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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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Introduction

The Glasgow Climate Summit (COP26) deserves credit for getting many developing countries to accept, for the first time ever, a long-term commitment to reduce the level of carbon emissions to net zero. This is a major break from their position in Paris 2015, where they only committed to reducing the emissions intensity of their gross domestic product (GDP). The new position reflected an acknowledgment of the seriousness of the problem of global warming and of the opportunities presented by new technology.

The seriousness was highlighted by the Inter-governmental Panel on Climate Change (IPCC), which warned that if nothing is done global warming is 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 the technology presented new opportunities making it possible to meet the energy demand from renewables, thus effectively decoupling emissions and economic growth.

Most advanced countries, including some developing countries like South Africa, Vietnam, Thailand, etc., announced 2050 as their net zero date.[1] China, Russia, Saudi Arabia, Indonesia, Nigeria and others committed to reach net zero by 2060, and India by 2070.

This paper examines the challenges India will face in implementing its commitments. 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,[2] viz: power generation (50% of emissions in 2019), industries (32%), transport (13%), and buildings (5%)[3]. 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. A Framework for Assessing India's COP26 Targets

India's targets on emissions reduction consist of three inter-related interim targets for 2030 and a longer-term target for 2070.

1. Emissions intensity of GDP to be reduced by more than 45% by 2030, compared to the 2005 level;
2. Total projected CO2 emissions between 2022 and 2030 to be reduced by 1 gigatonne (Gt), compared to business-as-usual;
3. Total non-fossil fuel electricity generation capacity to be raised to 500 gigawatts (GW) by 2030. This includes 450 GW of renewable energy (RE), predominantly solar and wind, which would be 50% of the total generating capacity in 2030;
4. Net CO2 emissions to be reduced to zero by 2070.

The commitment to reduce emissions intensity of GDP[4] by at least 45% enhances the Paris target set in 2015 (to reduce emissions intensity by 30–35% by 2030). The target of reducing the absolute level of emissions by 1 Gt specifies the change in absolute emissions, though it is ambiguous since no baseline is given. The target for increasing non-fossil fuel generating capacity by 2030 is quite precise and is a critical instrument of the strategy for reducing emissions intensity.

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[1] Some advanced countries have announced earlier dates viz. Germany (2045), Sweden (2045), Iceland (2040) and Finland (2035).

[2] CO2 accounts for about 72% of all the greenhouse gases (GHGs) emitted in India.

[3] Source: CAIT Historical GHG Emissions. 2022. https://www.climatewatchdata.org/ghg-emissions

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

It should be noted that 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. This should not be surprising, because India's per capita energy consumption is currently only a sixth of the average of OECD[5] 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. However, as stated above, if the energy demand of rising GDP can be met by renewables, it is possible to delink economic growth from emissions, but there are limits on the pace at which this can be done. This means emissions will fall but not immediately.

The longer-term objective of getting to net zero can be achieved by a combination of demand- and supply-side actions. On the demand side there is scope for: (i) increased energy efficiency through adoption of energy-efficient technologies, combined with lifestyle changes, which will moderate the growth of energy demand for any given growth of GDP; and (ii) shifting from direct use of fossil fuels to electricity as the final energy source wherever possible. Action in these areas needs to be combined with a number of supply-side actions such as: (iii) shifting away from electricity generation using fossil fuels (coal, diesel and gas) to electricity from RE (mainly solar and wind); (iv) development of green hydrogen (H2), as a substitute for fossil fuels in key areas; (v) expanding forest area to increase natural carbon sinks; and finally, (vi) developing CCUS techniques to make them commercially viable to offset CO2 emissions from residual use of fossil fuel that may remain.

In the sections that follow, we consider what can be done in each of the major sectors identified above to reduce emissions. Our analysis shows that success will not depend on one or two critical interventions or "magic bullets". It will require multiple interventions in each area, many of which are mutually reinforcing and therefore need to be coordinated. Much of the outcome will depend upon actions taken by the private sector but government will also have to intervene actively in many areas, including through increased public investment, improved market regulation and taxation.

Since it is not possible to define all the details of a strategy spanning several decades, it is best to work on the basis of a sequence of ten-year plans. We should aim at defining granular targets for the next ten years in each of the major areas, identifying the sector-specific objectives to be achieved. The responsibility for achieving these targets can then be assigned to relevant bodies, with suitable mechanisms to ensure coordination and oversight. Progress can then be regularly monitored, and targets adjusted as necessary. The national ten-year plan could be complemented by states announcing state-specific plans which indicate what needs to be done in each state. Similar ten-year plans can be prepared for the subsequent ten years taking on board the lessons from the first phase.

