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A Medium-Term Strategy for Transitioning to Net Zero by 2070

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Designed by Mukesh Rawat.

A Medium-Term Strategy for Transitioning to Net Zero by 2070*

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Table of Contents

List of Tables and Figures

List of Abbreviations

ADB	Asian Development Bank
ASPI	The Asia Society Policy Institute
BAU	Business-As-Usual
BEE	Bureau of Energy Efficiency
CBAM	Carbon Border Adjustment Mechanism
CEEW	Council on Energy, Environment and Water
CH_4	Methane
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CONCOR	Container Corporation of India
COP	Conference of the Parties
CSEP	Centre for Social and Economic Progress
ETS	Emissions Trading System
EV	Electric Vehicles
FAME	Faster Adoption and Manufacturing of EVs
FSI	Forest Survey of India
G20	Group of Twenty
GHG	Greenhouse Gas
GRIHA	Green Rating for Integrated Habitat Assessment
H_2	Hydrogen
ICE	Internal Combustion Engine
IESS	India Energy Security Scenarios
IEA	International Energy Agency
IGBC	Indian Green Building Council
LPG	Liquefied Petroleum Gas
MDB	Multilateral Development Banks
MNRE	Ministry of New & Renewable Energy
MoEF&CC	Ministry of Environment, Forest & Climate Change
MoRTH	Ministry of Road Transport and Highways
MSME	Medium, Small, and Micro Enterprises
NDC	Nationally Determined Contributions
PAT	Perform, Achieve and Trade
PLI	Production-Linked Incentive
PNG	Piped Natural Gas
PSU	Public Sector Undertaking
RBI	Reserve Bank of India
RE	Renewable Energy
RTS	Roof Top Solar
SCM	Standard Cubic Meter
SERCs	State Electricity Regulatory Commissions
SECI	Solar Electricity Corporation of India
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

Abstract

This paper assesses the feasibility of India achieving its stated goal of net zero by 2070 and presents a medium-term strategy for what would be required over the next decade to achieve this objective. It advocates a combination of price-based measures, such as an Emissions Trading System (ETS), and sector-specific interventions to facilitate the transition. The key elements over the next ten years would be (i) the design of the ETS, (ii) the pace of expansion of renewable energy (RE) capacity, (iii) the electrification of transport, and (iv) the shift to energy efficient systems, such as from private to public transport and from road to rail for freight. The paper also estimates that the additional investment needed to make this transition will be about 2% of India's GDP by 2030, much of which will have to come from additional public and private savings. In this context, some form of carbon pricing would help generate additional revenue. A major challenge is that action will need to be taken across several areas, with responsibilities divided among different ministries in the central government and, in many cases, with state governments. An internally consistent and cost-effective strategy can only be developed through close consultation between the different actors, and this will require the establishment of a high-level commission chaired by the Prime Minister. As some of the actions needed are also politically difficult, it will be necessary to build a broad political consensus on the need for change. This would be facilitated if the strategy were discussed and endorsed by a high-level centre-states forum. A subset of the targets in such a strategy could become India's new Nationally Determined Contributions (NDCs) to be submitted to the UN Framework Convention on Climate Change (UNFCCC) in 2025.

The global stocktake at COP28 in Dubai showed that the world is not on track to meet the global warming target, and all countries need to take stronger actions to reduce emissions if we are to avoid climate catastrophe. The issue is particularly important for India, as it will be one of the worst affected countries. India's response is also important for the world. Although India's per capita emissions are very low, they are rising rapidly due to robust growth, making India the fourth-largest emitter after China, the US, and the EU. Thus, India is systemically important in the struggle to control global emissions.

This paper explores what could be a credible medium-term plan for India consistent with its COP26 target of reaching net zero by 2070. The paper is organised as follows: Section 1 presents an assessment of whether it is technically feasible to reduce emissions to net zero, based on various quantitative studies that have examined the issue. Section 2 examines the role of price-based interventions—such as a carbon tax or a suitable alternative—in promoting a shift from polluting to non-polluting sources of energy, which is a critical part of the strategy. Sections 3 to 6 examine sector-specific interventions in various sectors that would help the decarbonisation objective. Sections 7 and 8 discuss, respectively, the steps that can be taken to build domestic manufacturing capacity to support the energy transition and the investment requirements of the transition. Section 9 draws the main conclusions.

1. Is Net Zero Technically Possible?

India's per capita income places it in the lower spectrum of the group of middle-income countries, and the government has set its developmental objective as elevating the country to "developed" status by 2047, which is the 100th year of India's independence. If this is interpreted as moving into what the World Bank categorises as the "high-income countries" group, it would require an average growth rate of 8.5% over the next 23 years.

Rapid growth at this rate will inevitably lead to an increase in energy demand, which would normally imply a substantial increase in energy-related emissions. To reconcile this with reaching net zero by 2070, India must follow a three-pronged strategy, as outlined below:

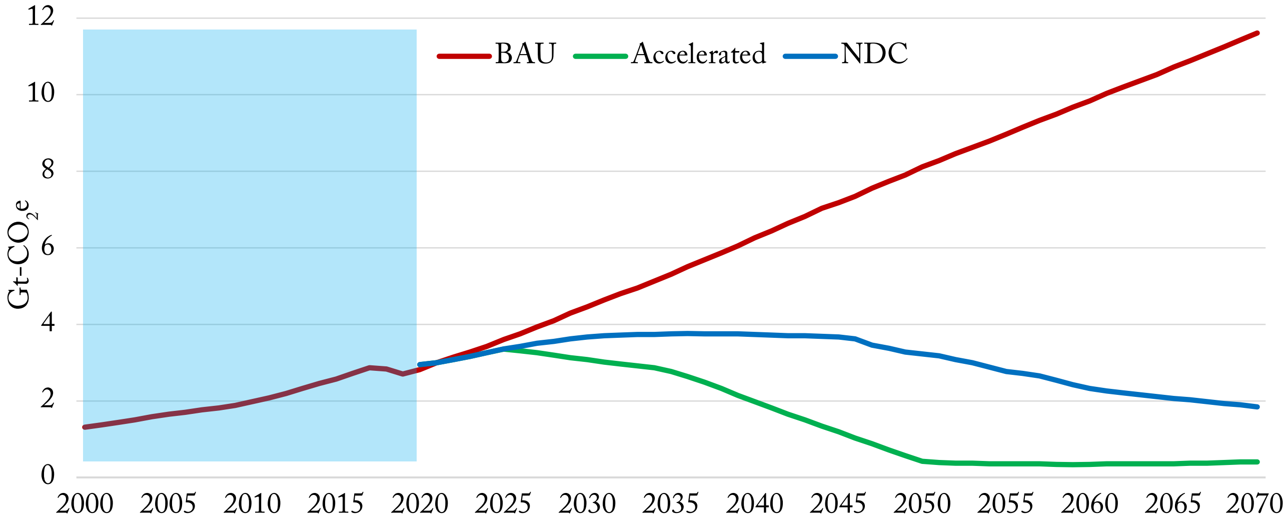
i) Improving Energy Efficiency Across Sectors. This will help reduce the growth in total energy needed to support faster GDP growth. This can be achieved through the adoption of more efficient processes in industry, as well as more energy-efficient appliances for individual uses, e.g., machines, cars, and appliances. Higher levels of energy efficiency can also be achieved by shifting to more energy-efficient systems, e.g., switching from private to public modes of passenger transport and from long-distance road freight to rail. The International Energy Agency (IEA 2021) estimates that on a path consistent with net zero, energy efficiency would account for about 17% of the reduction in energy sector emissions by 2040.

ii) Electrifying all sectors where possible to reduce the direct use of fossil fuels in individual sectors. Electrification is commercially viable in many sectors but not yet in all. For example, it is not yet viable in heavy freight movement by road, air transport, shipping, mining, steel and cement production, etc. In these cases, alternative energy carriers such as green hydrogen, which are being explored, or carbon capture, utilisation, and storage (CCUS) could provide solutions. These present a range of problems with varying degrees of complexity, but it is reasonable to expect that technological advances in the future will make them commercially successful. However, electrification alone will not achieve decarbonisation if the electricity used continues to be generated from fossil fuels. This makes the third component of the strategy, outlined below, absolutely critical.

iii) Shifting Electricity Generation to Renewables and Other Clean Sources. This is an essential complement to electrification, especially because the electrification of final energy use will accelerate the growth of electricity demand. Fortunately, there are good reasons to be optimistic about this component of the strategy, as India has significant potential for solar and wind power. There is also scope to increase the supply of hydro and nuclear power, though both are subject to other constraints.

The extent to which India could reduce its total emissions has been examined in several studies, including by TERI/Shell (2021), the IEA (2021), CEEW/Chaturvedi & Malyan (2022), ASPI (2022), McKinsey/Gupta et al. (2022), and NITI Aayog (2023). These studies differ in several respects, including the underlying growth rate assumed, but the broad picture that emerges is that emissions can be reduced substantially, provided strong actions are taken in several areas. The scale of the challenge in getting to net zero is illustrated by Figure 1, taken from McKinsey/Gupta et al. (2022), which shows the extent to which the business-as-usual (BAU) projection has to be bent by following alternative policies.

Figure 1: McKinsey's Projections of India's Annual GHG Emissions



Source: McKinsey/Gupta at al. (2022)

Note: Includes emissions from land-use, land-use change and forestry.

The red curve represents a BAU scenario showing the likely trajectory of India's GHG emissions, assuming that the emissions intensity of GDP continues to decline at the historical average rate of 1.3% p.a. The outcome is a steady rise in emissions, which is clearly inconsistent with India's declared net zero objective.

The blue curve shows the impact of implementing India's NDCs by 2030 and continuing at a similar level of effort thereafter, but with no significant increase in ambition. This is a significant improvement over the BAU projection, with the emissions trajectory growing slower and then flattening and declining gradually thereafter, but remaining well above zero by 2070.

