising to 60% within five years. Similar incentives are being planned to establish manufacturing capacity for H2 electrolysers 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 favoured 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 designed, recognising 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.

(ix) 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% of India's territory, or roughly half the

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

[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; March 15, 2022.

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

area of Punjab.[24] 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 favouritism.

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.[25] A policy framework for repowering old wind farms, including measures for disposal of old turbine blades, could make the replacement process easier.

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 about half that in other East Asian countries 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 paper, but it illustrates the extent to which management of climate change requires a “whole-of-the-economy” approach, with close collaboration with state governments.

III. Decarbonising Industries

The Industrial sector accounts for a third of India’s CO2 emissions, and about half of this comes from steelmaking, oil refining and solid-fuel transformation,[26] and cement production. The rest is emitted from mining and quarrying, brick manufacturing, pulp and paper, fertilisers, textiles and petrochemicals, and other non-specific industries.

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, fertilisers, 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 H2, (i.e., H2 produced through electrolysis using RE) may be a solution in some areas.

Green H2 can be used as a substitute for coking coal for iron-ore reduction in steelmaking. In fertiliser production, it can replace natural gas to make ammonia. Oil refineries need H2 to de-sulphurise petrol and diesel. This is done at present with grey H2 from natural gas, which emits CO2. Switching to green H2 would eliminate these emissions. The only problem at present is that the cost of producing green H2 is very high.

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

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

[26] For instance, converting coal to coke

India's H2 demand is expected to double over the next 10 years, and the government has targeted production of 5 million tonnes (mt) green H2 by 2030.[27] This is half the level targeted by the EU.[28] Large industrial consumers of H2 are being pushed statutorily to use green H2 for part of their needs. For example, fertiliser producers and oil refiners are required to meet 5% and 10% of their respective H2 demands from green H2 from 2023 onwards, to be raised to 20% and 25% 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 have announced large investments towards developing green H2 production capacity (see Box 2). Although these are at present only public announcements, they reflect the fact that corporations are thinking actively of the part they can play in the green transition. The cost of producing green H2 is expected to fall from $5-6/kg at present to less than half of that level by 2030. To support this, inter-state electricity transmission charges for green H2 producers have been waived. Reliance Industries, which is expanding into renewables and green H2 areas, has announced an ambitious target of bringing down the cost of green H2 production to $1/kg by 2030.

Cement manufacturing relies on coal for heat and on the use of limestone as raw material, both releasing CO2 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 CO2-efficient in the world, they contribute significantly to the total CO2 emissions of the country. According to IPCC (2022b), CCUS, through the reverse-calcination process, could be a feasible solution to decarbonise this industry as the costs become favourable. Dalmia Cements of India has committed to becoming carbon negative by 2040 by utilising CCUS, and similarly, ACC (Cements) Ltd. has announced that it will reduce the CO2 intensity of its cement operations by 20% by 2030 over 2018 levels.

[27] There have been news reports of the government planning to have 10 GW of H2 electrolysis capacity by 2030 (Reuters; Sept 8, 2021). This much capacity may not be insufficient to produce the targeted 5 mt of greenH2 by 2030.

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

BOX 2: Indian Corporate Initiatives on Green H2

The following is a list of announcements by public sector and private sector corporations on their plans for green H2.

Public sector:

- Indian Oil Corporation Ltd. (IOCL) plans to replace 10% of grey H2 it consumes with green H2 by 2030. It is targeting production of 70 kilo-tonnes per annum (p.a.) green H2 by then.
- Gas Authority of India Ltd. (GAIL) is setting up a 10 MW electrolyser unit at one of its gas processing plants by the end of 2023. It expects to produce 1.4 kilo-tonnes p.a. green H2 for blending with natural gas for industrial supply.
- NTPC has awarded a US-based company the construction of a pilot-scale H2-based energy storage project, at one of its power stations in Andhra Pradesh. NTPC also operates a 5 MW plant in Uttar Pradesh and intends to build a large-scale plant at its upcoming 5 GW solar park in Gujarat.
- Oil India Ltd. (OIL), in partnership with H2e Power Systems (India), has recently commissioned a 100 kW (10 kg/day) AEM-based H2 electrolysis unit in Assam, as part of a pilot project to blend green H2 with natural gas to use as fuel for city-buses. In a separate pilot project, OIL is supporting the development of fuel cell engine powered city-buses.