II. Decarbonising the Power Sector

Decarbonising the power sector by shifting from fossil fuel-based power generation to RE sources is the most important element of the energy transition for two reasons. First, the sector accounts for about half of the total CO2 emissions in the economy and therefore has a very large potential to avoid emissions, and second, decarbonising other sectors will involve switching from direct use of fossil fuels to electricity as the final energy source (e.g., in transport) which will increase the share of electricity as the major energy carrier.

The traditional 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

[5] Organisation for Economic Co-operation and Development

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. Emerging technologies like small modular nuclear reactors could be considered in the future portfolio of emissions-free energy sources.

The real scope for generating electricity on a large scale, without CO2 emissions, lies in switching to RE using solar and wind power plants 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 target. India's RE capacity was only 6 GW in 2005 and it has expanded to about 113 GW by May 2022, most of it through private sector investment.[6] This is an impressive achievement, but it is likely to fall short of the 175 GW target for 2022. To achieving the 2030 target the rate of annual capacity addition has to increase to 38 GW for the next eight years, compared with an average of about 11 GW in the last four years.

The structural obstacles that may limit the pace of decarbonising the power sector are discussed below, along with suggestions on how to overcome them.

(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 not difficult to counter imbalances through other modes of generation when needed, which until now were surplus to the needs of the system. However, the COP26 target implies that RE sources will account for 30% of the total electricity supplied in 2030. At this level, balancing will become more difficult, and these problems will increase beyond 2030. Chaturvedi and Malyan (2022) project that net zero by 2070 would require the share of solar in electricity mix rising to 70%.

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 and the most promising are: (i) pairing RE generation with gas-based power plants, to begin with; (ii) pumped-hydro storage, where possible; and, (iii) use of grid-scale battery storage. Each of these methods entails additional costs, and that will make RE costlier.

[6] The four-largest private sector RE developers (in the decreasing order of their respective installed capacities) are: ReNew Power, Greenko, Adani Green and Tata Power.

BOX 1: Balancing Intermittent Supplies

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

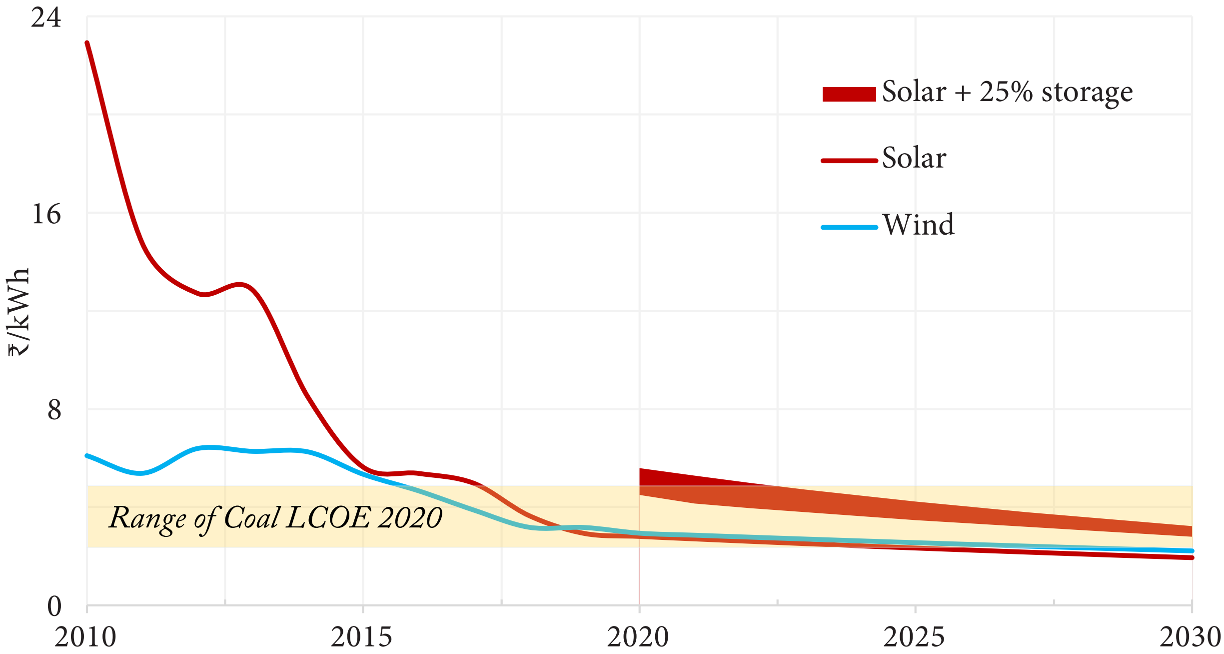
1. Optimising solar to wind capacity ratio can moderate the variation in total supply, since wind can complement solar generation during evenings.
2. Wind-turbine installations can be spatially spread out to locations that complement inter-seasonal peaks in wind.
3. Offshore wind power tends to be more 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.
4. 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.
5. 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.
6. 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.
7. Demand can be managed 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 metering.

