INDIA'S JOURNEY TO NET ZERO

A CONCEPTUAL FRAMEWORK FOR ANALYSIS

Ajay Shankar | Sanchit S Agarwal | Taruna Idnani

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Creating Innovative Solutions for a Sustainable Future

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We would like to thank Director General, TERI for her vision in conceptualizing this initiative and encouraging and motivating TERI colleagues in their endeavours.

Industry Charter for Near Zero Emission Ambition Instituted by TERI

TERI's Industry Charter for Near Zero Emissions Ambition by 2050, instituted in the year 2020, is a coalition of like-minded industries bound in their voluntary pledges to reduce greenhouse gas (GHG) emissions and united in their belief in the role of industries in achieving the Paris Agreement goals.

The Coalition shares best practices, facilitates outreach and communicates technology and business models on industrial decarbonization among key stakeholders such as industry groups, global organizations, government and financial institutions.

The findings, analysis and outlook from the paper "India's Journey to Net Zero: A Conceptual Framework for Analysis" will be helpful for the Coalition in their annual and long-term planning. It will also aid in the allocation of resources towards credible actions on their decarbonization pathways.

From the Desk of Director General, TERI

While global climate change challenges impact all, India is at the forefront of the transition to a sustainable future. Hon'ble Prime Minister, Shri Narendra Modi has envisioned a pathway towards decarbonization, promoting a greener economy and building a resilient future. At COP26 in Glasgow in 2021, he made the landmark announcement that India would become net zero by 2070.

The transition to a low carbon economy is gaining momentum. Achieving net zero is a tall order but India is committed to achieving its target. India is at an early stage of development with our per capita emissions being considerably lower than the world average. India aspires to meet the dual objectives of becoming a developed economy by 2047 while reducing the carbon intensity of the economy and achieving net zero by 2070.

While 2070 appears far off, we at TERI have taken the lead in setting up a Task Force to work towards the journey to net zero. This paper, "India's Journey to Net Zero: A Conceptual Framework for Analysis" examines the transition journey for each of the major GHG emitting sectors in India. It delineates a pathway to the peaking of emissions and subsequent decline through the lens of delinking growth from an increase in carbon emissions.

This is an initial exercise of sketching a pathway to net zero and putting forward a conceptual framework of analysis. The intent is to begin the dialogue on what is involved in achieving the net zero ambition. Each of these sectors needs more comprehensive analysis, generation of scenarios, and associated climate finance imperatives. It suggests in-depth studies that would be crucial for further comprehension and planning.

While the path ahead is complex and challenging, collaboration among all stakeholders would be key to its success. We believe this study opens up opportunities for meaningful deliberations, reflections, and further research.

We welcome your invaluable thoughts and suggestions which would immensely help in shaping the journey ahead.

Dr Vibha Dhawan

Director General, TERI

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LIST OF ABBREVIATIONS

AWD	Alternate Wetting and Drying
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilization and Storage
CEA	Central Electricity Authority
CNG	Compressed Natural Gas
COP	Conference of Parties
CSP	Concentrated Solar Thermal
DISCOM	Distribution Company
ESO	Energy Storage Obligation
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt Hour
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land Use Change and Forestry
$MtCO_2eq$	Million Tonnes of Carbon Dioxide Equivalent
MW	Megawatt
PMSY	Pradhan Mantri Suryodaya Yojana
PNG	Piped Natural Gas

PSP	Pumped Storage Plant
RE	Renewable Energy
RE-RTC	Renewable Energy Round-The-Clock
RPO	Renewable Purchase Obligation
UNFCCC	United Nations Framework Convention on Climate Change

1

INTRODUCTION

In the landmark 2015 Paris Agreement on Climate Change adopted at The Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) 21, or COP 21, all the 196 nations parties to the UNFCCC resolved to limit global mean temperature rise to well below 2°C and pursue efforts towards restricting temperature rise to 1.5°C. According to the Intergovernmental Panel on Climate Change (IPCC), temperature rise should not cross 1.5°C (IPCC, 2023).

At COP28 in November 2023, the IPCC warned that with current policies, global warming was set to cross 3°C (UNEP, 2023). This would be an unmitigated disaster. To avoid this, immediate and deep emissions reductions were imperative. The G20 Summit held under India's Presidency in September 2023 in its declaration reiterated *"...commitment to achieve global net zero GHG emissions/carbon neutrality by or around mid-century..."*

At COP26, held at Glasgow in 2021, Prime Minister Shri Narendra Modi announced that by 2030 India would create 500 GW of fossil fuel free power generating capacity and would reduce the emissions intensity of its GDP by 45% from its 2005 level (MEA, 2023). This is one of the highest increases in ambition of responsible climate leadership in the short run.

The Prime Minister also announced that India would become net zero by 2070. This gives India an additional 10 years from 2060, the year that China has announced for achieving net zero. This is reasonable as India is still at an early stage of development.

Figures 1 and 2 represent per capita and total emissions on a global level (Crippa et al., 2023).

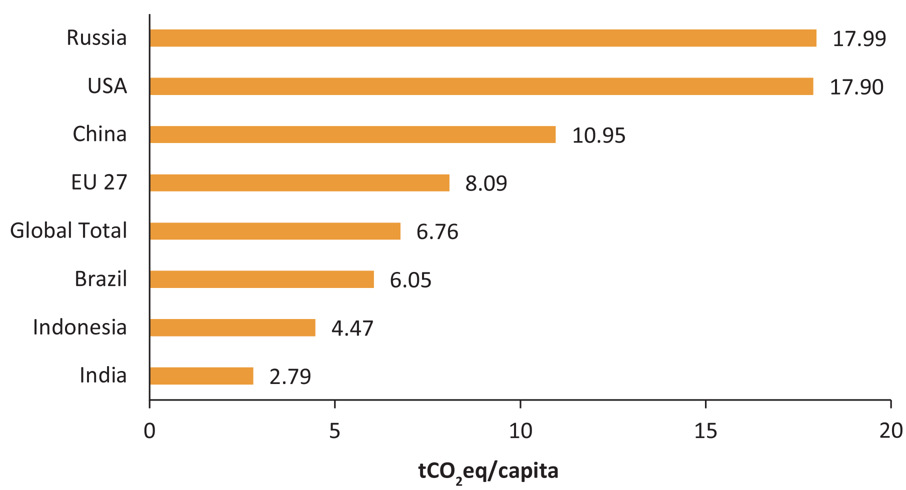


Figure 1: Country-wise per-capita GHG emissions

Russia and the USA have one of highest per capita emissions followed by China. India's per capita emissions are much lower than the global average of 6.76 tCO_2eq. India is still a developing nation and has a long journey ahead in becoming a developed country. China leads the global emissions share followed by the USA. India has the third largest emissions while the European Union (EU) is a close fourth.