The green curve presents the results of a McKinsey study by Gupta et al. (2022) to reach net zero by 2050. It includes a much faster expansion of renewable energy (RE) capacity beyond 2030, an accelerated transition to electric vehicles (EVs), a shift to low-carbon steelmaking, adoption of less carbon-intensive methods of agriculture and cattle rearing, introduction of carbon taxes, technological breakthroughs in CCUS, complete waste treatment and material recycling, etc. Since this scenario is calibrated to reach net zero by 2050, whereas India's current target is net zero by 2070, it can be argued that the measures India will need to take would be less demanding than those implied by the green curve but would still be extensive. If we are persuaded to improve our net zero target, as a result of what happens in the upcoming COPs and what other countries do, then the policies would need to be significantly strengthened.

1.1 A Medium-Term Agenda

The projection implied by the blue curve in Figure 1 demonstrates why the global stocktake at COP28 concluded that the current climate change mitigation actions by all countries are inadequate to meet the internationally agreed targets, and that all countries need to do more.[1] All countries, including India, have been asked to submit updated NDCs containing more ambitious mitigation actions for the period 2025 to 2035, and this presents an opportunity for India to go beyond the existing NDCs and propose stronger targets as its contribution to building a global consensus on a "just transition."

India's current NDCs are listed in Box 1. They consist of selected aggregate targets up to 2030, with no commitment on expected total emissions. Since the announcement of the net zero target at COP26, there has been much discussion in different government ministries, corporate boardrooms, think tanks, and within civil society on what needs to be done. Some state governments are also starting to define state-level climate action plans. These discussions provide the basis for a more substantive medium-term plan for 2025-2035.

[1] Climate Action Tracker, a well-known independent group that assesses countries' climate commitments, has stated that India is likely to meet or even exceed its 2030 NDCs; however, these commitments are not strong enough to meet the global climate target. Based on this criterion, CAT has rated India's actions, as well as China's, as "highly insufficient." The US and the EU are rated as "insufficient."

Box 1: India's Current NDCs

The main elements of India's COP26 NDCs are as follows:

(i) Reduce the emissions intensity of GDP by more than 45% by 2030, compared to the 2005 level. This is an improvement over the 33-35% committed in Paris in 2015.

(ii) Increase the share of non-fossil fuels-based electricity generation capacity to 50% of the total capacity, or 500 GW by 2030, up from the previous target of 40%. The new target is based on a separate RE target announced in 2019, aiming for 280 GW of solar and 140 GW of wind power capacity by 2030.

(iii) The afforestation target announced in 2015—to create an additional 2.5-3 Gt-CO_2e forest sink by 2030—remains in force although it was not explicitly mentioned.

An obvious area where we could elaborate our NDCs is to do what many other countries have done and include some quantitative medium-term targets for total emissions. The EU, for example, aims to reach net zero by 2050 and has committed to reducing emissions by 55% by 2030 and 90% by 2040 compared to 1990 levels. Similarly, the US has committed to reduce emissions by 51% compared to 2005 levels by 2030, making electricity 100% carbon-free by 2035, and achieving a net zero economy by 2050. China has pledged to peak CO_2 emissions before 2030, reduce the CO_2 emission intensity of GDP by more than 65% by 2030 from 2005 levels, and reach net zero by 2060. Indonesia, Brazil, and South Africa have also defined emission targets in terms of absolute emission levels to be reached by 2025 and 2030.

India could set more specific targets related to the total level of emissions for the period from 2025 to 2035. For instance, we could indicate the date after which no new coal plants will be approved and also the date by which emissions from electricity generation will peak. Specifying such targets will increase international recognition of India's commitment to climate change mitigation, and also help raise domestic public awareness of what needs to be done.

In the rest of this paper, we outline a feasible approach to defining a more detailed plan for reducing emissions. We focus only on the mitigation component of the strategy, recognising that it is only one part of climate change management. Adaptation is the other part, which deals with how to respond to the climate change that has already occurred and will continue to occur even on optimistic assumptions about mitigation because of lagged effects. Given India's high vulnerability to the effects of climate change, adaptation must be part of any national climate change management strategy. It also calls for a wide range of measures, including building climate-resilient urban infrastructure, introducing water conservation and management systems to cope with changes in precipitation and floods, developing heat-resistant crop varieties, etc. In fact, in many areas, such as buildings and agriculture, there are strong synergies between mitigation and adaptation. We touch on these at various points in the paper, but a detailed discussion of adaptation is beyond the scope of this paper.

There is merit in unveiling a national strategy for managing climate change that includes both mitigation and adaptation. Since NDCs are international commitments, it might be felt that they need not contain all aspects of the national strategy. The issue of which part of the domestic strategy to include in the NDCs for submission to the UNFCCC can be decided separately. However, publishing a more detailed plan of what we hope to achieve by 2035 has many advantages. It will certainly add to international credibility and, more importantly, help build public support in India, including getting state governments on board.

2. Setting a Price on Carbon

Switching from fossil fuels to renewable energy (RE) would not be a problem if RE were cheaper. Market forces would bring about the switch because all new electricity generation capacity, both for expansion and replacement, would automatically be RE. The costs of both solar and wind power have indeed declined sharply over the past two decades, but electricity from RE remains more expensive than coal-based power because it is intermittent and requires storage to ensure an even supply. Cost comparisons based on market prices suffer from a serious distortion because the price of coal does not reflect the social costs arising from its adverse impacts on global warming and local air pollution. If a carbon tax were imposed on coal to reflect the social costs of its use, it would make RE the preferred option.[2] The tax would also generate revenue, which could be used to compensate low-income households that need protection from the distributional impacts of the tax, as well as to fund some necessary adaptation measures.

Although this provides a strong theoretical basis for the introduction of a carbon tax, the prospects for imposing such a tax are limited, as it has very few takers even among the large advanced economies.[3] Without global adoption, it is unlikely to gain traction in developing countries. What has gained more acceptance is the adoption of emission trading systems (ETS), which have been introduced by the EU, China, Germany, and some states in the US. An ETS operates, not through prices, but through quantities: it limits the emissions allowed for certain producers in energy-intensive sectors of the economy.[4] It has a similar effect to an explicit carbon tax in reducing the use of fossil fuels, although it is less directly visible because it is generally imposed on selected large producers covered by the ETS.

India does not have an ETS at present, but a recent amendment to the Energy Conservation Act 2001 allows it to be established and the Bureau of Energy Efficiency (BEE), an agency under the Ministry of Power, is reportedly working out the details. It is expected that the ETS will initially apply to larger producers in select industries viz., iron and steel, cement, fertilisers and chemicals, and pulp and paper. It is not clear whether the power sector will be included; in our view, it should be included, at least very soon if not immediately.

The BEE has previously administered the Perform, Achieve and Trade (PAT) scheme, which aimed at improving energy efficiency by setting annual energy efficiency targets for different industries. There are similarities between the PAT and an ETS, but the latter will be much more demanding as it will not be sufficient just to aim for a reduction in emissions. It will have to aim for reductions to net zero emissions by a target date. In our view, the ETS should have the following features:

(i) Each producing unit should be allocated emissions allowances based on output (e.g., t-CO_2 per MWh of electricity or tonne of steel). This could be set initially at the industry average of the previous year. Units exceeding their allowance would need to buy credits from under-emitting units across all industries covered, creating a unified market-priced carbon credit system.[5] The regulators can also set floor and ceiling prices of the credits to ameliorate price uncertainty issues and create confidence in the system.

(ii) Emission allowances for different sectors will need to be steadily reduced over time consistent with national decarbonisation targets. This is crucial for the country to progress towards net zero emissions.

(iii) Allowances could be distributed for free in the initial years, followed by an increasing proportion being auctioned over time. Auctioning would generate revenue for the government which could be used for climate-related expenditure, thus providing some of the revenue advantages of a tax.

Administering the ETS will require a high-quality regulatory system to determine (i) the initial allocation of allowances across industries and (ii) to calibrate the pace of emission reduction in each industry. It will also require a credible mechanism to accurately measure both direct and indirect GHG emissions to check whether a unit has saved or exceeded its allowance.[6]

[2] The social cost of carbon has been estimated at around $100 per tonne-CO2, and in one recent study, it was as high as $185 per tonne-CO2 (Rennert et al., 2023). Even a carbon tax of $25 per tonne would double the price of coal.

[3] As of 2023, the only exceptions with explicit carbon taxes in addition to fuel taxes are, Switzerland and Liechtenstein at $131 per tonne, and Sweden with a carbon tax of $126 per tonne. Source: World Bank (n.d.).

[4] It should be noted that while those outside the system are not directly affected, they are subject to second-round effects. The increased operational costs incurred by the larger producers within the ETS will be reflected in the prices of their outputs, thus indirectly raising costs for all downstream producers.

[5] Allowances are linked to output. If total output is less than what was initially reported, the left over allowances need to be surrendered without claiming them.

[6] Indirect emissions could be on account of, for example, the use of electricity that is purchased from the grid and not captively generated. If these are not included, units covered by the ETS could avoid the need to reduce emissions by shifting their demand to the grid.

At present, there are industry-specific regulations for reducing emissions (e.g., RE purchase obligations on discoms or green hydrogen use obligations, both of which are discussed later in this paper).[7] The ETS could be superimposed on the existing system. Once confidence in its functioning is established, industry-specific regulations on fuel use could be phased out to reduce distortions in the market price of credits.

The need to purchase allowances or credits will add to the costs in emitting sectors. This is a real cost that must be borne by the polluting industry in accordance with the "polluter pays" principle of our environmental policy.[8] The industry, in turn, will pass the higher costs on to consumers, just as would happen with an optimal carbon tax.

The proposed ETS could also help address border carbon adjustments tariffs that would be imposed by the EU/UK on carbon-intensive exports such as steel and cement from countries without domestic carbon pricing. Developing countries, including India, have protested these tariffs as a form of disguised protectionism that violates WTO principles. However, with the WTO's dispute resolution mechanism currently inoperative, appealing to the WTO may not be effective.