Private sector:

- ACME Solar group has set up a 5 tonnes/day demonstration plant in Rajasthan to produce green ammonia using the company's own solar power unit. It is also building a 2.4 kilo-tonne/day green ammonia plant in Oman with other international partners.
- California-based Ohmium started in 2021 India's first PEM electrolyser manufacturing unit in Karnataka. The unit has a capacity to manufacture 500 MW of electrolysers per year and is expandable to 2 GW.
- Greenko group has recently announced a partnership with Belgium-based John Cockerill, to build a 2 GW H2 electrolyser factory in India. John Cockerill has a 33% share in the global electrolyser market, and this would be the largest electrolyser factory in the world outside of China.
- L&T has signed a memorandum of understanding (MoU) with HydrogenPro (Norway) to establish a joint-venture plant in India to manufacture H2 electrolysers at GW-scale.
- Reliance Industries, which owns and operates the world's largest oil refinery in Gujarat, has committed to become net zero and has announced plans to set up large-scale green H2 production plants in India. It also plans to invest $76 billion over the next 15 years in building GW-scale electrolyser/fuel cell, solar PV and battery manufacturing plants. The company has entered partnership with Chart Industries (US) to develop and commercialise H2 supply chain in India. It also has an agreement with Stiesdal (Denmark) to manufacture the latter's electrolysers in India.
- Adani Group has recently entered into an agreement with Total Energies to create H2 production and export ecosystem in India. It is targeting to invest $50 billion over the next ten years and aims to produce 1 mt per annum of green H2 by 2030. The group is simultaneously exploring opportunities to set up a green steel plant in India in partnership with South Korean steel-manufacturer POSCO. It has also signed an MoU with Italian engineering contractor, Maire Tecnimont, to explore the development of other industrial projects based on green H2 in India, and another with Ballard Power Systems (Canada) for fuel-cell applications.

IV. Decarbonising 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% of India's CO2 emissions.[29] It is now technologically possible to avoid emissions by electrifying most of these areas, but not yet all.

(i) 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.[30] 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 US 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 is more energy efficient than road transport on a per tonne-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 centres, cities, and seaports.

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 mobilise 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 needs to be carefully worked out. Standardising 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 recently announced a target of becoming net zero by 2030. This would have a very

[29] International shipping by convention is not part of country's CO2 emissions inventory.
[30] Economic Times, Dec 10, 2021.

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.

(ii) 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., Mumbai, Bengaluru, Indore, etc.). However, it is early days yet, and EVs at present account for less than 2% of the total automobile sales in the country by number, dominated by two- and three-wheelers. This is comparable to Indonesia or Brazil, but much lower than the 15% 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 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.[31] 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 incentivise 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 programmes 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. This is necessary to ameliorate "range anxiety" which would otherwise discourage adoption of EVs. Mandating standard chargers across EV-models will help in quickly scaling up the network.[32] Public-sector oil marketing companies that run fuel stations, can set up such charging

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[31] 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.

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

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 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 recently put out a draft National Battery Swapping Policy aimed at creating a battery-swapping framework.[33] 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 February 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 synchronised with peak solar hours.

(iii) 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 incentivise 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%, 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 labour-intensive nature of the work.

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.[34] 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.

(iv) 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

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

[34] 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.

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. 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 towards 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 summarised in Box 2. The state governments and local authorities have to play a major role in this transition.

BOX 3: Promoting Public Transport

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

1. Behaviour 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. They will more likely to make the switch if the quality of public transport can be upgraded.
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.
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-subsidise public transport. Special cess on properties along the public transport routes can also be considered.
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.