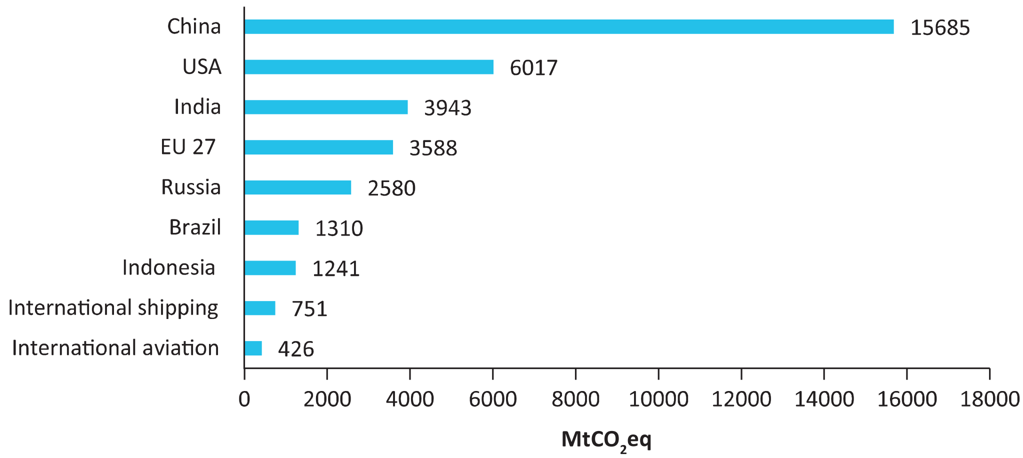


Figure 2: Total GHG emissions at the global level

1.1 Objective of the Paper

India seems to be on track towards achieving its 2030 goal of having 500 GW of fossil fuel free power generating capacity. It has launched a highly ambitious National Hydrogen Mission. This Mission is rapidly taking shape and is being well funded. This would position India well to undertake decarbonization of the hard-to-abate sectors.

This, therefore, seems the right time to begin analysis and discussion on how India's journey to net zero could be undertaken and what it would entail. This paper is a preliminary attempt in this direction. It assumes that India in the coming decades would become a developed country. It would have their levels of per capita incomes, and consequently energy consumption.

It looks at the sectors which account for major shares of India's GHG emissions. For each sector it attempts a conceptual framework for analysis of the feasible transition to net zero. The underlying premise is that decoupling of the rise in carbon emissions from growth would be the key to moving towards net zero. This study takes into account factors which would lead to inflection points for decoupling. It is not a comprehensive study with modelling and financial projections under different scenarios. It attempts to delineate the kind of detailed sector-wise modelling and working out of financial implications for each scenario that would need to be undertaken. There would be a need to keep revisiting these exercises every few years as technological developments and movements down the cost curves are highly uncertain and unpredictable.

1.2 Conceptual Framework

For purely analytical purposes, it is assumed that India's per capita income and per capita energy consumption would reach current EU levels at some point of time in the future when India catches up and becomes a developed country. Net zero would be possible only with the decoupling of growth from increase in carbon emissions. India's per capita CO_2 emissions would rise, reach a peak, remain steady at a plateau, and then decline.

The time to reach the peak would depend on the complete penetration of carbon free technologies and would be different for different sectors ranging from a few years to decades.

The emissions would peak in a sector only when all the incremental energy demand would be met without using fossil fuels in that sector. Decoupling of growth in a sector from increase in carbon emissions would occur. This is the critical inflection point.

Once the peak is reached, emissions will plateau. This would mean that the emissions would remain at their peak level till the time the existing carbon emitting systems continue to function. But in the period after which the emissions have peaked, energy consumption would continue to rise. Emissions are then expected to decline once the carbon emitting technologies begin getting phased out of the system. As seen from Figure 3, the peak can be reached early through a sharper trajectory R1, or emissions can peak gradually through path R2, but a much higher level, as development would continue, more emissions would have occurred during the slow transition pathway. The peak in both the trajectories would remain either for a shorter or longer duration and decline would occur through paths D1 or D2, respectively. The decline of emissions could be fast, as shown in paths D1a or D2a, or gradual, as shown in paths D1b or D2b depending upon the rate of phase out of fossil based technologies, which would again vary from sector to sector.

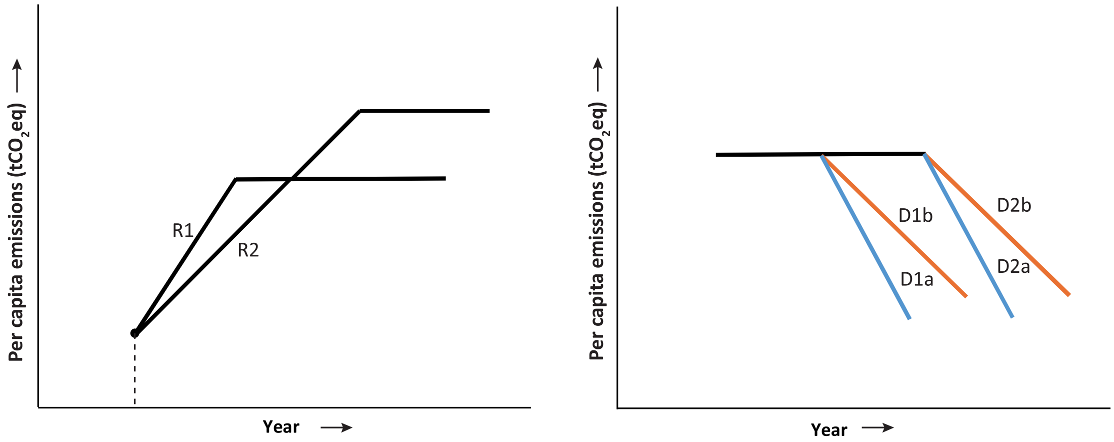


Figure 3: India's per capita emissions illustrative pathways

While emissions would decline, per capita energy consumption would continue to rise. Growth would get decoupled from carbon emissions. This decoupling would lead to net zero once carbon free energy begins replacing all fossil fuel-based energy consumption in a sector.

The higher the level of emissions at the time of peaking in a sector, the greater would be the cost of bringing the emissions down to zero as the number of carbon emitting plants. to be retired in any sector would be larger. To illustrate, at current levels, China would need to close down about 1390 GW of thermal power whereas India would have to close down only about 243 GW at current levels.

India has the late mover's advantage. Investment in creating lumpy long term carbon emitting capital assets need to be scrutinized through the prism of the future trajectory of the retirement of such assets. This would require assessing least cost options for reaching net zero in a sector through life cycle costing. Stakeholders need to engage with this issue and evolve a consensus on how to do so. Government would need to keep developing appropriate policy instruments to incentivize least cost investment decisions in the economy.