It should be noted that the mere introduction of an ETS will not guarantee an exemption from the Carbon Border Adjustment Mechanism (CBAM) if the implicit carbon price emerging from the Indian ETS is lower than that of the EU or the UK, which is very likely.[9] We could attempt to persuade the EU/UK to establish different levels of carbon prices as benchmarks for imposing CBAM duties, based on the income level of exporting countries.[10] Ultimately, if a CBAM tax on our exports becomes unavoidable, it would be more advantageous for India to impose a tax on our exports and retain the revenue, which can be recycled to support domestic decarbonisation efforts, than to let the importing country collect the tax and use the revenue.

3. Decarbonising Electricity Generation

Electricity generation in India depends heavily on coal and contributes to 36% of India's total GHG emissions. India's climate management strategy rightly emphasises the need to shift to non-polluting energy sources, and this is reflected in India's current NDCs, which target 500 GW of non-fossil fuel-based electricity generation capacity (see Table 1).

Good progress has been made in this area, with the total solar and wind capacity expanding from about 4.5 GW in 2005 to just under 134 GW in 2023. This is one of the fastest rates of expansion in the world, albeit from a small base. However, India's performance is similar to that of other developing countries. Between 2014 and 2022, India's RE capacity increased 3.7 times to 115.8 GW. In the same period, ASEAN countries' capacity increased by 3.9 times to 47.6 GW. China's performance was much stronger, with a sixfold increase in capacity to 793 GW. In fact, China added close to 300 GW of solar and wind capacity in 2023 alone! In terms of share, RE (excluding large hydro) accounted for 13% in India's electricity mix in 2023, compared to 18.2% in China.

Table 1: Total RE Capacity (excluding large hydropower): Achievements, Targets and Projections (GW)

	2005	2023#	2030	2040##	2050##
Solar PV (utility + rooftop)	-	73.3	280	576 - 983	1,372 - 2,172
Wind (onshore and offshore)	4.5	44.7	140	247 - 401	394 – 566
Other*	1.5	16	30	-	-
Total	6.0	134	450	823 - 1,384	1,766 - 2,738

**Other includes small hydro, biomass and waste-to-energy, concentrated solar, etc.*

#Source: National Power Portal (n.d.), ##Source: McKinsey/Gupta et al. (2022)

7 It is possible that overlapping regulations could lead to reduced demand for emission credits in the market, resulting in low carbon prices. This could be overcome by carefully allocating emission allowances to entities that have to comply with different regulations.

8 Although we recognise that this principle does not apply to units that are excluded from the ETS or receive free allowances.

9 For example, the average carbon price from the ETS in China , was \$8.15/t-CO2 in 2023, compared with \$96.3/t-CO2 in the EU (World Bank, n.d.).

10 An IMF Staff paper (Parry, Black & Roaf, 2021) suggested that carbon prices should vary for countries at different levels of development—\$25/t-CO2 for lower-middle-income countries (e.g., India), \$50/t-CO2 for upper-middle-income countries (e.g., China), and \$75/t-CO2 for high income countries (e.g., the US or the EU).

To meet the 2030 targets and maintain the momentum in the future, it is necessary to identify the key constraints that hinder the pace of expansion. In the next section, some of the initiatives needed, which could be suitably incorporated into the medium-term climate management plan for 2025-2035, are discussed.

3.1 Financial Viability of Discoms

The Achilles' heel of the Indian electricity system is on the distribution side. The distribution companies (discoms), which are mostly in the public sector, incur significant losses every year, even after accounting for state government subsidies. Since the present strategy relies heavily on private investment to achieve rapid expansion in capacity, the financial weakness of most discoms is a major constraint, discouraging potential investors due to the perception of a high risk of default. This would be a problem even if the capacity expansion were coal-based, but it is much more so in view of the energy transition being attempted because (i) renewables are more capital intensive and require much larger debt financing, and (ii) electricity demand will be much higher because of electrification.

The problem has been addressed for the time being by introducing a tripartite arrangement, whereby state governments agree that the RBI will pay the generator directly and debit the state government's account with the RBI in case of default by the state discom.[11] This has helped maintain the momentum of investment in the initial stage, but it is, at best, an interim solution. The permanent solution must lie in implementing reforms that strengthen the financial conditions of the discoms.

Experience in pushing for such reforms has not been encouraging so far. Four such reform efforts have been attempted by the government over the past two decades, and while there have been signs of improvement in some states, the problem largely persists.[12] The root cause is political: state politicians do not allow the discoms to charge adequate tariffs, and electricity prices for many categories of consumers are therefore kept much below supply costs.[13] Without adequate compensation to discoms for the shortfall in revenue collection, their losses continue to compound. Depoliticising the setting of electricity tariffs remains a major challenge.

Privatisation of discoms could be one way to address the problem, but it has very little support across the political spectrum, despite the fact that there are a few private discoms operating in India and they are performing quite well (Devaguptapu & Tongia, 2023). Many believe that since the problems arise from excessive political intervention, a private discom would not fare any better. This ignores the fact that the management of privatised discoms would have much stronger incentives to resist political interference or "otherwise manage" political pressures, something that managements of government-owned discoms cannot do. However, action in this area lies entirely within the domain of state governments. They should be persuaded to experiment by privatising some parts of the distribution system. This would at least provide benchmarks of how far privatisation can help in improving electricity distribution.

3.2 Intermittency and the Need for Storage

A second problem is that RE is intermittent and requires storage capacity to balance the intermittency of supply. The extent of intermittency can be reduced by combining solar and wind generation, but this will still require substantial investment in storage, which adds to the cost of RE. Opinions vary on how much this affects the competitiveness of RE. Some recent bids for "round-the-clock" power from blending solar, wind, and storage capacities have proved surprisingly competitive with power from new coal-based plants. However, this outcome may be very case-specific.[14]

11 Under the arrangement, a state, an RE generator, and the RBI enter into a tripartite agreement, which is administered by the Solar Electricity Corporation of India (SECI)—a Government of India company.

12 The latest of these reform programmes is the Revamped Distribution Sector Scheme, which was launched in 2021-22 for a period of five years. The scheme envisages financial incentives to state governments conditional upon improvements in discom's performance.

13 A recent study by Tyagi & Tongia (2023) estimates the gross annual losses before subsidies and other support at over ₹2.3 trillion for 2019-20, or about 1.2% of India's GDP. See also Devaguptapu & Tongia (2023).

14 In a tender for 1 GW round-the-clock power floated by the Railway Energy Management Company Ltd. in January 2024, NTPC Renewables was one of the winners with a capacity allocation of 500 MW at a bid price of ₹4.1 per KWh (Solar Quarter, 2023). In a separate tender for the installation of a 500 MW/1000 MWh battery by SECI in December 2023, the cost of energy storage discovered was ₹1.1 million per MW per month, or about ₹10.18 per kWh (MNRE 2023).

The government has tried to address the competitiveness problem by administratively forcing discoms to source a progressively higher proportion of their power from RE generators. While this increases the share of RE, it also raises average costs, much like a carbon tax would.

Optimists hope that this problem will disappear because: (i) the cost of solar and wind electricity will continue to fall as technologies improve, and (ii) battery costs will fall due to economies of scale. This may happen, but future trends in battery storage costs are difficult to predict. Existing battery technology relies heavily on refined lithium, the supply of which is controlled by China. Experiments are underway using other battery chemistries, e.g., sodium-ion, and if these prove successful, the situation could change.

3.3 Transmission Capacity for RE

Greater reliance on RE would typically favour the decentralisation of electricity generation compared to a coal-based system, in which generation is generally located near coal mines. However, in India, the transition will imply a major geographical shift in electricity generation toward the western and southern regions of the country, where solar and wind potential is high. Surplus electricity from these regions will need to be transmitted to other regions, necessitating new high-power interstate transmission lines.

Planning the transmission system for the future will present new challenges. Planning for grid expansion to reflect the anticipated location of future RE capacity is an activity that has to be taken up by the central government, through the Power Grid Corporation of India. As a central public sector organisation, it has experience with land acquisition and other regulatory clearances involving state governments and is well-placed to undertake this activity. The infrastructure once built could later be privatised to pay off debt or be used to fund new infrastructure. In planning new transmission systems, the addition of storage capacity near RE generation sites would help reduce the scale of transmission capacity required. This would defer the need for new high-capacity transmission lines, as not all electricity would need to be evacuated during RE generation hours.

The technical capacity of the system operator and load despatch centres will also need to be improved to enable better management of an RE-dominated grid. This would include incorporating weather forecasting capabilities to ensure any generation shortfall can be timely offset through other power reserves in the system.

3.4 Structure of Electricity Trading

Dealing with an RE dominated power system with high variability in supply has implications for electricity markets. It will increase reliance on short-term contracts to meet shortfalls. The present framework prescribes discoms to have at least 75% of their total capacity requirements covered by long-term PPAs and at least 10% by medium-term contracts.[15] It may be necessary to allow a larger volume of short-term contracts traded on power exchanges, considering the expected increase in demand for short-term balancing. The markets would need to expand and the regulators to facilitate the expansion in anticipation of the growing demand.

Greater potential variability in supply should also be reflected in greater variability in prices, including prices charged to consumers through time-of-day tariffs. Price-based interventions like these can help reduce peak demand, which, in turn, can considerably reduce the need for storage. Tariff regulation constitutionally falls under the purview of state electricity regulators, although the central government can, and does, issue advice. At present, many states allow time-of-day variation in tariffs for large industrial and commercial consumers, but not for residential consumers.[16] The central government has pronounced that all State Electricity Regulatory Commissions (SERCs) should implement variable tariffs before April 2024 for all commercial and industrial consumers and from April 2025 for residential consumers. However, the range of intraday price variation is currently limited to 20%. This may need to be widened to encourage a greater demand response. State electricity regulators should prepare for such changes in anticipation of the ongoing energy transition.