(ii) Cost Competitiveness of Solar and Wind Electricity

The pace at which we can shift to RE sources depends critically upon cost competitiveness. The good news on this front is 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 technological improvements combined with economies of scale in manufacturing. This has made solar and wind power competitive with the cost of electricity from new coal-based plants, if we look only at unit costs for RE as available i.e., accepting intermittent supply. However, as shown in Figure 1, if the cost of battery storage to even out supply is added, it would raise the cost of solar electricity by 60–100% making it uncompetitive. The picture may improve in future if costs of battery storage decline, but for the present obtaining a balanced electricity supply from RE is expensive compared to coal power plants.

This has not been an impediment thus far because, as pointed out above, the share of RE in the electricity mix is still relatively low. The central government has also helped to boost demand for RE by making it obligatory for distribution companies (discoms) to source 21% of their power from RE generators (including large hydro) by 2022-23 (this includes 10.5% from solar power units). Current regulations also compel discoms to take up contracted RE supplies, whenever they are available.

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.

(iii) Financially Weak Discoms Pose Payments Risk for Private Investment

The fiscal constraints on the government and the public sector make it essential for the bulk of the investment in expanding RE capacity to come from the private sector. However, the poor financial condition of discoms is a major impediment to private investment in this area.

Most discoms in India are owned by state governments, with a few exceptions that are privately owned. They buy power from generators for delivery and sale to consumers within the state at tariffs regulated by independent state regulators. The tariffs 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.

Discoms should not make a loss as long as they adhere to the prescribed tariffs and efficiency levels, but in fact almost all state-owned discoms make large losses. Several efforts have been made to reform the system but they have been unsuccessful and most discoms continue to suffer from severe financial weakness. This poses a serious problem because private investment in RE generation will not take place if investors perceive that financially weak discoms are likely to default on payments due. This problem would arise whether the investment is in conventional generation or in RE, but it is magnified in the case of RE which requires a larger volume of capital investment upfront.

The financial weakness of the discoms is also impeding the adoption of rooftop solar panels. The target for solar rooftop installations by 2022 was 40 GW (as part of the 175 GW target). Against this, the actual achievement has been only 12 GW in 2021.[7] An important reason is that many discoms do not allow net-metering of the power generated and consumed. Instead, rooftop solar generators are offered a feed-in tariff that is much lower than the tariff charged for power supplied from the grid. Discoms clearly do not want to lose high paying customers whose higher tariffs help to cross-subsidise others, but the low feed-in tariffs discourage full exploitation of rooftop solar potential.

[7] Business Standard; June 8, 2022.

The regulators must find a viable pricing mechanism that does not discourage consumers from installing rooftop solar panels.

Restoring the financial health of the discoms should obviously have high priority. It is often assumed that the problem arises because of the large technical and commercial losses, which in turn is because the discoms are in the public sector which often restricts management from taking steps to increase operational efficiency. Public sector ownership is indeed a problem, but there are also several other reasons which need to be tackled.[8] One of these is the interference of state governments to keep tariffs low. Where discoms are owned by the public sector, this is easily done because the state governments can simply instruct the discoms to not ask the regulator for tariff increases on the grounds that they will make large efficiency improvements.

Discoms are also forced to charge lower than prescribed tariffs for certain categories of consumers, such as farmers and low-income households which consume less electricity. The law allows this, provided the difference is offset by an explicit subsidy from the state budget. This would not hurt the financial position of discoms if the subsidy is actually paid but in fact the subsidy amounts provided are often inadequate and, in any case, rarely paid on time. It is high time that electricity subsidies in the form of low tariffs, which generally benefit all groups, are replaced by direct cash transfers which can be targeted to the poorest consumers.[9]

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. All this, combined with interest on delayed payments and on loans to cover past losses, adds up to most discoms facing serious cash-flow problems.[10]

The root cause of the poor financial condition of the discoms 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. Artificially lowering the price for some consumers can be offset by overcharging commercial and industrial consumers, but this only reduces competitiveness and leads to slower growth in employment and incomes.

It will take extensive education of the public and an improvement in political culture to overcome this problem, and that will take time. There is therefore a case for special risk-mitigation measures to encourage private investment in RE. A good example of such risk mitigation 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. There is evidence that private sector generators prefer to enter into PPAs which benefit from such a protection. In principle, the measure only shifts the risk to the state government, but 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 involvement of the central government is also seen to discourage state governments from attempting to cancel or renegotiate PPAs signed earlier, which has happened in the past.[11,12]

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8 See for reference Tyagi and Tongia (*forthcoming*)

9 This is being done in domestic LPG distribution under the PAHAL scheme of the Government of India.

10 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 (e.g., the UDAY scheme of 2015).

11 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.

12 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.