Energy efficiency is a low hanging fruit. It results in modest decoupling of growth from increase in carbon emissions. This is because the same level of service can be delivered with less energy consumption, or the same energy can deliver more service output. In both scenarios, increase in energy consumption and emissions becomes lower. However, for the achievement of net zero, the use of fossil fuels would need to end altogether.

In the subsequent sections, the decarbonization pathways of the major sectors are delineated. These are:

- Electricity,
- Surface transport,
- Residential cooking, and
- Hard-to-abate sectors—industry, shipping, aviation, and agriculture.

The decoupling between sectoral growth and carbon emissions which will be the key to the transition to net zero will be examined.

India's total GHG emissions, excluding land use and land-use change and forestry (LULUCF), amounts to 3132 $MtCO_2eq$ (NITI Aayog, 2024). Figure 4 represents the emissions from different sectors and their share in total emissions (NITI Aayog, 2024).

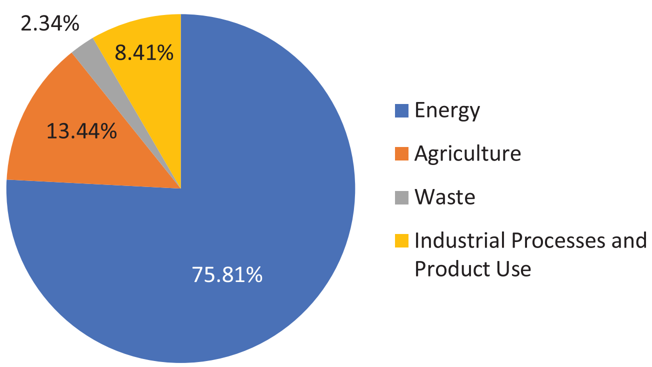


Figure 4: India's sectoral emissions share

Figure 5 represents the break-up of India's energy sub-sector emissions. The total emissions from energy sector in 2019 is about 2375 MtCO_2eq. From Figure 5, it can be inferred that electricity production has a 52% share of energy sector (1240 MtCO_2eq) emissions followed by industry and transport (NITI Aayog, 2024).

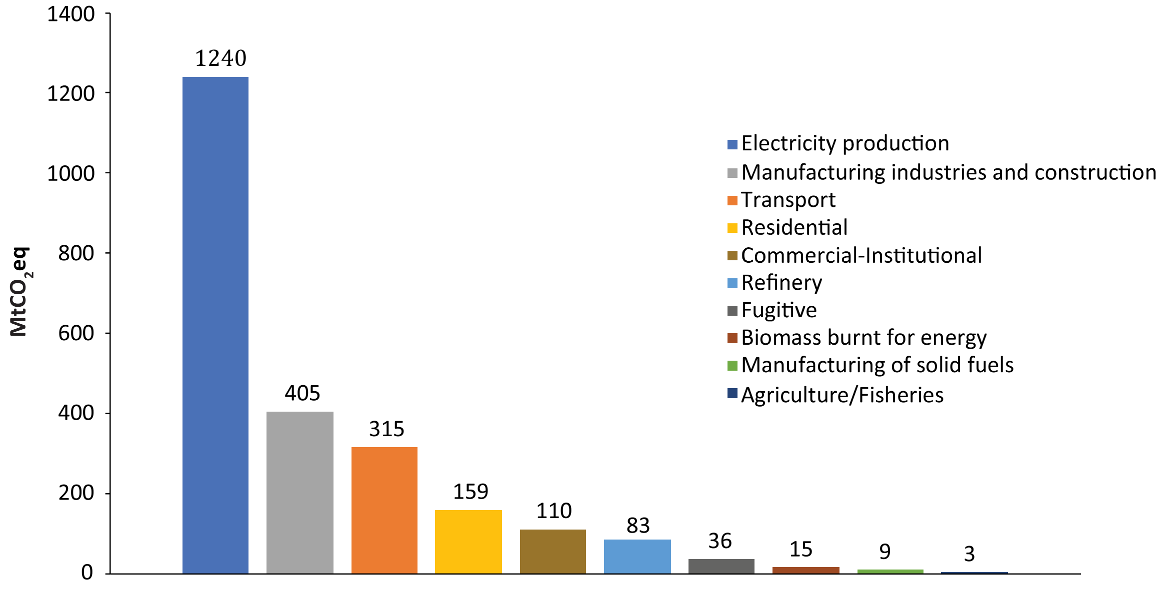


Figure 5: India's energy sector emissions

2

CARBON FREE ELECTRICITY

2.1 Emissions from Electricity Sector in India

Emissions from electricity sector is 1240 $MtCO_2eq$ which amounts to 39.5% of India's total emissions in 2019 (NITI Aayog, 2024). The power sector is the single largest emitter of CO_2 in India. The average emission per unit of electricity in 2019–20 is estimated to be 0.668 $kgCO_2/kWh$.

India is at an early stage of development and would catch up with the advanced economies. Its per capita GDP and electricity consumption would reach their levels. Its per capita electricity consumption is low at 1255 kWh in 2020–22, about one-third of the global average (CEA, 2021). For conceptual analysis, we are assuming that India's electricity consumption is going to rise and will ultimately reach European levels. Europe's per capita electricity consumption was 6687 kWh in 2021 (Climate equity monitor, n.d.). Hence, about 1.4 billion population would be expected to have an electricity consumption of about 9362 billion kWh ultimately. As India, in due course, becomes an advanced economy, its electricity consumption is likely to grow by 5–6 times and peak when it reaches present EU levels, a reasonable assumption for purposes of analysis.

For India to achieve net zero, full decarbonization of the electricity sector would have to take place. This would require decoupling of increase in electricity production and consumption from carbon emissions from the electricity sector. This would be achieved by the generation of electricity from non-fossil fuel sources. India's per capita electricity consumption would then increase, yet its carbon emissions per unit of electricity would decline. The CO_2 emission intensity would decline with an increasing share of electricity generation without the use of fossil fuels.

The share of generation from non-fossil fuel sources in total electricity generation is 21.7% in 2023 (MOP, 2023). India aims to achieve its 500 GW of non-fossil fuel capacity target by 2030. The share of non-fossil fuels in installed capacity is already 43% as of May 2024 (MOP, 2024). As the share of non-fossil fuel sources would rise, the carbon emissions per unit of electricity would decline. The key inflection point would be reached when all additional demand is met from non-fossil fuel sources. This would require success in grid scale storage so that demand can be fully met when the sun is not shining, and renewable energy (RE) generation is inadequate.

India's electricity sector decarbonization would have the following trajectory:

1. Once all incremental electricity demand is met by non-fossil resources and no new investment in thermal plants is needed, emissions will peak. The peak could be reached through different paths, either steeply (R1), i.e., the penetration of non-fossil energy resources is faster for electricity production, or gradually through (R2), i.e., penetration of non-fossil resources is slower. In path R2, the peak would be reached at a much higher emissions level, as with

growing electricity demand, more emissions would be released due to slower penetration of non-fossil generation technologies.