[15] The existing Resource Adequacy Planning Framework of the Ministry of Power (2023) prescribes that discoms should have at least 75% of their total capacity requirements covered by long-term PPAs and at least 10% via medium-term contracts.

[16] Several states (Karnataka, Madhya Pradesh, Gujarat, Rajasthan, and Tamil Nadu) have implemented time-of-day tariffs for industrial and commercial users with connections above a certain rated power.

3.5 Constraints on Rooftop Solar Capacity

An area where capacity expansion has been substantially below targets is rooftop solar (RTS). RTS capacity in 2023 had reached only 10.5 GW against a target of 40 GW by 2022 (Mercom India, 2024a). This is primarily because the low feed-in tariffs offered by discoms result in very low returns on investment in RTS systems, even after accounting for capital subsidies offered by the government.

In many states, RTS operates through feed-in tariffs offered by discoms, which are calibrated to the cheapest source of power they buy. This reduces the return to consumers from investing in RTS. If "net metering" were permitted, households would be able to draw on electricity generated from their RTS and be charged only for the power they draw from the grid. However, discoms are unwilling to do this for fear of losing business from high-consumption households, who pay a higher tariff (and are also more likely to install RTS), as this is seen as cross-subsidising the low tariffs charged to low-consumption households. There should be a middle way, with discoms offering a higher feed-in tariff that would increase the incentive for households to invest in RTS, while providing discoms reasonable compensation for serving as a source of stable power supply.

3.6 Phasing Out Coal-Based Electricity Generation

The need to phase out unabated coal-based power generation has come up repeatedly in COP discussions. India has resisted pressure to make commitments on this issue for good reasons. India's power generation capacity is heavily coal-based, its coal plant fleet is relatively new, and several new plants are under construction to meet growing power demand. However, it is also true that phasing out coal-based generation is an essential part of a net zero strategy, and there is, therefore, a case for spelling out the pace of the transition in more detail.

It makes sense to announce a target year, within this decade, after which no new greenfield unabated coal power plant would be approved for construction. Coal power plants have an average life of 35 to 40 years. This means that if the last new coal plant is commissioned in the late 2020s, all coal plants would be phased out by 2065 at the latest, and possibly sooner depending on the pace at which RE costs fall and emissions pricing is introduced under ETS.

Similarly, a target year could be set for when coal-based electricity generation would peak. China has announced that it will peak coal-based electricity generation within this decade. India could plan for peaking sometime in the next decade.

Phasing down coal mining will be a major structural change, affecting the livelihoods of many households directly and indirectly engaged in coal production. The impact will also be concentrated in a few states that are also among the poorest in India. Although the transition to RE will create new jobs, and these are likely to be of better quality than coal mining, most of these will be in other states. Fortunately, this process will take about a decade or so to start unfolding and will be stretched over two decades, but it makes sense to anticipate it and prepare a national policy for reskilling younger coal miners to enable them to find jobs in other sectors.

The decline in coal production after 2035 will have a fiscal impact on coal-producing states, which currently benefit from royalties on coal sales. Additional transfers from the Centre to the states may need to be considered in due course to compensate for the loss of revenue. This issue can be taken up by future finance commissions. Additionally, there is the challenge of sharing revenues from the auctions of allowances under the ETS between the Centre and the states. These revenues would help meet the fiscal costs of the energy transition and should logically be shared between the Centre and the states. However, as they do not constitute tax revenue, they would not be covered by the terms of reference of the finance commissions.

3.7 Expanding Other Clean Energy Sources

Hydro and nuclear power are other potential sources of clean energy that should be expanded faster than planned. The expansion of hydro capacity has been held back in the past by environmental and resettlement concerns, but it is an extremely valuable source of power, especially because it can be used to balance intermittent supply from RE sources. The scope for faster expansion of hydropower, with more generous compensation for displaced people and due regard for environmental concerns, makes sense and should be urgently explored.

Hydropower imports from Nepal and Bhutan are part of the current policy. There is a case for offering a higher tariff during low RE generation periods to incentivise Bhutan and Nepal to shift the timing of supply to India during periods when it would help balance intermittent supply from RE.

Nuclear capacity is another area where a much larger effort is necessary. India's present nuclear capacity of 7.5 GW contributes less than 3% of electricity supply, much lower than in many other countries.[17] The US, UK, France, Canada, South Korea, and Japan have pledged to triple their nuclear power capacity by 2050. India's operational nuclear capacity is expected to double over the next decade, but much more ambitious expansion would be needed in the subsequent decades.

A faster expansion of nuclear capacity would be aided by allowing greater private sector involvement, which would ensure better financial planning and execution. However, this will call for a change in current policy, which restricts the private sector to a minority shareholding and also restricts its participation to "non-core" areas, excluding the operation of nuclear power plants. This needs to be urgently reviewed. The operation of nuclear power plants could be opened up to the private sector, subject, of course, to strict safety standards overseen by well-staffed regulatory bodies. Opening up to the private sector is especially important in view of the growing interest in small modular nuclear reactors.

Involving the private sector will also require an amendment to India's current Nuclear Civil Liability law. The current provisions are out of line with international practice and discourage private entities (whether domestic or foreign) from entering into active/majority partnership. This is an urgent reform that should be initiated immediately.

In summary, the apparently simple objective of switching from fossil fuels to RE requires a complex maze of supportive actions in many different areas. This is a clear case where implementation cannot be left to individual ministries and states acting in silos. It calls for a whole-of-the-economy approach.

4. Decarbonising Transport

Electrification involves using electricity to displace petrol, diesel, and natural gas as sources of final energy, and the greatest scope for doing so is in transport i.e., automobiles and trains. As pointed out in Section 2, electrification alone will not reduce total emissions if the electricity used is coal-based, but combined with the parallel shift to RE discussed above, it will ensure decarbonisation over time.

4.1 Electrification of Road Transport

Electrification of passenger transport is a low-hanging fruit that is being pushed by governments around the world with various kinds of subsidies. This is also being attempted in India with the FAME (Faster Adoption and Manufacturing of EVs) scheme, providing subsidies for the manufacture and sale of EVs.

India is still at an early stage of the transition, and the share of EVs in total sales in 2023 was only 5% for two-wheelers, 3.3% for buses, and 2.1% for passenger cars (MoRTH, n.d.).[18] It was very high at 53% for three-wheelers because these are commercial vehicles used for passenger and light goods transport within cities, generally for short distances where speed is not of much concern. Sales of EVs in all categories will pick up fast with new models being launched by established and new manufacturers. The availability of models at the right price points is critical, as demonstrated by the remarkable success of BYD in China, which has made China the largest producer of EVs, accounting for almost 60% of global EV sales.

The most important prerequisite for a faster uptake of EVs is the development of adequate standardised fast-charging infrastructure in and around cities and on major highways.[19] There are only about 12,000 public charging points (fast and normal) in India, mostly concentrated around major cities (Swarajya, 2024). This number has to be increased many times over. The government has a very important role to play in this process in various ways. Since the infrastructure needs to be in place in anticipation of the market, the responsibility has to be shared among the public sector oil marketing companies that operate fuel stations, the local discoms that provide the electricity, and private sector entities that can provide the charging equipment. Clear targets should be set for this area, with states agreeing to do their bit.

The automobile sector can be pushed to shift more rapidly towards the production of EVs. This

[17] France and South Korea, for example, generate 70% and 27% of their electricity from nuclear power, respectively, and even Japan generates 7%.

[18] The percentages include EV sales data for all states except Telangana whose data is not available on the national portal of MoRTH.

[19] The Ministry of Power (2022) has issued guidelines and standards for charging infrastructure for EVs.

can be done through a statutory ban on the sale of internal combustion engine (ICE) vehicles after a certain date. The EU has announced that no sale of ICE vehicles will be allowed after 2035. It is too early to make a comparable announcement in India, but once penetration in new sales for a particular category of vehicle reaches, say, 50%, a date could be set after which no sale of ICE vehicles in that category will be allowed. This implies that a firm date for phasing out the sales of ICE three-wheelers can be set now, in consultation with the industry, with similar dates for other categories to follow. An alternative approach is enforcing strict emission standards on vehicles or on automobile manufactures so that compliance with the new standards incentivises production of zero-emission vehicles.

The central government could give a further push by announcing that all new government vehicles, whether owned or leased, must be electric. This could also be prescribed for central government PSUs, and state governments should be encouraged to follow suit. State governments could also consider a policy of licensing only EVs for taxis by some date in the future. These administrative interventions are an indirect form of subsidy support for EVs but are necessary in the early years to accelerate the transition.

The shift to EVs will involve a consequential structural change in the auto components industry, as EVs require far fewer components. While automotive component production may decline, the scale of battery production will increase dramatically. Batteries are clearly a sunrise industry, as they will be needed not only for automobiles but also for grid-scale storage. For existing original equipment manufacturers that specialise in high-tech components, diversifying into battery component manufacturing, assembling, and recycling could be an option. When EV batteries reach their end of life, they could easily be adapted for static applications, such as behind-the-meter storage in conjunction with RTS systems.

4.2 Shifting From Private to Public Transport

As urbanisation accelerates in India, the demand for urban transport will increase, and if the trend towards increased reliance on private transport continues, it will cause higher GHG emissions and also particulate matter pollution. The latter is already at hazardous levels in most large cities. It will also lead to traffic congestion, which is a major problem in many cities. A shift to EVs will reduce tailpipe emissions and also particulate matter pollution, but the effect will be felt only as the proportion of EVs on the roads increases significantly, which will take time. Besides, it will do nothing to reduce the problem of traffic congestion.

This is where shifting from private to public transport could make a big difference over the next decade or so. Public transport is much more energy-efficient and has much lower emissions per passenger-kilometre than private transport. It also occupies much less space on city roads, thus easing congestion. However, persuading commuters to switch from private to public transport is not easy. It will only happen if the public transport system—a combination of buses and metros—is both reliable and comfortable. This is also an area where almost all responsibility rests with state governments and city corporations.