(v) 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 H2 may provide a solution for some of these areas, since it has a much higher energy density by weight, and vehicles running on H2 can be refuelled relatively quickly. Reconversion of green H2 back into electricity via fuel cells is very energy inefficient because nearly two-thirds of the energy used in producing H2 is lost in the process with current technology (Sepulveda et al., 2021). Nevertheless, since Li-ion batteries tend to be very heavy, H2 fuel cell systems may prove to be a viable fossil fuel-free alternative for long-distance freight transport applications because H2 has a high gravimetric energy density compared to other fuels. H2 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.

V. Emissions from Expanded Urbanisation

India has been slow to urbanise, but this is changing and the urban population is projected to increase from about 377 million (or about 31% of the population) in 2011, to over 605 million (40% of the total) by 2030, and 875 million (53% of the total) by 2050 (UN 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 towards higher energy efficiency to promote a less emissions intensive lifestyle.

(i) 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 renewable 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 programme (UJALA) helped in bringing down the retail price of LED bulbs by 80%, from ₹350-400 to ₹80-90 (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 CO2 emissions from electricity generation.[35] 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.

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

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% of the households have fans, only 3% have energy-efficient ones (ibid.). 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 subsidised electricity prices greatly reduce the incentive for households to switch. This illustrates the merit of abolishing the under-pricing 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% of households), refrigerators (35%), desert coolers (12%), washing machines (8%), air conditioners (3%), and water heaters (3%). Interestingly, the penetration of energy efficient models in these appliances is much higher than for ceiling fans: air conditioners (38% of total), refrigerators (34%), water heaters (28%) and washing machines (23%) (ibid.). 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.

(ii) 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 urbanisation projected over the next three decades in India, implies that about 70% 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[36] 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) Bill, 2022 introduced in the Parliament seeks to expand the coverage of energy 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.

(iii) 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 CO2 emissions directly, it has severe health consequences for women and

[36] 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.

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 H2 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 H2-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% by volume and plans to increase the ratio further. Supplying H2 in significantly higher ratios would require upgrading the pipelines.

(iv) Managing Intra-city Transportation

The expansion expected in urbanisation also provides an opportunity to integrate transport planning with urban development. Spatial planning has been ignored in Indian urbanisation, but it can help to maximise 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% CO2 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 decarbonisation.

(v) Managing Urban Waste

The rising amount of solid waste and sewerage generated in cities is a major source of non-CO2 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.

VI. Afforestation and CCUS

The IPCC (2022b) has recognised that even on favourable assumptions on mitigation action, fossil fuels cannot be completely eliminated, and some residual use will remain in hard-to-abate sectors. The resulting unavoidable CO2 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-CO2e 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% of its total area. The Forest Survey of India (FSI, 2019) estimates that to create a 2.5 Gt-CO2e equivalent carbon sink, India would require the area under forest and tree cover to increase by 18.7 million hectares, which is 3.4% 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% of the GDP (spread over several years). It is worth noting that this will not only help in sequestering CO2, 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 CO2 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-CO2 (median value) cumulatively, between now and 2100 (ibid.). The Ministry of Petroleum and Natural gas has recently published a draft policy document for CCUS in India, wherein geological sites with 393 Gt-CO2 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.[37] It is reasonable to hope that these efforts will fructify and when they do, the technology will become available to developing countries as well.

VII. Investment Requirements of the Transition

Implementing the strategy discussed in this paper 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 minimise 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. 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 (a longer period has a higher total investment volume, but the investment as a percent of GDP is lower as the economy is expected to grow over the years). Table 1 below presents a summary of the results of these studies.