2. The total emissions would remain at a peak, till the existing thermal fleet is functional in the system. These thermal plants could remain there for a shorter duration and decline through D1 or could remain there for a long time and decline through D2.

3. Once the existing thermal plants start getting decommissioned, the total emissions would start to decline. The decommissioning can be rapid with emissions declining steeply through D1a or D2a, or slow with the emissions declining gradually, through D1b or D2b.

The electricity emissions pathways illustration is represented in Figure 6.

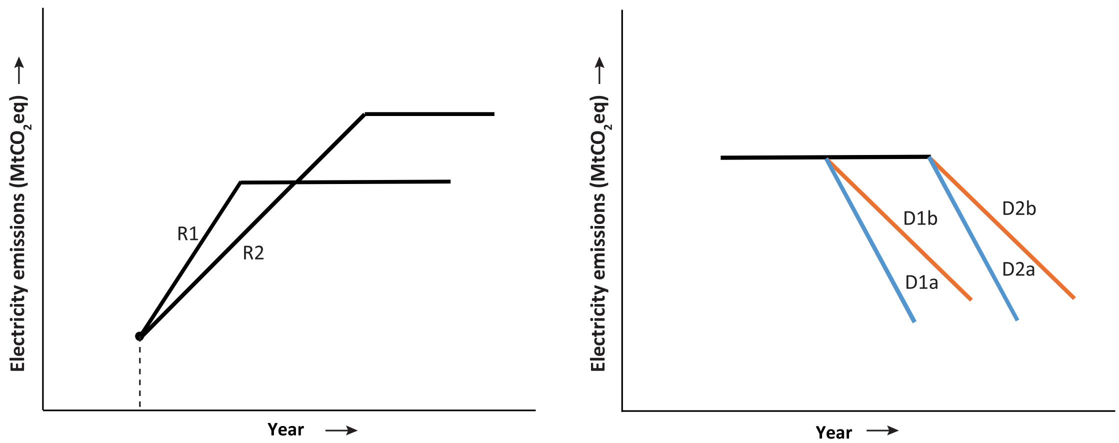


Figure 6: Electricity emissions pathways illustration

2.2 Key Strategies for Electricity Decarbonization in India

a) Energy storage

The key for the decarbonization of India's electricity sector lies in being able to meet all incremental demand from non-fossil fuel sources. For this to happen, success in creating large-scale grid storage is essential. India has created a competitive industry structure in renewables. The cost of solar power in India is amongst the cheapest in the world.

Storage is needed as generation from renewables, solar and wind, is intermittent. At certain times of the day, renewable generation would be more than the demand. The storage of excess RE would be necessary to prevent losing electricity, which has zero marginal cost.

Then if demand is to be met without the use of fossil fuels when RE generation is not taking place, this can be done only by using stored RE. Stored RE has to be large enough to provide reliable supply at all times of the day and throughout the year. Once this happens round-the-clock carbon free electricity supply on a large scale would become a reality.

b) Nuclear power

Nuclear power is a good stable source of fossil fuel free electricity generation with no carbon emissions. With storage, it can provide round-the-clock reliable supply to meet varying demands during the day across the year. The share of nuclear power in electricity in India is 1.7% (MOP, 2024). This can be increased. In the long run, having a reasonable share of nuclear power in the fossil fuel-free energy mix would be prudent. The cost of nuclear power from domestically designed and constructed plants is amongst the lowest in the world. The pace of development could be scaled up as the supply of fuel is no longer a constraint due to India having obtained the clearance of the Nuclear Suppliers Group for the import of nuclear fuel.

c) No new investments in thermal power plants

Solar energy along with storage has become cost effective as compared to new coal. Investing in solar plus storage could be the least cost option going forward. The tariffs discovered in Renewable Energy-Round-the-Clock (RE-RTC) tenders have proven to be highly competitive, with recent bid tariffs ranging between ₹4.25 and Rupee Foradian4.43 per unit (Renewable Watch , 2024). This is notably lower than the ₹5.2 per unit discovered in a recent bid for supply from coal-based projects (Shetty, 2023). Repeated tendering for large grid scale projects would be essential for accelerating the pace of creation of energy storage systems. With competition and scale, costs of storage may decline significantly. As of November 2023, more than 8 GW of energy storage systems (ESS) tenders have been awarded with more than 60% of this capacity being allocated in 2023 alone (IEEFA, 2023).

To support and develop a market for storage systems, the Ministry of Power implemented energy storage obligations (ESO) as a distinct and compulsory element of renewable purchase obligations (RPOs). According to the policy document, there is a stipulated annual increase in ESO for all obligated entities, beginning at 1% in FY2023–24 and reaching 4% in FY2029–30 (MOP, 2022). The Ministry of Power has also come up with the National Framework for Promoting Energy Storage Systems (MOP, 2023). The objective of this framework is to develop an ecosystem for ESS to be able to supply reliable carbon free green electricity. A TERI study on India's 2030 decarbonization target (Shankar, Saxena, and Idnani, 2022) has prioritized storage technologies while giving preference to pumped storage plants (PSP) and concentrated solar thermal (CSP) with storage (Shankar, Saxena, and Mazumdar, 2024a). TERI has carried out detailed studies on these two technologies, i.e., PSP and CSP with storage (Shankar, Saxena and Mazumdar, 2024b). The Solar Energy Corporation of India (SECI) has announced that it plans to issue tenders for a concentrated solar thermal storage project of 500 MW round-the-clock green energy in the next year (ET, 2024). The transition away from coal in India will depend on the speed, cost, and scale of the creation of large-scale grid storage. As confidence in the ability to meet full demand only from renewables and storage grows and as it becomes clearer that this is the cheaper way of meeting additional demand, the development of new thermal plants would end.

d) Decommissioning of thermal power plants

Once RE along with storage is being created on the scale needed to meet all additional demand, then total emissions from electricity would peak. Decommissioning of thermal power plants thereafter would be the way to get to net zero. There would be costs. A just transition needs to be carefully planned in the coming years.

Policy and regulatory measures would be required to implement the decommissioning of plants. The costs incurred in the process could be offset partially, or fully, by diversifying and gradually transforming coal companies into green energy companies. Coal India is cash-rich with a huge land bank. This land could be repurposed for use in other productive and revenue generating activities. Effective programmes for reskilling workers for the post coal economy in the coal mining areas need to be designed. Initial pilot project need to be undertaken when coal production from a particular mine ends and the mine is closed.