The introduction of e-buses can make a big difference, but they are up to three times more expensive than diesel/CNG buses, and most urban transport authorities are not financially in a position to acquire a large number of e-buses. An alternative approach that treats e-bus mobility as a service is being tried with promising results. Convergence Energy Services Ltd. (a central PSU) acts as an aggregator for city transport authorities by inviting bids for operating e-buses for ten years at a fixed cost per kilometre, with a guaranteed payment for a minimum number of daily kilometres. This has yielded bids that are competitive with the cost of running diesel/CNG buses. Private contractors acquire, operate, and maintain the buses for the transport authority, with the authority in sole charge of fare collection from passengers. The central government has also introduced the PM e-Bus Sewa scheme, which aims to deploy 10,000 e-buses in 169 non-metro cities in India over three years. The scheme includes a payment security mechanism to ensure that e-bus operators are paid in case a state government or local transport authority defaults.

The shift to public transport can be accelerated by other incentives, such as (i) interoperable mobility passes (e.g., the National Common Mobility Card) that allow the seamless use of bus and metro services in the city, (ii) mobile-based real-time information systems on bus arrivals at stops to facilitate commuting, (iii) shared mobility and active transport options (e.g., bicycles), and (iv) higher parking and/or congestion charges to discourage private car use in areas well served by public transport. The responsibility for urban transport lies entirely with state governments. They could be encouraged to start with a few cities and, based on the experience, expand the services to other cities.

4.3 Electrification of Railways

Indian Railways has electrified about 94% of its broad gauge rail network and expects to reach 100% by 2025. This is an important achievement, but electrifying the track does not ensure the electrification of all rail traction. To achieve this, the Railways will have to phase out diesel locomotives, which account for approximately 31% of the total locomotive fleet. Although demonstration projects are underway to convert diesel locomotives to electric locomotives and to power them with hydrogen fuel cells, these endeavours currently remain experimental (Economic Times, 2023).

A substantial reduction in emissions can be realised by shifting freight movement from road to rail. This will require a reversal of the downward trend in the share of railways in total freight movement, which has been falling steadily to 27% in 2022. The Ministry of Railways has set a target to increase the share to 45% by 2030 (Ministry of Railways, 2022). This would make a big contribution to decarbonising the transport sector, and progress towards this ambitious target should be closely monitored. It will be particularly difficult as the transport of coal, which is heavily dominated by the railways, is set to decline as electricity generation shifts to RE.

The Container Corporation of India (CONCOR) will undoubtedly play a major role in achieving the increase in the freight share but special efforts should be made to encourage private sector logistics companies to compete with CONCOR. These companies have a strong consumer orientation and could attract business from small and medium enterprises (SMEs), which generally have small consignments and prefer a door-to-door arrangement with strong consumer-facing logistics companies that can use a combination of road and rail transport to provide seamless movement of goods with real-time tracking. However, these companies will invest adequately in developing this business only if they are assured a level playing field vis-à-vis CONCOR, with non-discriminatory and transparent access to rail freight services. The existing policy framework should be carefully reviewed to see how it can be made more attractive to private players. There is a strong case for privatising CONCOR to ensure a level playing field.

The electrification of road and rail transport will reduce the demand for petrol and diesel, which are currently heavily taxed, and increase the demand for electricity, which is not. This is a major structural change with fiscal implications for both the Centre and the states. The total revenue loss from phasing out petroleum-based fuels could be as much as 3.2% of GDP by some estimates (Bhandari, Verma and Nandipati, 2023). The increase in demand for electricity due to electrification will have a negative impact on state budgets if discoms continue to run losses on electricity supplied. These possibilities underscore the need to protect state government budgets through a combination of (i) rationalising taxes on other commodities to offset the loss of petroleum tax revenues, along with (ii) some rationalisation of electricity prices charged to consumers to reduce losses. Both are politically sensitive issues, but state governments have to realise that these are unavoidable consequences of decarbonisation and start trying to convince voters that these measures are necessary.

We have not discussed the scope for decarbonising long-distance passenger and freight transport by road, sea, and air. There is scope for using green hydrogen, either through hydrogen fuel cells or hydrogen-fuelled combustion engines, as well as hydrogen-derived synthetic fuels. However, the majority of these technologies are still in trial stages, and even if proven successful, it would take some years before achieving full commercialisation. Therefore, it is not necessary to set targets at this stage for the upcoming planning period spanning from 2025 to 2035.

5. Decarbonising Industry

Industry accounts for 21% of total emissions, and decarbonising this sector has to be a part of any long-term strategy to achieve net zero. The scope for decarbonisation also prominently features in public statements by management of larger corporations, but the prospects for early and significant improvements in this area over the next ten years remain limited for a several reasons.

Approximately half of the industrial emissions stem from the use of fossil fuels (mostly coal) for heat in a wide range of industries, including brick kilns, textiles (use of steam), dyeing and other chemicals, pulp and paper, mining, and metalworking. While it is technically possible to switch to electricity in many of these cases, the switch would be costly, and many of the production units are relatively small, or at most, medium-sized. As a practical matter, it is perhaps best to address the decarbonisation of this segment after some success has been achieved with larger industries.

The large industries responsible for the other half of industrial emissions include steelmaking, cement production, oil refining, and solid-fuel transformation (e.g., coal gasification). Top management in these industries is fully aware of the global interest in going green and the possible economic costs of ignoring this aspect in the form of CBAM-type levies on exports. Moreover, they are also aware that having a positive green agenda resonates well reputationally and could even lead to preferential access to both debt and equity capital. This has led to many public announcements of the intention to go green, but the extent of actual progress is difficult to assess. The status regarding some of these industries is summarised below.

5.1 Steelmaking

Steel is a classic "hard-to-abate" sector because the production of green steel would require switching from: (i) the use of fossil fuels (coking coal or natural gas) to green hydrogen for iron ore reduction, and (ii) coal-fired furnaces to electric furnaces powered by RE for heat generation. Green steel is estimated to be up to 40% more expensive than conventional steel (Devlin et al., 2023). Since the industry has a large exposure to European markets, it will be affected by the CBAM once it comes into force. Large Indian steelmakers (such as Tata and JSW) are experimenting with technologies that would reduce the emission intensity of their produce.

5.2 Fertilisers and Petroleum Refining

These industries currently use grey hydrogen (derived from natural gas) to produce ammonia for fertilisers and to refine petroleum products, respectively. Together they account for almost all of India's current hydrogen demand of about 5.5 mtpa. However, the production of grey hydrogen generates CO_2 which can be avoided by switching to green hydrogen produced from electrolysis of water using RE, but this is currently very expensive.

The government is considering issuing regulatory directives to mandate fertiliser producers and oil refiners to meet 20% and 25% of their respective hydrogen demands through green hydrogen by 2028. These directives will raise costs that should be passed on to consumers or be absorbed by a higher subsidy burden on the state. As pointed out earlier, these administrative mandates would not be necessary if there were a high enough carbon tax.

5.3 Cement

India's demand for cement will expand rapidly in the future to meet the continuing need for infrastructure and housing, and this will lead to a commensurate growth in emissions unless the industry can be decarbonised. Major cement manufacturers like ACC and Dalmia have announced targets to decarbonise cement production by different years, but not much is known about how they plan to do this. CCUS and emission offsetting through afforestation seem to be the likely options.

With current technology, cement produced in an integrated plant with CCUS is estimated to be 60% costlier (Subraveti et al., 2023). Cement manufacturers in advanced countries have commissioned demonstration projects involving CCUS or other process-based innovations, but commercialisation may be many years away. As in other areas, the potential for technological advances should not be underestimated. Success in CCUS technology would be crucial in India, not only in cement manufacturing but also in decarbonising other industrial processes that use fossil fuels.[20]

To summarise, larger industries are well aware of the problem, and steps are being taken to explore the scope for decarbonising the major industrial sectors. This includes experiments with various technologies, but it is too early to project what success can be expected over the next ten years.

[20] Long-term geological storage of CO2 on the scale required for the operation of commercial CCUS plants is also largely unproven and prohibitively expensive, except at a few sites on Earth.

6. Decarbonising Other Sectors

Decarbonisation also needs to be pursued in several other sectors, some of which are briefly discussed below.

6.1 Afforestation and Land-Use

Expanding forest cover to sequester CO_2 from the atmosphere is part of India's climate action plan and is reflected in its NDCs (see Box 1). However, the afforestation target set in 2015 has not been updated since. A more ambitious target for expanding forest cover, with a realistic assessment of cost,[21] should be part of India's climate change management planning.

The Forest Survey of India (FSI, 2019) has assessed that almost half of the NDC target could be met by restoring existing but degraded forest land and open forests (7.4 million ha). The rest would require afforestation of 11.3 million ha of new land, which is about 3.4% of India's geographical area. This would expand the area under forests and trees by 14%. Afforestation to achieve net zero would require large investments that must be factored into the budgets of the relevant agencies over the coming years. It should be noted that afforestation not only contributes to carbon sequestration but also yields considerable co-benefits such as ecological restoration and natural resource management, especially water conservation, which will be a major stress point because of climate change.

In addition to the demand for land for afforestation, there will also be demands from the massive solar PV installations and biofuel production needed to support a net zero economy. Some of this demand for land can be met by using inarable land, but some will cut into land for food production. ADB (2023) estimates that the additional demand for land will reduce the share of land available for food crops from 30% of total land at present to 24% by 2070.[22]

A reduction in land available for food crops on this scale raises legitimate concerns about food security. However, it must be acknowledged that land productivity in India is much lower than in many developing countries because of poor water availability combined with inefficient irrigation and cultivation techniques, and insufficient research into developing the right seed varieties for India's climatic conditions.

6.2 Agriculture: A Problem Area

Agriculture contributes 21% to India's total GHG emissions, and any long-term mitigation strategy must deal with this problem. Agricultural emissions are of different types, as shown in Table 2.