The case for continuing public ownership of discoms also needs to be reconsidered. State governments may not be willing to privatise the whole distribution system, but they could perhaps be persuaded to privatise parts of it. If these privatised segments produce better results – as they have in many cases – it will provide benchmarks of performance for the rest of the public system and in due course could weaken the resistance to relying on private management.

(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 have to take a lead 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. The appropriate strategy would therefore be for the Power Grid Corporation—a central government undertaking—to take on this task. As these 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 the electricity storage capacity needed. Investment in battery storage will defer or avoid the need to install excess transmission and transformation capacity for peak generation periods, which would be under-utilised during the rest of the time.

(v) Reforming the Electricity Market for RE

Increased intermittency and decentralised electricity generation from a steadily rising share of RE will also call for more sophisticated electricity markets. Discoms will need to rely more on short-term markets to buy additional power if supply falls, and also to sell excess power in case of oversupply.

Electricity exchanges in India[13] 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). 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. The market is expected to reduce curtailment rates in RE-rich states by facilitating the sale of surplus electricity to RE-deficient states or other large consumers. As the market grows, with addition of large producers of green H2 looking to source RE, it would provide support to large RE developers looking to expand capacity to meet demands from financially viable entities. Expanding the market to include conventional generators will allow creation of competitive wholesale electricity markets and better price discovery. This would help in lowering the cost of electricity procurement for discoms, who have shown little interest in signing long-term contracts with power producers in the recent years.

As for the small-scale RE producers, extending open access to green energy to small consumers (under 1 MW), will add to their serviceable market. The MoP has recently notified the rules for this.

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

(vi) Phasing Out Coal-based Power

Coal is the dirtiest of fossil fuels, and there was much discussion in Glasgow on phasing out coal-based power. India's net zero commitment implies that coal-based power will be phased out over the coming decades, but we have not made a specific commitment for the phase-out. This reflects the fact that coal accounts for 70% of power generation at present[14] and a large proportion of the capacity is relatively new, with a long remaining life.

While the reluctance to make specific commitments is understandable, there is a good case for planning to phase out 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.[15] The governments of Gujarat, Maharashtra, Karnataka and Chhattisgarh have announced that they will not fund any new coal power plants in their respective states. The central government could also declare that it will not undertake construction of additional coal power plants beyond those which are already under-construction.

Retirement of functioning coal plants should ideally be incentivised by provision of international concessional financing because the benefits of early retirement accrue to the global community. 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.[16] 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.

Phasing down of coal-based power is an unavoidable consequence of getting to net zero, but it also involves a structural change that could be disruptive. The coal sector directly employs nearly 1.2 million people (CIF, 2021). Phasing out coal-based power will initially lead to a decline in coal imports, but this will be followed by a decline in domestic coal mining, leading to loss of both employment and incomes. 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 also lose royalty from coal production, and since these states happen to be relatively poor, this will call for some compensatory action, probably through additional central government transfers.

Besides the direct impacts, phasing out coal will also affect the railways because coal transport is a major source of income for the Indian Railways (IR), allowing it to cross-subsidise passenger fares. The elimination of this source of surplus earnings will force railways to rationalise rail tariffs. This highlights the need to establish a Rail Tariff Regulatory Authority, which has been on the agenda for many years.

Since the transition will stretch over the next two to three decades, there is time, but work should begin now on spelling out a plan for generating new employment, and safeguarding livelihoods of the vulnerable population. As part of the transition, Coal India Limited could also restructure itself and diversify into minerals mining and in the RE and green H2 areas.

[14] 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.

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

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

(vii) Carbon Taxation

The case for retiring older coal plants would become much stronger if a carbon tax is levied. India currently has a cess of ₹400 on per tonne of coal, which is approximately $3.5/tonne-CO2. A recent IMF Staff Paper 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 (Parry, Black & Roaf, 2021). If a tax is levied at the level recommended by the IMF paper, the price of coal will increase substantially. It would raise the cost of coal-based electricity by at least 37% leading to an earlier phase-out of coal power plants with a faster shift to renewables.

Consumption of petrol and diesel should also be liable to such a carbon tax, but these fuels are already very heavily taxed in India and some fraction of the existing taxes could be redesignated as a carbon tax without any need for additional taxation or increase in consumer prices.

The introduction of carbon taxation can not only help to accelerate the transition to RE, it can also generate revenues to help finance other elements of the climate management plan and to provide support to those adversely affected. Given the persistent fiscal constraints of both the centre and the states there is a strong case for considering some form of carbon taxation. The Government of Gujarat has recently announced to implement a cap-and-trade market for restricting carbon emissions from large industries and power plants in the state.