2.3 Studies Needed for Decarbonization of Electricity

The following detailed studies would be needed on an ongoing basis to get greater clarity on the feasible pathways for achieving a carbon emissions free electricity system:

- Generate alternative scenarios of demand growth and undertake modelling exercises to determine timelines and cost implications for the installation of RE and large-scale grid storage for reaching the inflection point when reliable supply for additional demand would not need new thermal capacity.
- Feasible pace of creating new nuclear capacity. Trajectory of cost reduction to make life cycle cost comparable to RE plus storage.
- Feasible options for transition of Coal India and thermal power companies, NTPC and others, into green fossil fuel free energy companies.
- Studies and pilot projects with stakeholder consultation for repurposing of land of exhausted coal mines for productive use and revenue generation.
- Costs of just transition away from coal: loss of jobs, royalties to the states. Feasibility of meeting these partially or fully with repurposing of land and revenue generation from other economic activities.

3 SECTORAL TRANSITIONS TO NET ZERO THROUGH GREEN ELECTRICITY

3.1 Surface Transport

India's transport emission is about 315 $MtCO_2eq$ (NITI Aayog, 2024), which is about 10% of total national emissions.

Electrification would be the driver of transport decarbonization in India. This is the case in Europe and California.

The rising share of electric vehicles (EVs) in India is represented in Figure 7 (MoRTH).

EV adoption in Delhi shows a highly positive trend, represented in Figure 8 (MoRTH). Apart from the three-wheelers with more than 70% of EVs in annual registrations, electrification of buses has been phenomenal with almost 46% of new registrations being EVs.

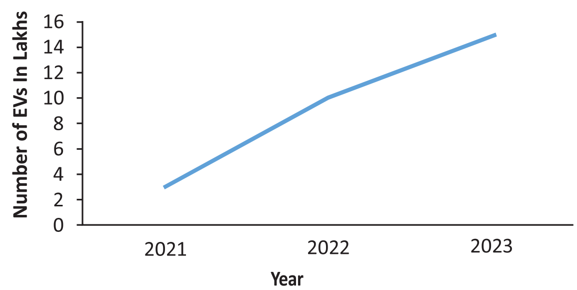


Figure 7: National trend of EV penetration

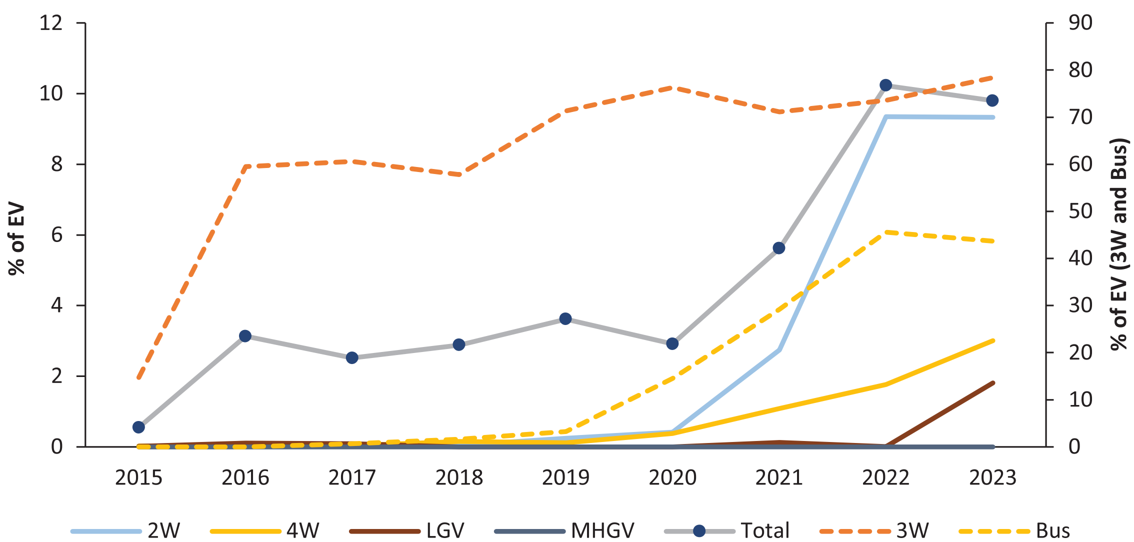


Figure 8: Trend of EV penetration among newly registered vehicles in Delhi

Blending of biofuels for use by vehicles is similar to energy efficiency as an intermediate option to lower carbon intensity. Vehicles which run only on biofuels are carbon free as biofuel is a renewable source of energy. But if forests are cut for sugarcane plantations to get ethanol as a biofuel, then the negative impacts far outweigh the benefits. Similarly, if price signals for biofuel lead to diversion of food crops for human beings for biofuels, this is an outcome which must be avoided. India does not have the land and water endowments for biofuel to be a significant option for decarbonization of transport.

The decarbonization path of road transport would be as follows:

I. The share of EVs in new sales rises rapidly.

II. All new vehicles on the road become electric.

III. Share of RE in electricity rises. Per passenger kilometre emissions begin to decline.

IV. Electricity becomes carbon free making all EVs carbon free.

V. Heavy-duty trucks become green hydrogen trucks.

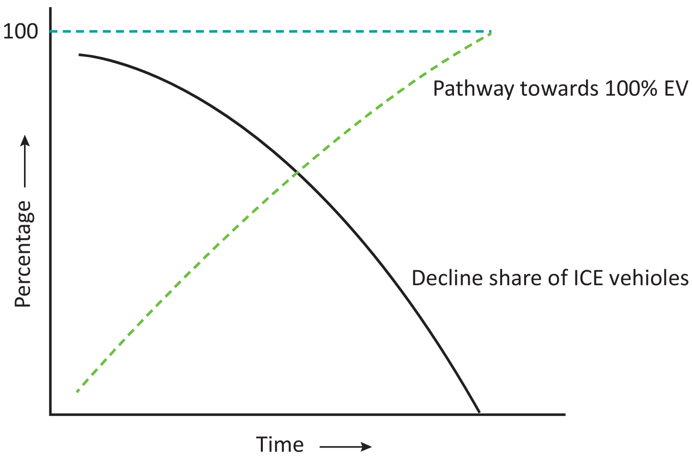
VI. Once all new vehicle sales are of EVs or hydrogen trucks, the emissions will reach their peak and plateau.

VII. The emissions would begin to decline, with the phasing out of existing internal combustion-based vehicles.

VIII. As the economy grows, passenger kilometres will rise. The corresponding per kilometre emissions will rise, plateau, and then decline towards zero.

Once sales of new vehicles are entirely electric and hydrogen-based heavy-duty trucks, carbon emissions from road transport will peak. The existing vehicle fleet of petrol/diesel/compressed natural gas (CNG)/hybrid will begin to retire simultaneously and once these vehicles age and are fully phased out of the system, the direct carbon emissions from vehicles would become zero. But overall carbon emissions from electricity generation have to peak, decline and become zero for the same effect to be seen in road transport. The peak and decline of carbon emissions from road transport would depend upon the penetration of green vehicles reaching 100% on the one hand and the electricity system getting fully decarbonized.