Table 2: Shares of Different Sources of Agricultural Emissions, by GHG (2016)

	Methane (CH4)	Nitrous Oxide (N2O)
Enteric fermentation in livestock	54.6%	-
Fertiliser application	-	19.1%
Paddy cultivation	17.5%	-
Manure management	0.6%	6.1%
Crop residue burning	1.6%	0.6%

Source: MoEF&CC (2021)

There is scope for mitigating emissions in each of the areas listed in Table 2, but it requires intervention in different areas. Some of the necessary changes in agriculture are politically sensitive. For example, free or near-free electricity for farmers encourages excessive water use and leads to severe depletion of groundwater levels. Similarly, massive under-pricing of urea leads to its overuse, contributing to high nitrous oxide emissions. Correcting these distortions is both technically and economically desirable, but the political groundwork for making these changes has to be carefully prepared, with both the Centre and the states on the same side.

Efforts are being made to address some of these issues. In the case of crops, new methods of rice cultivation and direct seeding of rice, application of organically enhanced fertilisers to inhibit nitrification in soils (e.g., neem-coated urea), better manure management, controlled grazing, etc., are being encouraged. Efforts are also being made to reduce emissions from livestock through improved cattle feed (e.g.,

[21] According to the FSI (2019), the total cost of meeting this target by 2030 is about 1.5% of the 2019 GDP. This may need to be carefully reviewed and updated.

[22] According to ADB (2023), this is a result of rising demand for land for biofuels production and afforestation, with their shares in land cover increasing from nearly 0% to 8%, and from 23% to 33.5%, respectively, between 2020 and 2070.

using bypass proteins) and controlled grazing. These efforts should be intensified, but we need to recognise that much broader change is needed, for which farmers have to be brought on board. Farmers readily accept new seeds when they see an improvement in yield within one crop season, but they are less willing to change long-established farming practices to avoid long-term impacts on soil fertility and groundwater table. Devising changes to avoid negative effects, especially those with a longer time horizon, is more challenging.

The Asian Development Bank (ADB 2023) has estimated that if global efforts to mitigate climate change are not successful, agricultural productivity in India may decline by 15% by 2100. Countering this decline will require irrigation methods that economise water use, improved groundwater retention through afforestation and rainwater harvesting, and expanded research to develop climate-resilient crop varieties. These initiatives are all part of adaptation and should be a top priority in our medium-term agenda.

The initiatives in agriculture mentioned above should certainly continue, but at this stage, it may not be feasible to set credible targets for emission reduction in the sector. This is perhaps best deferred to the period 2035-45.

6.3 Emissions from Buildings

Growing urbanisation and rising incomes will lead to a significant increase in energy demand for cooling, particularly as temperatures continue to rise even under optimistic scenarios. This will greatly add to emissions from the building sector. The following initiatives can help to mitigate the impact.

Design of Buildings

Given India's ongoing urbanisation, many buildings—both commercial and residential—required by 2050 are yet to be built. Steps taken now to improve building designs and the choice of construction materials can contribute to energy efficiency and thereby reduce emissions, and also improve climate resiliency. The responsibility for regulating building design rests with state governments, and they should be encouraged to mandate higher standards for energy efficiency, as reflected in Green Rating for Integrated Habitat Assessment (GRIHA) or Indian Green Building Council (IGBC) ratings. However, these standards need to be enforced by municipal bodies, and their capacity must be strengthened to implement and monitor compliance with the standards. They should also be regularly updated to reflect leading international benchmarks, such as LEEDS (US) or BREEAM (Europe).

The central government should lead by example by ensuring that all new buildings owned or leased by it meet higher efficiency standards. State governments should also take similar action as part of state climate action plans. The corporate sector, too, has a crucial role in ensuring that its buildings adhere to high-efficiency standards.

Energy efficiency of appliances

Improving the energy efficiency of electrical appliances used in homes and commercial buildings can help reduce energy demand and, therefore, emissions. Statutory minimum efficiency standards for high energy-consuming appliances, such as refrigerators and air conditioners, are crucial in this context and should be regularly updated to reflect technological advancements.

Cooking

In rural areas, cooking is predominantly done using biomass (mainly wood and cow dung cake), kerosene, and sometimes even coal. Liquefied petroleum gas (LPG) is a cleaner and safer cooking fuel, and the priority should be to transition from biomass-fed stoves to LPG. Although a fossil fuel, LPG has much lower emissions than the alternatives and can be seen as a transition fuel, as it is in urban areas. In the long run, decarbonising cooking can only be achieved by switching to electric cook stoves.

Municipal waste management

Solid waste and wastewater produced in urban areas in India currently contribute to 2% of total emissions, mostly non-CO_2 GHGs. While this may seem small, rising urbanisation and incomes will compound the problem and increase its share of emissions. Proper management of municipal solid waste will not only contribute to mitigation but also bring significant co-benefits in terms of improved health, environmental quality, and resource use.

Recycling of commonly discarded materials, especially electronics, is a valuable source of certain metals required for the manufacture of new energy equipment, the demand for which is bound to increase in the years ahead. Establishing standards for the use of recycled materials in new products and mandating the 'right to repair' would be effective steps towards a circular economy. This becomes particularly important as the growing demand for grid-scale batteries with the shift to renewables will require battery recycling in due course.

7. Domestic Production to Support the Energy Transition

The energy transition described above will create domestic demand for new products embodying decarbonisation technologies and new energy carriers such as green hydrogen. This presents opportunities for encouraging domestic production to meet this demand in a cost-effective manner.

7.1 New Energy Products

The energy transition will generate demand for new products such as solar PV modules, wind turbines, batteries for both EVs and for grid-scale storage, smart meters, hydrogen electrolysers, fuel cells, etc. India has the capacity to manufacture these products, and the scale of domestic demand will be large enough to enable efficient production. Domestic manufacturing of these products will also create high-quality jobs to replace those lost elsewhere because of the energy transition.

China has built impressive domestic capacities in solar PV cells and modules and lithium-ion batteries and is today a dominant global supplier of these products. India has the scale to follow this approach. The additional solar capacity to be installed in India over the next 25 years is around 1.3 TW. This expansion will rank among the largest in the world outside of China. In contrast, India's solar cell production capacity in 2023 was around 6 GW, with its PV module capacity approximately 65 GW (Mercom, 2024b). While these capacities are expected to increase fourfold by 2026, a much larger expansion is needed over a longer period. The desire of many developed countries to shift sourcing of some of these products away from China helps in this context by creating space for India. This is also an area where India's own security concerns argue for reducing dependence on China.

In these circumstances, there is a case for proactive support for domestic producers in the initial years, including protection from dumping and other unfair competition. This support can be supplemented by direct assistance in the form of Production-Linked Incentive (PLI) schemes and the separate capital subsidies available for some products.[23] However, since this is an area where technology is rapidly changing, trade policy must be carefully designed to avoid open-ended protectionism, where domestic producers have no incentive to keep up with developments in technology. For example, the efficiency of solar PV cells is currently around 20%, but the potential is estimated to be as high as 44%. Shielding domestic industry from import competition risks locking it into outdated technology, which will only increase the cost for domestic users.

The objective should be to build a domestic industry that is not only domestically competitive but also capable of serving export markets. These export markets will be substantial as all countries transition to RE. The fact that many developed countries are looking to restructure supply chains away from China is an added opportunity that India could seize. However, it requires careful policy design and constant review to ensure that the domestic industry remains technologically up-to-date and globally competitive.

7.2 Green Hydrogen

Green hydrogen is being hyped worldwide as the fuel of the future, with both the government and the private sector involved in building a credible domestic green hydrogen value chain. India's demand for hydrogen is currently 5.5 mtpa and is expected to double to 10–12 mtpa by 2030.

The government has announced a Green Hydrogen Mission with a target of 5 mtpa green hydrogen production capacity by 2030. The EU and the US have targets of 10 mtpa each by 2030. The mission envisages a range of fiscal incentives including (i) a waiver of inter-state transmission charges on RE, which reduces the cost of electricity used for green hydrogen production, (ii) direct cash incentives of up to ₹50/kg of green hydrogen produced, and (iii) a PLI scheme for supporting the establishment of elec-

[23] To create demand for EVs, for example, the central government introduced the FAME scheme to subsidise the ownership cost of electric two-wheelers and commercial EVs, and to support the creation of charging infrastructure. Some state governments, such as Tamil Nadu, Karnataka, and Telangana, also offered capital subsidies and tax concessions for setting up EV and battery manufacturing capacity in their respective states.

trolyser manufacturing capacity in the country. The beneficiaries of subsidy schemes will be determined through competitive processes.

Several private sector corporations such as Reliance, L&T, Adani, Greenko, etc., have drawn up plans to establish electrolyser manufacturing and green hydrogen production capacity in India. Public sector corporations like NTPC Renewables, Indian Oil, and GAIL are also moving forward in this area with MW-scale green hydrogen production projects. How far India can go down this route will obviously depend upon how effectively costs can be reduced. Reliance, for example, has announced a sizeable investment in setting up electrolyser manufacturing and RE generation and electrolysis capacity, and has set an ambitious target of reducing the cost of green hydrogen production from the current $5-6/kg to $1/kg by 2030. It is too early to judge whether this order of cost reduction can be achieved, but it is necessary if green hydrogen is to become cost-effective.

While it makes sense to experiment with producing green hydrogen, cost-effectiveness cannot be ignored. For example, the proposed production target of 5 mtpa green hydrogen would require 125 GW of dedicated RE generation capacity and 55–70 GW of electrolyser capacity.[24] Since the RE used to produce green hydrogen could alternatively be used to replace conventional electricity in the grid, the use of green hydrogen only makes sense if the emission reduction achieved is greater than that from displacing coal-based electricity in the grid by RE (Sun et al. 2024).[25]

Tongia and Patel (*forthcoming*) have estimated the cost of emissions reductions resulting from the use of green hydrogen across different sectors. They find that the cost is relatively low for petroleum refining, where it is technically easier to switch to green hydrogen. However, the cost of abatement is much higher when blending natural gas with green hydrogen for piped gas distribution in cities, which is currently being experimented with by GAIL.[26] Similar results have been found in other applications like H_2 in public transport buses (see Poggio et al., 2023).