The case for carbon taxation will be greatly strengthened if advanced countries introduce similar taxes, and levy border adjustment taxes on imports of goods from countries that do not have a comparable tax, as the EU has announced it will do from 2026. If this is implemented, we should be willing to introduce a system of carbon taxation that would qualify to exempt our exports from imposition of such duties.[17]

(viii) Building a Production Base for RE

The long-term transition to net zero implies total RE capacity reaching 7400 –8400 GW by 2070 (Chaturvedi & Malyan, 2022). This will create large demand for solar PV modules, wind turbines,[18] 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 production-linked incentive (PLI)[19] scheme for establishing domestic manufacturing capacity in the solar-PV area—covering polysilicon wafers, solar cells and modules. The scheme is accompanied by increased tariffs 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 (about 10% of global capacity) to 36 GW over the same period.[20]

In a similar PLI scheme for batteries the government has recently concluded the bidding process for the allotment of $2.4 billion in PLIs to four companies[21] over five years to set up combined 50 gigawatt-hours (GWh) of battery manufacturing capacity in India. The scheme requires 25%

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[17] 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.

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

[19] 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.

[20] PV Magazine; March 15, 2022.

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

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.

As we try to build domestic manufacturing capacity to service 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. Renewables is an area where technology is evolving rapidly and we should avoid insulating the domestic industry from technical change. A case can be made for modest import duties, but these should ideally be phased down over a period.

High import duties to protect the domestic production of these items only raises the costs for domestic users, hurting the country's global competitiveness. This is already being felt in the solar sector, where higher import duties have raised the cost of generation from new solar capacity.

The government has rightly emphasised the need to make India a global manufacturing hub for these new products, and to that end 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. Domestic R&D efforts by the industry should also be encouraged. Putting a well-articulated policy in place in this area should have top priority.

(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 area of Punjab.[22] 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 also 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.[23] 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. However, this may be less serious than imagined 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.

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[22] 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.

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

III. Decarbonising Industries

The Industrial sector accounts for a third of India's CO2 emissions, and about half of this is emitted from steelmaking, oil refining and solid-fuel transformation,[24] 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 emit CO2 from burning 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 in steelmaking, as a substitute for coking coal for iron-ore reduction. In fertiliser production, it can be used to replace natural gas to make ammonia. In oil refineries, H2 is needed to de-sulphurise petrol and diesel, and at present the refineries rely on grey H2 from natural gas, which emits CO2. The technology for producing green H2 is known, but the costs are currently very high.

India's H2 demand is expected double over the next 10 years, and meeting part of that demand with green H2 will help to reduce emissions from grey H2 production and natural gas. The government is pushing large consumers of H2 (e.g., chemicals industry, oil refiners, fertiliser producers) 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, and this will be raised to 20% and 25% respectively by 2028. Many public and private corporations in India have announced large investments towards developing green H2 production capacity in the country (see Box 2). These are public statements, but they reflect the fact that corporations are beginning to think of what they can do to accelerate the transition. If successful, they will set the stage for faster adoption of green H2 as a carbon neutral alternative for industrial processes.

The government has targeted production of 5 million tonnes (mt) green H2 by 2030.[25] This is half the level targeted by the EU.[26] The cost of green H2 production in India is expected to fall from $5-6/kg at present to less than half of that level by 2030. To support this, fiscal measures like waiving inter-state electricity transmission charges for green H2 producers have been announced. 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. Full upstream integration of electrolysis systems with RE generation would help to cut some costs (which Reliance plans to do by setting up own RE generation capacity).

Cement manufacturing is very carbon-intensive due to its reliance on coal for heat and 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.

The private sector is coming forth with proposals to address this problem. 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.

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[24] For instance, converting coal to coke

[25] 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.

[26] REPowerEU 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.
- National Thermal Power Corp. (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 $10 billion in building GW-scale electrolyser/fuel-cell, solar PV and battery manufacturing plants.
- Adani Group has recently entered into an agreement with Total Energies to create H2 production and export ecosystem in India. It is targeting a production capacity of 1 mt p.a. 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, to explore the development of other industrial projects based on green H2 in India.

IV. Decarbonising Transport

The transport sector depends heavily on petroleum and natural gas and accounts for about 13% of India's CO2 emissions. This sector includes railways, road transport, inland shipping,[27] and airlines. It is now technologically possible to avoid emissions by electrifying most of these areas, but not yet all.

(i) Railway Electrification

Indian Railways (IR) is currently the fourth-largest rail network in the world, and it relies on both electric and diesel traction. It has long been engaged in electrifying its tracks and about 80% of the broad-gauge track network is now electrified. Electrification of the entire network is targeted to be completed 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.[28] 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 the 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.

A low-hanging fruit is to reverse the long-standing trend of shifting of general freight cargo movement from railways to roads. A reversal of this trend will save on fuel, since railways are more energy efficient than road transport on a per tonne-km basis. It will lead to a bigger impact on emissions since the IR network 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.