Figure 9: represents a stylized (a) trajectory of change in percentage of internal combustion engine (ICE) vehicles and EVs; and (b) the parallel decline in carbon emissions per unit of electricity.



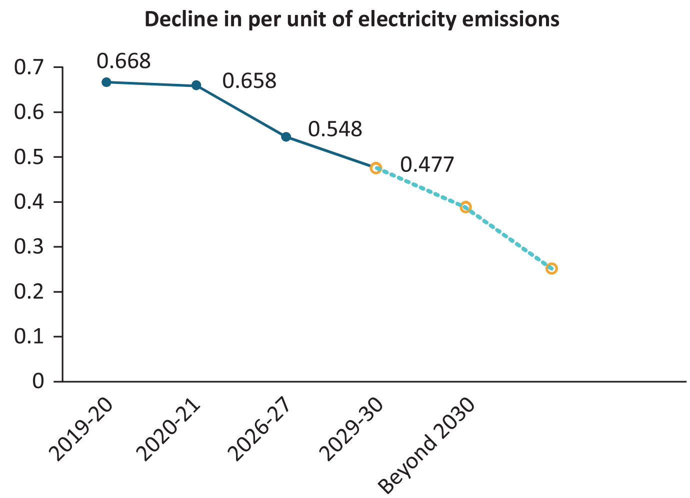


Figure 9: Change in share of ICE vehicles and EVs and decline of carbon emissions per unit of electricity

The Indian Railways have a 3% share of transport emissions. They have announced their intention to reach net zero by 2030. This could be achieved with the following measures:

- Completion of full electrification of Railways for all passenger and freight movement.
- Electricity consumed by Railways would have to become carbon-free by 2030. For this the use of captive solar power generation with green energy open access would be necessary.

Figure 10 represents the expected emissions trajectory in the transport sector. Emissions can reach their peak through two trajectories R1 or R2 depending on trajectories of EV penetration. In case of pathway R2, the emissions will peak at a much higher level, as number of vehicles will continue to rise due to rising demand, and more emissions will be released, by the time the electric and hydrogen based vehicle penetration takes place at a slower pace. In the transport sector, emissions are expected to decline after reaching a peak and not stay at a plateau. The emissions would follow path D which would be gradual. The retirement of old vehicles is a continuing process. Once all new vehicles are electric, the older internal combustion engines which would be retiring would result in the decline of total emissions from the sector straight away.

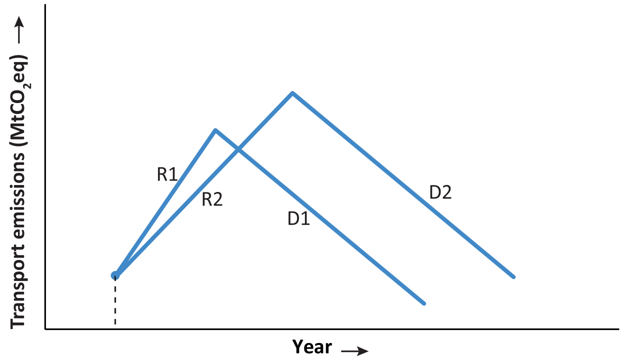


Figure 10: Transport emissions pathways illustration

3.1.1 Studies Needed for Decarbonization of Transport

a) Electric vehicles

- Scenarios on EV penetration of having the dominant market share and then complete market share.
  - 2 wheelers
  - 3 wheelers
  - 4 wheelers
  - Bus
  - Light duty vehicles
- Provision of charging infrastructure to keep pace with the growth of EVs.
- Study of challenges and policy instruments for achieving 100% share of EVs.
- Estimation of additional electricity demand required for the EVs and impact on the demand curve. Distribution Companies (DISCOMs) to incorporate this in their demand projections.
- Technical and commercial implications of converting roads into electric highways.

b) Heavy duty trucks

Green hydrogen is presently seen as the viable substitute for fossil fuels in heavy-duty trucks. Technological development of batteries for heavy duty trucks is being pursued. Incentives needed for the replacement of heavy-duty diesel trucks by hydrogen vehicles.

3.2 RESIDENTIAL COOKING

Residential cooking in India utilizes multiple fuels with varying proportions in rural and urban households. Currently, urban dwellings use liquefied petroleum gas (LPG), piped natural gas (PNG), and limited application of electric cooking, in households with higher incomes. In rural areas, LPG and biomass are the main cooking fuels with LPG rapidly replacing biomass due to the Ujjwala programme.

The adoption of electricity for cooking and electricity becoming carbon free would be the twin drivers for the decarbonization of cooking. The use of electric cookstoves at the household level in place of gas for cooking would be the key challenge. The person cooking must find the experience of using an electric cookstove for all traditional Indian dishes satisfactory.

Prime Minister Shri Narendra Modi recently announced the Pradhan Mantri Suryodaya Yojana (PMSY) 2024, under which 10 million households will be provided with solar PV panels. This would enable a faster transition towards electric cooking especially in the households of the weaker sections for whom the price of an LPG cylinder appears high. Electricity in comparison is cheaper. A few states are giving free units of electricity to households, ranging from 100 to 300 units per month. The price signal for use of electricity is strong. But change in consumer perception and experience is a prerequisite for large scale switch over from gas to electricity for cooking.

The use of biogas as a renewable source of energy for cooking has potential. But production and reliable supply of biogas for cooking along with a viable business model needs to be successfully demonstrated in some pilot projects. Scaling up would become a feasible option only after successful implementation of pilot projects with consumer satisfaction.

3.2.1 Studies Needed for Decarbonization of Cooking

- Getting electric cooking stoves out in the market which find acceptance from consumers as a replacement for gas for cooking of traditional food preparations.
- Explore feasibility of aggregation and cheaper supply of induction stoves through DISCOMs through a programme design based on the successful LED promotion programme.
- Pilot projects to develop a robust scalable model for biogas production and use for cooking in rural homes.
- Estimation of additional electric demand for cooking and its incorporation in DISCOMs demand planning.
- Feasible policy instruments for phasing down the use of LPG, for the complete decarbonization of residential cooking.

4 HARD-TO-ABATE SECTORS

Hard-to-abate sectors are those in which current levels of technology and costs today are such that decarbonization appears difficult. These sectors include industry, shipping, aviation, and agriculture. In some sectors such as agriculture, carbon sinks will be the primary or the only solution for achieving net zero.

India has plans to transition towards Green Hydrogen economy. The Ministry of New and Renewable Energy (MNRE) has launched Green Hydrogen Mission (MNRE, 2023) which will build capabilities to produce at least 5 million metric tonne (MMT) of green hydrogen per annum by 2030, with potential to reach 10 MMT per annum with growth of export markets. It is envisaged that green hydrogen production, supply, and uses would create the ecosystem and the domestic capacities for rapid scaling up by the end of this decade. The Mission aims to develop and scale up green hydrogen production technology and make it affordable and widely accessible.