The objective of making India a hub for the export of green hydrogen has been mentioned by official spokesmen (Reuters, 2023). It is difficult to assess the likelihood of this objective being achieved. The current production target of 5 mtpa by 2030 will only meet half of the projected domestic demand, so no surplus is expected. Besides, transportation of hydrogen poses its own problems (Liebreich, 2022).

8. Investment Needs of the Transition

It is clear from this paper that transitioning to net zero calls for a major restructuring of the energy and related sectors, and this in turn will require substantial additional investment. The feasibility of the transition depends critically on whether the additional investment can be financed.

The scale of the additional investment needed in India has been examined in several studies, and the results are summarised in Table 3. Some of the studies distinguish between the total investment needed (Column 4) and the additional investment needed above the BAU level, which will include some normal increase over time. Conceptually, we need to be concerned with the level of investment needed above the BAU amount. This magnitude varies between 1% and 3% of GDP.

[24] This is about four times the global electrolyser manufacturing capacity in 2022 (Bloomberg NEF, 2022).

[25] For example, an H2 fuel cell bus consumes 9 kg H2/100 km. To produce 9 kg of green H2 requires approximately 450 kWh of RE. Meanwhile, a diesel bus consumes 35 litres of diesel/100 km and emits 94.5 kg of CO2. In other words, 9 kg of H2 or 450 kWh of electricity saves 94.5 kg of CO2 when an H2 fuel cell bus replaces a diesel bus. The average emissions from Indian grid electricity are currently 0.71 kg/kWh. Therefore, feeding 450 kWh of electricity into the grid would avoid 320 kg of CO2, assuming it displaces coal-based electricity.

[26] The emission intensity of piped natural gas (PNG) is 1.86 kg-CO2/SCM. A 5% PNG-H2 blend by volume would have an emission intensity of 1.83 kg-CO2/SCM. Assuming the cost of green hydrogen to be $1.5/kg, the CO2 avoidance cost would be $231/t-CO2 (Tongia and Patel, *forthcoming*).

Table 3: Estimates of Annual Investments in Energy and Other Sectors in India

Study	Sector coverage	Scenario	Total	Additional*		Period
			2020 $, billion	*2020 $, billion*	*% of GDP (cumulative)*	
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
McCollum et al., 2018	Energy	+1.5°C by 2100 (50%)	$313	$147	2.6%	2016 - 2050
CEEW, 2021[#]	Power, Road transport and H_2 production	NZ by 2070	$202	$107	1.0%	2020 - 2069
IEA, 2021	Energy	NZ by 2070	$160	$107	3.1%	2022 - 2030
McKinsey, 2022	All	NZ by ~2060	$240	-	3.5%**	2021 - 2050
ASPI 2022	All	NZ by 2070	-	$259	2.7%	2022 - 2060
ADB 2023	Power	NZ by ~2070	-	-	2.65%**	2020 - 2050

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

***Refers to total investment figure.*

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

The variation across studies is partly due to differences in the breadth of sectors covered and the time period analysed. There is also a conceptual problem in deciding what should be considered additional for the economy as a whole. For example, the transition clearly involves a shift to RE, and this will require heavy investment in new RE capacity. However, not all of this investment can be called additional because it substitutes for investment in conventional capacity. RE is more capital-intensive than conventional capacity, and the additional cost of RE compared to conventional capacity could be considered an additional burden. However, even this may not be appropriate, as RE has no fuel costs. This suggests that either the discounted value of the fuel savings over the years must be considered, or alternatively, the savings in investment that would otherwise be made in producing fuel (e.g., in coal mining) should be netted out.

We do not have the information needed to adjust for different assumptions across studies, but after reviewing all these estimates, we proceed on the assumption that India may need to increase its rate of investment above the BAU level by about 2% of GDP to cover investments in energy and related sectors. This additional investment will have to be financed by some combination of (i) increased domestic savings from the public and private sectors, (ii) some reallocation of investment, and (iii) increased inflows of international finance.

The issue of increased international financial flows, necessary to assist developing countries in financing the transition, is currently on the agenda of COP29. The annual $100 billion commitment outlined in the Paris Agreement has not been fulfilled. Moreover, this amount is now considered woefully inadequate due to the new commitments undertaken by developing countries. A new figure has to be agreed upon before 2025.

Some indication of the scale of international financial assistance needed can be gleaned from the report of the Expert Group appointed by the G20 Finance Ministers in 2023, during India's presidency of the G20 (G20, 2023). The Group estimated that the incremental investment needed by the emerging market and developing economies (EMDEs), excluding China, for climate change management would be about $1.8 trillion by 2030 or about 4.5% of the GDP of these countries.

The Expert Group's estimate is more than twice of our estimate based on the various India-specific studies. The Expert Group report does not provide country-specific estimates, so it is not easy to reconcile the difference. One reason could be that the Expert Group estimates 'incremental' investment with reference to the level of investment in the base year 2019, whereas it should be calculated with reference to the projected BAU level for any year in the future. Another possible reason is that the investment needed to implement climate change adaptation and resiliency measures in middle-income countries (like India) would be lower (0.5% of GDP on average) than in low-income countries (6-7% of GDP), which are also more vulnerable to climate change impacts (Bhattacharya et al., 2022).

It should be noted, however, that although the Expert Group has identified a large investment need, they do not envisage this amount as being met entirely by international flows. In fact, the Group has suggested that up to two-thirds of the investment will have to be mobilised through domestic resources, and only about one-third through external sources. Applying the same proportions to our estimate of 2% of GDP, the additional external financing needed for India would be about 0.7% of GDP or about $50 billion by 2030.

The first issue to consider is whether the proposed volume of additional external finance is consistent with domestic macroeconomic stability. An increase in external finance can only be absorbed by a corresponding widening of the current account deficit (CAD). In India's case, the CAD has hovered between 1% and 1.5% of GDP in recent years, and an increase in foreign capital flows of 0.7% of GDP implies a widening of the CAD to a little over 2% of GDP. In our view, this would not endanger macroeconomic stability, especially if the increased flows are for long-term, non-volatile in nature, and directed into climate-related investments.

The G20 Expert Group has suggested that external flows should comprise equal parts of additional private flows (FDI plus private commercial lending) and public flows (bilateral and multilateral). This would imply an additional $25 billion or so from each source to meet India's total external financing needs of $50 billion by 2030. India's ability to attract FDI and private flows on the scale indicated should be rated as "good" as long as its economic performance remains strong. The overall supply of capital in global financial markets could easily provide flows of this magnitude, as long as India's economic performance remains strong and foreign investors perceive the Indian government's policy towards FDI as positive, especially in climate change-related sectors.

Turning to bilateral and multilateral flows, the proposed additional amount of $25 billion per year will enhance India's ability to expand investment in climate change management, especially if the lending is explicitly designed to leverage additional private flows. However, the availability of these flows depends on the decisions of the developed countries that control these institutions.

These countries are all members of the G20, and the G20 Expert Group report has clearly recommended that the Multilateral Development Banks (MDBs) should play a much larger role in financing climate-related investments, through both direct lending and by using MDB financing to leverage expanded flows of private finance. The Group specifically recommended tripling MDB lending from the current level by 2030. It also noted that it may be necessary to increase the authorised capital of the MDBs to allow them to play this role.

The G20 Finance Ministers have generally welcomed the report, but there is no firm decision yet on the volume of the proposed increase in MDB lending or on whether a capital increase would be possible.

9. Conclusions

The broad conclusion emerging from this paper is that India can achieve net zero by 2070 while also pursuing high and inclusive growth. This will require a three-pronged strategy consisting of (i) systematic pursuit of energy-efficient processes and a shift to energy-efficient systems, (ii) electrification of all sectors wherever possible, and (iii) shifting from fossil fuels renewables, mainly wind and solar, for electricity generation.

This transition will call for action on several fronts, many of which will be politically difficult. This paper argues for a combination of price-based measures to discourage fossil fuels, as well as a series of sector-specific measures that would ease the transition in individual sectors.

The ideal price-based measure would be an explicit carbon tax, but since this is unlikely to be acceptable, an Emissions Trading System (ETS) along the lines discussed in Section 2 would be a good substitute. Key issues in the design of the ETS relate to (i) the inclusion of the power generation sector, (ii) the pace of reduction of emission allowances to be consistent with the net zero date, and (iii) the auctioning of emission allowances by a given date in the future.

Turning to sector-specific interventions, the most immediate areas for action are the expansion of RE capacity and the electrification of road and rail transport. Implementing this transition will require several specific interventions, which are discussed in sections 3 and 4. These could form part of a medium-term strategy for the next ten years. There is more uncertainty about what can be achieved in the medium term in areas such as industry, where decarbonisation with existing technology is costly, and agriculture, where there are socio-political sensitivities. Some initiatives are underway in these sectors, and they need to be pushed forward, but it may be premature at this stage to specify a detailed plan of action in these areas.

An important challenge in implementing the strategy advocated in this paper is that it requires action by several different ministries and state governments. While a number of initiatives are being considered, the national strategy cannot be the sum of proposals from different ministries or states acting as silos. It is necessary to ensure that these initiatives are internally consistent and reflect a cost-effective approach.

The need for internal consistency can be illustrated by the fact that the net zero target implies a shift from coal-based power to RE, which in turn implies a fall in demand for coal. Internal consistency requires accepting this structural change and incorporating it into a plan for phasing out investment in thermal power plants and also phasing down coal mining over time.