To regain a higher share in freight, the IR should consider partnerships with customer-facing logistics companies that can use road transportation 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. The terms on which railway freight movement capacity can be booked by partners needs to be carefully worked out. Gaining share in general freight cargo will help to offset the loss of coal traffic in future as coal power plants are phased down.

Electrification of the railway network also opens the possibility of an assured offtake of RE by the 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. Achieving this target would bolster confidence in what is otherwise a challenging journey.

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

(ii) Electrifying Road Transport

Electric vehicles (EVs) are gaining popularity in advanced countries, and they have begun to appear 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 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. 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 private sector actions, but it cannot be achieved by taking a few initiatives and 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 ownership 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

Conscious promotion of EVs as reflecting a more responsible and sustainable lifestyle is essential. The central and state governments could signal this 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.[29] The pace at which the vehicles can be rolled out 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 said 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.

Establishing an EV-charging network

The establishment of EV-charging infrastructure will be critical for the pace of expansion of EVs as otherwise "range anxiety" would discourage the adoption. Mandating standard chargers across EV-models will help in quickly scaling up the network.[30] Public-sector oil marketing companies that run fuel stations, can set up such charging points within their premises. The discoms could also fit plug-in paid chargers on lamp posts in cities, as is being done in many cities in advanced countries. This should be a top priority for the large cities. The regulators can prescribe electricity tariffs for such charging stations, which incentivise adoption of electric vehicles.

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[29] 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.

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

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.[31] The draft has proposed extending the existing fiscal incentives on regular EVs to EVs with swappable-batteries. China is leading in this area, having 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

Since India has a large automotive manufacturing base, consideration should be given to how to push the sector to adjust to EVs and also help it to do so. 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.

If the economy is to become net zero by 2070, it is reasonable to plan for passenger transport to become emissions-free by 2050. This is in addition to raising the 2% of sales to 100%, because even when EVs account for all the sales, the fleet of cars in operation will have many ICE vehicles for several years. If we want the entire fleet to be of EVs by 2050, we should perhaps announce 2035 as the terminal year for sale of ICE vehicles (assuming that it will take 15 years for most ICE vehicles to go out of operation). 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 for the components sector since 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. As stated earlier, the SMEs could also do well in 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 spontaneously catching fire.[32] Establishing standards for battery design suited to Indian conditions and for charging and recycling, and also enforcing these standards will be necessary. This will only be possible with close coordination between industry and the government.

(iv) Promoting Public Transport

Shifting from vehicles to public transport is known to make an important contribution to reducing emissions. This would be true even if public transport relied on fossil fuels because it is much more fuel-efficient on a per person-km basis than private transport. The reduction in emissions will be much greater if public transport is electrified, which is possible relatively quickly with government actions.

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

[32] 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.

Metro trains for mass rapid transit are an important medium for electrifying urban transport. Such metros are currently operating across 13 metropolitan regions in India and there are ambitious plans to expand the metro rail network to more cities in future. Another way of electrifying public transport is by expanding the fleet of electric buses. Several cities have taken steps to order electric buses, and 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 cannot, however, be achieved by isolated initiatives, such as deploying electric buses and introducing urban metros. It requires a 'system reform' of the urban passenger transport system, which calls for action on several fronts. Some of the critical elements are described in Box 3 to suggest the multiple areas where action is needed.

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 in developing countries, where poor quality often discourages many individuals in upper-income groups from using public transport.
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, and Bhopal), 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.

(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 however is very energy inefficient – nearly two-thirds of the energy is lost in the process with current technology (Sepulveda et al., 2021). Still, 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. 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.

Since this is an area of ongoing research, 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's 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). Since this urban expansion will be accompanied by an increase in per capita incomes, it will lead to higher demand for urban housing, and domestic appliances for lighting, refrigeration and cooling/air conditioning. All this will raise electricity demand and, since electricity will not become free of fossil fuels for some time, it will generate higher emissions.

The need for intra-city transport will also impose a burden of higher energy use and emissions, and even if this is mitigated by electrification there will be a burden of congestion unless spatial planning can reduce the demand for transportation. These developments have to be countered by a sustained push towards higher energy efficiency—through consumer awareness, and behavioural changes—to promote a less energy-intensive lifestyle.

(i) Energy Efficiency of Appliances

Shifting to energy-efficient appliances calls for actions on several fronts. India's experience in these areas has lessons for what needs to be done in the future.

Energy-efficient lighting

India has made commendable progress in promoting a switch 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 (~$5 to $1) per bulb, and has succeeded in distributing 370 million LED bulbs since 2015. This has effectively saved 48 billion units of electricity per annum, or avoided 386 mt of CO2 emissions from electricity generation.[33] Almost all households in India have electric lights, and about two-thirds of them are LED bulbs (Agrawal et al., 2020). This proportion must increase further.