4.1 Industry

India's industry emissions (manufacturing industries and construction) is about 688 $MtCO_2eq$* (NITI Aayog, 2024), which is about 21% of total national emissions. The industrial sector accounted for 56% of total energy consumption in 2021–22 (BEE, 2022). Approximately half of all industrial carbon emissions originate from the following six large industrial segments:

a) Iron & Steel

b) Cement

c) Aluminium

d) Fertilizer & Ammonia

e) Pulp and Paper

f) Petrochemicals

The CO_2 emissions from the industrial sector can primarily be attributed to combustion of fossil fuels in furnaces and boilers, process emissions and electricity usage in the plants.

The main pillars of industrial decarbonization are:

a) Industrial electrification (non-fossil/RE)

Industrial electrification involves transitioning industrial processes away from the use of fossil fuel-based energy to electricity to the extent it is technically feasible. As electricity production

* This excludes indirect emissions from grid electricity consumption in the industries, which are already accounted under section 2.1.

moves towards becoming carbon free, these industrial processes would in parallel start becoming carbon free.

b) Solar thermal

The use of solar thermal power for low/medium temperature heating in industrial processes has considerable potential as a substitute for fossil fuels. This is a low hanging relatively neglected fruit. It needs to be promoted with appropriate policies to evolve in partnership with industry.

c) Green hydrogen

Green hydrogen has great potential for the decarbonization of hard-to-abate sectors. India is implementing an ambitious Green Hydrogen Mission. To illustrate, the use of green hydrogen can be the key to the decarbonization of fertilizer and steel production.

As India makes its transition to becoming a developed economy, high growth in industrial production would take place. The emissions would continue to rise till the time additional energy demand for industrial production is met completely by carbon free electricity, solar thermal, and green hydrogen. Emissions would then peak. The emissions would remain at their peak till the time that the existing carbon-intensive technologies continue to function. The emissions would begin to decline when the carbon emitting industrial units are phased out of the system.

A stylized trajectory is shown in Figure 11. The pace of rise and decline of emissions would depend upon the rate of penetration of green technologies and then the closure of carbon emitting plants. The emission rise and decline can happen in multiple trajectories, as shown in Figure 11, R1 for a steep rise, R2 for a gradual rise. In case of path R2, the emission will peak at a higher level, as the demand for industrial products will continue to rise with India's growth journey. Conceptually, the peak could remain for a shorter duration and emissions could decline using either D1a (steep) or D1b (gradual), while the peak could also stay for a long time and emissions could then decline rapidly using path D2a, or gradually using path D2b.

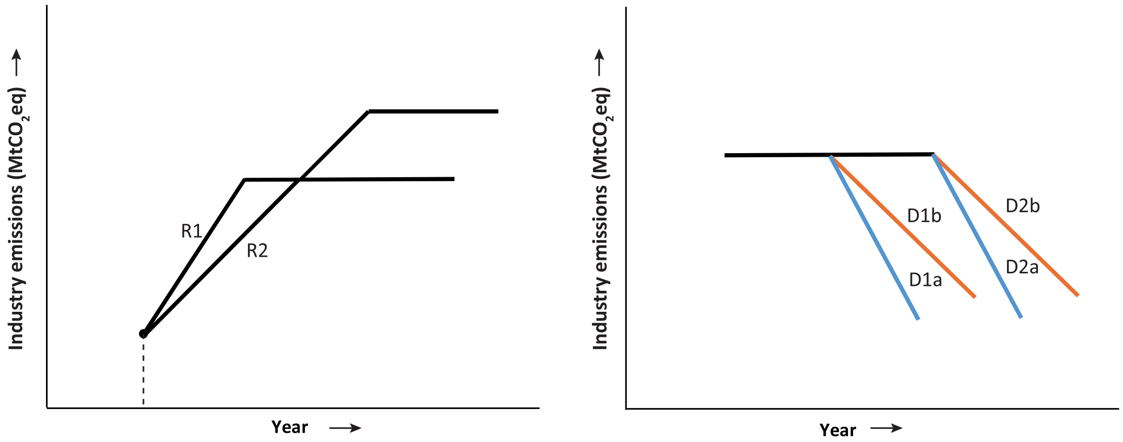


Figure 11: Industry emissions pathways illustration

To shift to a greener path and decouple growth from increase in emissions would be a difficult challenge for each industry. Technologies for doing away with the use of fossil fuels in production need pilot projects to discover the cost. Pilot projects need to be taken up in each industry segment as the technology for lower carbon or carbon free production emerges. India could try and be on the global frontier in decarbonization of industry.

The products manufactured in the pilot plants without using fossil fuels would be more expensive than the ones in the market using fossil fuels. The transition to having all new plants becoming carbon free would pose many complex challenges for policymakers.

Deciding on the policy for the closure of existing plants would be even more challenging. So much would depend on the costs at that point of time.

4.1.1 Studies needed for green hydrogen - Industry

- Prepare implementation design for pilot projects and demonstration plants using green hydrogen for production of green carbon free fertilizer and steel. Assess financial support required.
- Mapping of optimal locations for green hydrogen production based on various factors including water needs and availability.
- Proramme design for production of green hydrogen from biowaste.
- After initial pilot projects, an assessment of scenarios for the likely decline of costs with larger volumes.
- Feasible policy instruments for scaling up with cost implications. scaling up with cost implications.

4.2 Shipping

Green hydrogen or green ammonia made from green hydrogen are potential carbon-free substitute fuels for engines in shipping. In the shipping sector, pilot projects may be started to discover costs for both.

From an air and water pollution perspective all inland waterways should become fossil fuel-free under a national programme. Smaller boats can use electric engines and the larger ones, hydrogen-based fuel.

4.2.1 Studies needed

- Green hydrogen as the substitute for fossil fuels in shipping either as direct use or as green ammonia.
- Studies on complete switchover to green fuels: Affordable and feasible policy instruments.

4.3 Aviation

In the aviation sector, India may have to follow global trends. The key is development of planes by the global majors, Boeing and Airbus, which can run on biofuel or hydrogen. For short haul flights, even electric routes might be feasible.

India could also choose to become more ambitious. It could begin a programme for development of hydrogen-based engines for aviation either on its own or in partnerships with others global players.