[37] 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

Table 1: Estimates of annual investments in energy and other sectors in India (2020 $, billion)

Study	Sector coverage	Scenario	Total	Additional*	% of GDP *(cumulative)*	Period
McCollum et al., 2018	Energy	+1.5°C by 2100 (50%)	$313	$147	2.6%	2016 - 2050
CEEW, 2021[38]	Power, Road transport and H2 production	NZ by 2070	$202	$107	1.0%	2020 - 2069
IEA, 2022[39]	Energy	NZ by 2070	$160	$107	3.1%	2022 - 2030
McKinsey, 2022[40]	Energy and land-use systems	NZ by 2050	$600	$228	3.7%	2021 - 2050
ASPI 2022	All	NZ by 2070	-	$259	2.7%	2022 - 2060

**Estimates of additional investment indicate the amount above a reference level, or business-as-usual projection, wherein investment as a percentage of GDP increases over time.*

The estimates in the table distinguish between total investment and the additional investment required to achieve the energy transition over the different periods indicated. The additional investment is the excess amount needed in addition to the investment that would occur in the normal course. 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 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.

A detailed analysis of the extent to which the studies mentioned above have dealt with these factors is beyond the scope of this paper. We have proceeded by accepting the 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% 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.

[38] Singh & Sindhu, 2021; based on the preprint version of Chaturvedi & Malyan (2022)

[39] IEA Commentary dated 10 Jan 2022 by Fatih Birol and Amitabh Kant. Available at https://www.iea.org/

[40] McKinsey 2022 reports only the total investment needed at the country/regional level. We calculate an approximate estimate of additional investment assuming that 40% of the total amount is additional, based on the global average reported in the study.

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 UN 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 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 in subsequent COP meetings. 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 Ahluwalia and Patel (*forthcoming*).

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.

It is worth noting that our climate change negotiators have not emphasised flows from MDBs, such as the World Bank, the International Finance Corporation, the Asian Development Bank, the European Investment Bank and others, as important channels for international finance for climate change. They have instead favoured the UN Green Climate Fund as the preferred channel for this purpose. However, given the scale of financing needed, it is unlikely that the requisite amounts can be achieved without active involvement of the MDBs.

The prospect for getting the international community to expand multilateral lending on the scale needed may be low at present, given the preoccupations in the advanced countries with managing the rise in inflation and in public debt, coping with supply-chain bottlenecks arising from the pandemic, and dealing with the consequences of the Russian invasion of Ukraine. However, these are short-term preoccupations which will settle down, while financing climate change is a long-term challenge which the world will have to confront. The logical forum to push for expanded MDB lending is the G20. Indonesia is the current Chair of the G20, followed by India in 2023, and Brazil in 2024. This is a unique occasion where three large developing countries will hold the G20 Chair in succession. They could work together to put expansion of MDB lending in support of climate finance firmly on the global stage.

VIII. 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 CO2 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 summarised 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 focussing 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 (centre, states, and cities) 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 mobilise multilateral funding to help finance the reforms needed. There are also areas which call for cooperation between the centre and the states, as for example in setting up tripartite arrangements between the centre, 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 forgetting to net zero. There are too many uncertainties, including in technological development, which could affect the choices we make in 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 ten 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 ten years are the following:

1. 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 of 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.

2. A date could be set for peak economy-wide CO2 emissions sometime in the 2030s.

3. 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 publicised as

part of our decarbonisation strategy. Efforts could also be made to mobilise financing from the MDBs in support of this effort. The states could also be encouraged to set targets for privatising some parts of the distribution system.

4. 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.

5. Any strategy for decarbonisation 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 introduced Energy Conservation Bill 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.

6. 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 H2. The relative expectations from the private sector and the public sector should be made public up front.

7. 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.

8. 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 ten-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 IC-engine vehicles will be banned.

9. 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.

10. 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.

11. Finally, we should ensure progress towards our Paris target of afforestation and perhaps even plan to ratchet it up. A bold afforestation programme will not only help mitigate CO2 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 privatising 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, electrolysers, 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 provision of international financial assistance to developing countries to support their energy transition is an important part of the UNFCCC. However, the delivery of such assistance has been much below the $100 billion per year that was promised to be achieved by 2020. The Glasgow Pact calls for the fulfilment of the promised sum at the soonest and through to 2025, and also urges that the amount must be substantially increased thereafter. India's own requirements call for long-term public 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 focussing on this long-term objective, but India's chairmanship of the G20 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 CO2 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 & Patel, 2022).

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