Energy-efficient fans

Another important area for potential action, but the UJALA scheme, which was very successful with LED bulbs, has had disappointing results thus far in promoting energy-efficient fans. There are several energy efficient ceiling fans in the market, which consume about half the electricity used by conventional ceiling fans. However, although 90% of the households have fans, only 3% have energy-efficient ones (ibid.), partly because of lack of knowledge of the implications of energy efficiency, and because energy efficient fans cost twice as much as conventional ceiling fans.

Subsidised electricity prices also account for the low adoption of energy efficient fans, since it greatly reduces the incentive for households to switch. This highlights the merit of abolishing the under-pricing of electricity through subsidies, and substituting it with direct cash transfer to targeted households.

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

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 consume more electricity and fall in the higher slabs of electricity tariffs.

An effective way of pushing for higher levels of energy efficiency over time is to enforce statutory minimum standards which all products must meet, while also giving enough notice to manufacturers in advance. This would be most useful in the case of fans and air conditioners, and it should be systematically pushed up reflecting developments in technology. 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 construction materials. The massive 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 customising building design to achieve high levels of energy efficiency.

Regulatory mechanisms could enforce LEED/GRIHA[34] 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 authority to regulate building designs etc., lies with state governments, but the central government[35] can take the lead in encouraging states to act, and by establishing high standards for its buildings and that of public sector undertakings.

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 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.

34 Green Rating for Integrated Habitat Assessment.

35 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.

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 a 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 massive expansion expected in urbanisation also points to the need for integrating transport planning with urban development. Spatial planning has been ignored in Indian urbanisation, but it can help to minimise transportation in private vehicles, and maximise walkability and usage of public transport within cities. This is more difficult to do when urban development takes the form of expansion of existing cities, than when an entire greenfield city is being planned, but much is still possible. 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

There is also the challenge of the rising amount of solid waste and sewerage generated in cities, which 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, fossil fuels cannot be completely eliminated, and some residual use will remain in hard-to-abate sectors. The resulting 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 this to be 1.5% of the GDP. However, this will not only help in sequestering CO2, it will also have substantial co-benefits including ecological restoration and water management.

Carbon Capture, Utilisation 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.[36] 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 mitigation strategy discussed in this paper will involve massive investments. The shift towards renewables-based electricity requires large investments in RE generation capacity, transmission infrastructure, and battery storage. Producing the required capital equipment (e.g. solar PV panels and wind turbines) in the country will also require investments in setting up manufacturing capacity in these areas. 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 will also call for additional investments include efforts to reduce emissions from industries, households, and commercial establishments in urban areas, and to promote afforestation.

Investments related to mitigation must be supplemented by investments aimed at adaptation. Rising global temperatures will cause extreme weather events such as prolonged droughts and heavy floods to occur more frequently. 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 the sectors covered, the underlying GDP growth assumed, and also the time-period considered. Table 1 below presents a summary of the results of these studies.

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[37]	Electricity, EVs and H2 production	NZ by 2070	$202	$107	1.0%	2020 - 2069
IEA, 2022[38]	Energy	NZ by 2070	$160	$107	3.1%	2022 - 2030
McKinsey, 2022[39]	Energy and land-use systems	NZ by 2050	$600	$228	3.7%	2021 - 2050

**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.*

[36] 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

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

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

[39] 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 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 compared to a business-as-usual projection, where much of the expansion in electricity generation capacity would be through increased conventional capacity. Additional investment in RE, in this case, should net out the savings from the investment in conventional capacity that would otherwise have taken place. Admittedly, RE requires more capital per unit of electricity produced than coal-based plants, which could show up as higher investment. However, 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, by 2025 needed by all developing countries (excluding China) by 2025 would be about 3.8% of their combined GDP or $960 billion. The amount is even larger for later years.

This additional investment should not be viewed as a burden which comes at the cost of growth because the option of proceeding in a BAU 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.

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, as much as possible, to ensure that the private sector carries the burden.

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, with 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 and the shortfall is acknowledged in the Glasgow Pact, which noted that it 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.

What does this imply for India? Bhattacharya et al. (2022) suggest that of the $960 billion additional investment per year that developing countries (excl. China) have to make by 2025, nearly 44% could be mobilised through aggressive domestic effort, with the remaining 56% coming from international flows consisting of 22% from bilateral and multilateral international public funding, and 34% from private flows. They also suggest that the multilateral flows could be leveraged to encourage private flows into climate finance to their full potential.

The additional bilateral and multilateral flows together amount to about 0.8% of the GDP of developing countries other than China. Adopting these percentages for India, and given India's expected GDP of $3.8 trillion in 2025,[40] we can conclude that additional public international flows (multilateral and non-concessional bilateral) of about $32 billion per year would be needed by 2025, and these could be used to leverage private flows of almost $50 billion per year into climate related areas by 2025. These flows must be substantially expanded thereafter.