4.4 Agriculture

The agriculture sector is the main source of CH_4 and N_2O emissions. Methane (CH_4) emissions occur mainly due to livestock rearing and rice cultivation. The agriculture sector contributes 13.4% of the total national GHG emissions which is about 420 $MtCO_2eq$ (NITI Aayog, 2024). The sub-sectoral emission bifurcation is shown in Figure 12 (NITI Aayog, 2024)

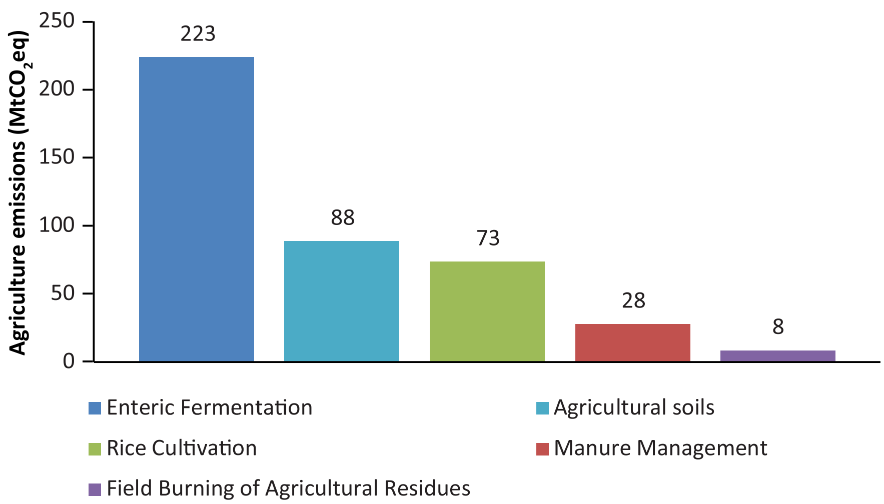


Figure 12: Agricultural sector emissions

a) Addressing emissions from enteric fermentation

In 2019, emissions from livestock category accounted for about 223 $MtCO_2eq$. The total livestock population is 535.780 million and rising and so are the emissions (DAH, 2019).

The mitigation options for reducing emissions from enteric fermentation are changes in feed of livestock and improvements in dietary contents. High-quality pasture has been shown to lower methane yield by 12–51% as compared to traditional low-quality grazing systems.

There is, however, no technical solution for complete mitigation of emissions. Carbon sequestration by creating sinks would be required to achieve net zero ultimately.

b) Emission reduction from rice cultivation

In India, approximately 47.6 lakh hectares of land are under rice cultivation (PIB, 2020). Methane emissions from rice cultivation systems vary depending on existing ecological and environmental conditions. In 2019, emissions from rice cultivation amounted to 73 $MtCO_2eq$.

The potential mitigation strategies for reducing emissions from rice cultivation are a System for Rice Intensification (SRI) and Direct Seeded Rice (DSR) or Alternate Wetting and Drying (AWD).

These techniques lead to a reduction of 30%–50% emissions and co-benefits such as improvement in soil health and reduction in water use, i.e., around 10%–20% without reducing yield.

However, for achieving net zero altogether carbon sinks would have to be the solution.

c) Emission reduction by using biowaste as a renewable source of energy to reduce fossil fuel use

The quantum of crop residues from India's farm economy is about 500–680 million tonnes out of which 180–240 million tonnes is surplus crop residue every year. In most parts these residues are used as fodder. These residues are a rich source of renewable organic carbon that can be used to produce fuel, chemicals, biochar, or petrochemical feedstock. Developing biochar from crop residues is a good substitute for coal in thermal power plants. Biochar cofiring has the potential to reduce the CO_2 emissions from coal burning in thermal power plants, by 165 MT annually, i.e., 7% of overall emissions by India (Anand, Pathak, Kumar, & Kaushal, 2022).

d) Emissions from manure management

The government is promoting the usage of dung-based manure. Manure management initiatives have the potential to generate biogas equivalent to 50% of India's present LPG consumption and produce bio-slurry equivalent to 44% of India's Nitrogen, Phosphorus, and Potassium (NPK) requirement. The potential opportunities for the conversion of cow dung into commercial applications include emissions from manure value chains, conversion of cow dung to biogas, and setting up of biogas-based energy generation for dairy plants (PIB, 2019).

4.4.1 Studies needed

- Feasible change in feed of livestock to reduce emissions.
- Design a programme for use of cow dung as a renewable source of energy with zero methane emissions.
- R&D for biotechnological or thermochemical routes for efficient use of crop wastes.
- Design a programme to use all the crop waste, that is being burnt and causing a spike in air pollution, to produce pellets and for their use as a substitute for coal in thermal plants.

5

CONCLUSION

The pathway to decarbonization of electricity has some clarity. Modelling exercises and alternative scenarios with cost implications which are reasonably realistic can be generated. These can be revised and updated as the transition unfolds. Peaking of emissions from electricity can be achieved without additional costs and may even result in some cost savings.

Reducing emissions from their peak to zero would have costs. But there could be potential gains if the transition is well planned, and these may offset partially or even fully the costs from the phasing out of thermal power and consequent closure of coal mines at a future date. This would need ongoing analysis and stakeholder consultations in the coming years.

Electrification of surface transport creates the pathway for reduction of emissions in tandem with the decarbonization of the electricity sector. As emissions from electricity reach zero and all transport becomes green, about 50% of our present emissions would get eliminated.

For the hard-to-abate sectors, it is too early to see the contours of the journey to net zero. Pilot projects for downstream use of solar thermal and green hydrogen in different segments need to be implemented. Some clarity on the higher cost resulting from the giving up of the use of fossil fuels as well as the potential for cost reduction with scale would emerge on completion of pilot projects. A view on the affordable pathways to net zero in each of the hard-to-abate sectors could then emerge under alternative scenarios.

Some emissions are expected to continue in segments where hydrogen and electricity cannot be a full substitute for the existing use of fossil fuels. Cement is a good example. No substitute is available to replace cement and no technological advancement has taken place to fully decarbonize its manufacturing process.

The absorption of such residual emissions would be a challenge. Creation of sinks through afforestation would be one option. Carbon capture and storage (CCS) and carbon capture utilization and storage (CCUS) would be the other options. These may need to be utilized for the last steps in the journey to becoming net zero.

This paper is a simplified macro view of the pathways to net zero in the major GHG emitting sectors and sees the transition through the prism of decoupling of growth and increase in total energy consumption from carbon emissions which would peak, plateau and then decline to become net zero.

Each sector has complexity and would need detailed modelling, generation of alternative scenarios with timelines and cost implications. Alternative policy instruments for facilitating and accelerating the transition would need to be designed with stakeholder consultations. A long-term net zero perspective backed by increasingly rigorous analysis would make it easier to take optimal decisions which steer us to the least cost pathways towards net zero.

It is hoped that this paper would generate interest and the process of undertaking the detailed sectoral studies envisaged in the paper would begin. Discussions on these studies would help in the emergence of some consensus on the way forward and contribute to India continuing to display climate leadership while accelerating its transition to becoming a developed globally competitive green economy.

6

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