Cost-effectiveness is another important consideration. Different emissions reduction initiatives have different costs, and since resources are limited, it is important to adopt the least-cost option. This is particularly important when emission reduction efforts involve some subsidies or another form of financial support. This is not to deny the need to experiment with different options initially, but as experience is gained, the national strategy should ensure that the bulk of our limited resources are directed towards the least costly options.

A major challenge in devising a national strategy for managing climate change is that several of the areas for intervention are in the domain of state governments. These include electricity distribution, agriculture, urban transport, building codes, etc. Several state governments are developing state-level climate action plans covering these areas. Each state must ensure that its plans are internally consistent and also consistent with its resource constraints. The state government's plans must also be consistent with the national decarbonisation target.

There is need for an effective mechanism for consultation between the Centre and the states on these issues. South Africa has set up a Presidential Climate Commission, and there is a strong case for setting up a similar high-level decision-making body chaired by the Prime Minister of India and including key central ministers and all chief ministers of the states. This body could approve the national strategy, review its progress periodically, and modify it in the light of experience and technological developments. A detailed ten-year national action plan, emerging from such a body, would also provide the basis for building broader public support. It would also contribute to international credibility in this important area.

The transition to net zero will require significantly higher investments in energy and related sectors. We estimate that this could amount to an additional 2% of GDP by 2030. Much of the increase in investment in areas such as RE capacity, storage, and EVs, could be undertaken by the private sector. However, there will also be a need for increased public investment in areas such as electricity transmission, railways, public transport, urban infrastructure, agriculture R&D, forestry, etc.

The public sector will also have to bear the burden of investment in adaptation, which has not been covered in this paper but is undoubtedly important. The need for expanded public sector investment highlights the importance of increasing public savings to meet the additional public investment requirements. Carbon pricing (through a carbon tax or an ETS) would help generate much-needed revenue.

The provision of additional international flows to support climate change mitigation and adaptation is part of the current global consensus on a "just transition," and discussions are underway to decide on the scale of the new commitment to replace the current pledge of $100 billion per year. The G20 Expert Group, which submitted its report to the Finance Ministers, made it clear that about two-thirds of the additional investment would have to be financed by domestic resource mobilisation, and one-third could come from additional international flows. Half of this is expected to consist of private flows (FDI and commercial borrowing) and the rest of bilateral public MDB flows. Applying this to our estimate of additional investment of 2% of GDP for India yields about $25 billion of private flows and the same amount in non-concessional long-term loans from MDBs and official sources.

India's ability to attract private flows will depend largely on how investors perceive our policies and growth prospects. Official pronouncements by foreign governments help create a conducive atmosphere, but the dominant factor governing private flows will be investor perceptions. However, access to the proposed level of additional public flows from bilateral and multilateral sources will depend critically on the decisions of the advanced countries. For example, the G20 Expert Group has called for a tripling of MDB flows. This would not only provide direct access to resources but, if properly leveraged to influence private flows, could also lower risk perceptions among private investors. No decision has been taken thus far on this recommendation, and it is unlikely that there will be more clarity until after the 2024 US Presidential election. India could use its position in the 2024 G20 Troika to push for an early decision.

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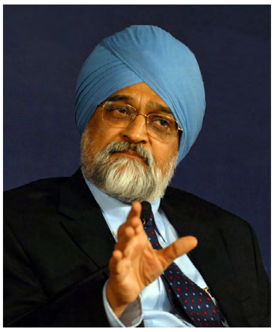

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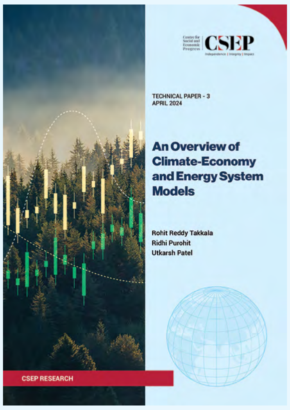

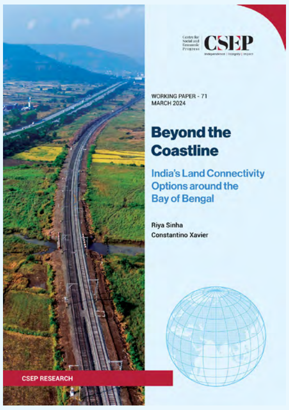

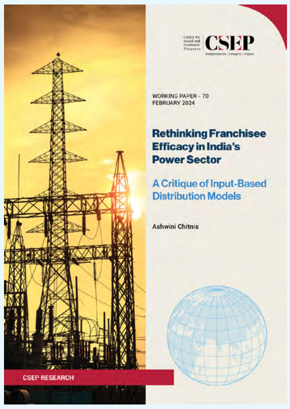

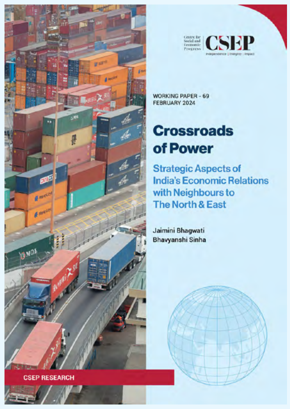

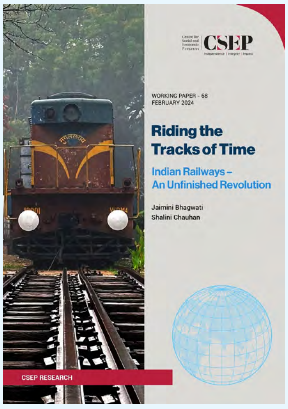

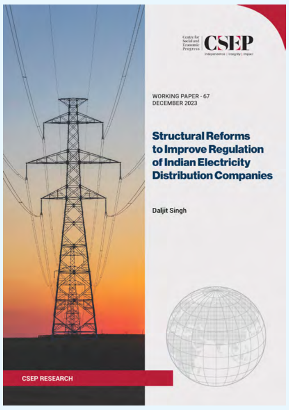

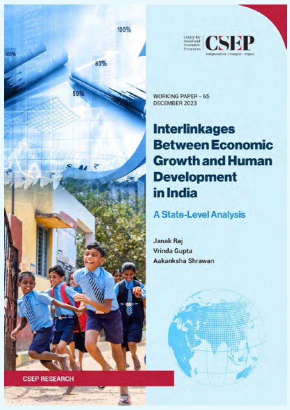

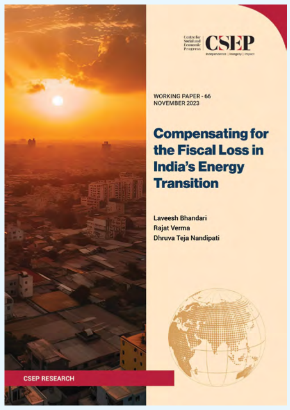

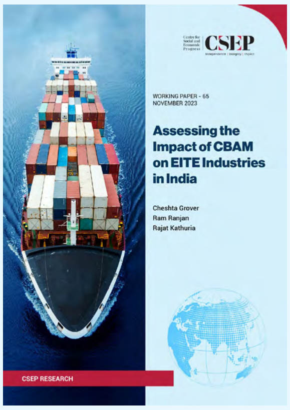

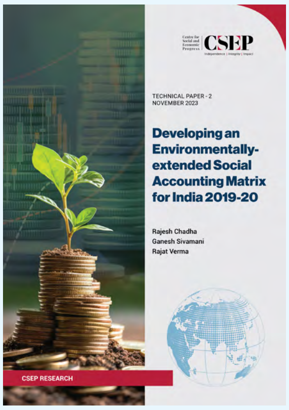

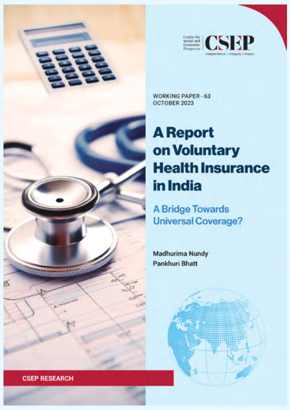

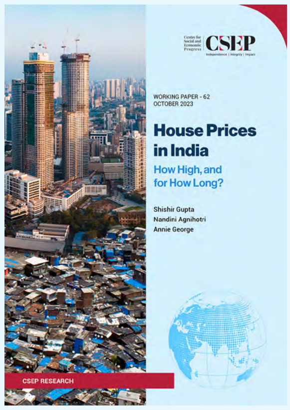

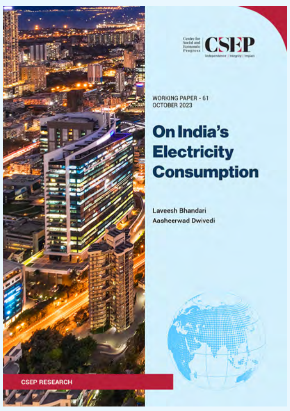

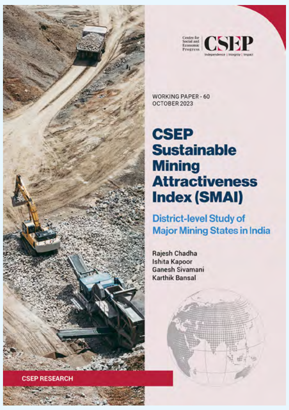

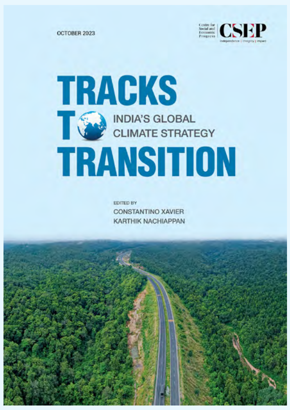

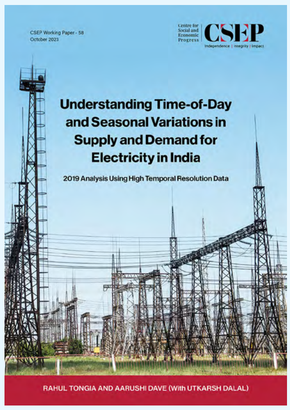

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