Our climate change negotiators have not emphasised flows from multilateral development banks (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 this scale 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 in due course, 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 emerging from our analysis is that there is considerable scope for reducing the volume of emissions 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. Some of the major conclusions on the feasibility of reaching net zero are summarised below.

1. The transformation required is feasible but it cannot be achieved by relying on a few critical innovations. Multiple inter-related interventions will be needed across several sectors: power generation, industries, transportation, buildings/cities and forestry. The cost of these interventions will be affected by future developments in technology, but with the whole world focussing on these challenges, it is reasonable to expect that costs will decline in future.

2. The multiplicity of interventions and their interconnectedness highlight the need for a "whole-of-the-economy" approach. It will be necessary to coordinate across different ministries, and different levels of government (centre and states) 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 the pace of electrification of the railways, but electrifying public transport is in the hands of state and local governments. Electrification of personal transport has to be led by the private sector automobile and battery manufacturers. Discoms, which are in urgent need for reforms if private investment is to be attracted into RE generation, are entirely in the hands of state governments. There are also areas which call for cooperation between the centre and the states, as seen in the security scheme of a tripartite arrangement between the centre, the state governments, and the RBI for assuring timely payments to power generators. The

[40] Based on the IMF World Economic Outlook (April 2022) forecast.

central government can also mobilise multilateral funds to support reform programmes in the discoms. Public-private partnerships will be required in setting up EV charging infrastructure in urban areas.

3. It is not possible to prepare a detailed plan for all the elements of the strategy spanning several decades in the future. There are too many uncertainties, including in technological development, which could affect how we progress in future. The best way to proceed is to outline well-defined, sector-specific plans for each of the major sectors for the first ten years based on current technological assumptions. This plan should have sufficient granularity so that those responsible for implementation are clear about what has to be done and progress can be effectively monitored. The national plan should be complemented by state-specific plans prepared by state governments, with adequate mechanisms for coordination between the two.

4. Examples of specific targets that could be set for the first ten years could include: (i) affirming the Indian Railways' target of reaching net zero by 2030; (ii) retiring old and inefficient coal power plants, and peaking use of coal around 2030 with subsequent phasing down; (iii) improving the financial health of discoms by setting efficiency improvement targets and encouraging state governments to privatise some parts of the distribution system (iv) building green H2 production capacity; (v) peaking CO2 emissions sometime soon after 2030; (vi) increasing the share of EVs in total auto sales; (vii) raising the minimum energy efficiency standards for the popular household appliances; and (viii) encouraging state governments to prepare climate action plans for major cities. Quantitative targets along these lines are important because they can be the guideposts to monitor progress towards the end objective. We can be sure that there will be some progress in all these areas: the question is whether it will be at the pace desired.

5. The approach of detailing plans for ten years at a time, leaving subsequent plans to be detailed later, gives much needed flexibility to deal with the fact that changes in technology may open new possibilities. For example, faster than expected progress in CCUS may allow a larger role for natural gas as a transition fuel, reducing the dependence on battery storage to deal with intermittency. Similarly, technological breakthroughs in H2 space may justify a different course of action in hard-to-abate areas.

6. 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.

7. The scale of the energy transition envisaged implies that there will be a large domestic demand for products related to the low-carbon economy like solar PV panels, batteries, electrolysers, wind turbines etc. It is logical to push 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.

8. The energy transition required will involve large investments in the energy and other sectors of the economy. Estimates of the additional investment needed vary, but it could be around 3% of India's GDP. Some of this will have to come from the public sector, but since the finances of

both the central and state governments are under stress, it is important to ensure the maximum possible private sector involvement. This means policies must be designed to encourage private investment, both domestic and foreign. Private investors from whom investments are expected should be actively involved in the process of designing policies so that their concerns can be suitably addressed. They must also be encouraged to express their concerns frankly.

9. 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 by 2023 at the latest 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.

10. The international community has to decide on the scale of financial assistance to be promised to developing countries before 2025, but the current international environment is not conducive to focussing on this long-term objective. India's chairmanship of the G20 in 2023 provides a well-timed opportunity to push for a bold global initiative in this area. At a time when the advanced countries are likely to slip into recession, a major push to investment demand in the emerging market countries would be just what is needed to give a fillip to the global economy.

Finally, it is important to note that although the actions announced by all nations in COP26 are a commendable break from the past, they 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. Since the consequences of exceeding +1.5°C are alarming, with India likely to be one of the worst sufferers, we should take an active role in pushing all countries to do more.

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. If this approach is accepted, the advanced countries would need to tighten their emissions trajectories and plan to reach net zero 5–10 years earlier than currently targeted. China too would have to advance its net zero date to 2050 (Ahluwalia & Patel, 2022). We should also be willing to do our part and tighten our trajectory commensurately if others agree to do so. Fairness requires that the advanced countries should take the lead in announcing tighter transition targets and the others can then follow.

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