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ECONOMIC POLICIES FOR AFFORDABLE, SECURE AND CLEAN ENERGY
INSIGHTS FROM INDIA

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SUMMARY

India is making significant strides toward affordable, secure and clean energy with the help of ambitious economic policy packages. Yet, like in other countries, many challenges remain.

The country aims to have 50% of its power generation capacity to be based on non-fossil fuel sources by 2030. By 2024, it had already reached 45%. Expanding low-carbon electricity production will be pivotal in meeting the rapidly increasing demand, which necessitates substantial investments over an extended period. However, India's low electricity prices, while beneficial for consumers, limit revenue for clean energy investments. The financial viability of state-run electricity distribution companies (DISCOMs) remains a concern, with persistent losses impacting the scope for reforms.

India's transport sector contributes significantly to greenhouse gas (GHG) emissions. Policies like FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) and the Prime Minister's E-Drive Scheme support electric vehicle (EV) adoption, with a target of EVs accounting for 30% of all car sales by 2030. In freight transport, railways and dedicated freight corridors are being prioritized for decarbonization.

Households' access to electricity has been strongly improved by government programmes such as the Saubhagya scheme, which achieved near-universal household electrification and promoted energy-efficient lighting in rural areas. Switching to clean cooking, with its beneficial impact on local air quality and people's health, has progressed – but too slowly particularly in rural areas. Solar cooking initiatives and improved biomass stoves aim to reduce dependence on polluting fuels, though adoption remains limited by high costs and cultural resistance.

India's industrial sector is the largest final consumer of energy. This substantial energy demand, predominantly met through fossil fuels like coal, underscores significant challenges. Technical solutions such as green hydrogen, CCUS, and recycling are being tested, but costs remain prohibitive.

Transitioning to cleaner energy sources and improving energy efficiency are critical to ensuring India's sustainable growth. But socio-economic compulsions as well as its ability to meet peak demand will perpetuate the dominant position of coal in the energy power mix. The 'Economic Survey' released on 31 January 2025 by the Indian government acknowledges the crucial role of coal in meeting the energy needs given the low availability of domestic natural gas. The report highlights the role of supercritical, ultra-supercritical and advanced ultra-supercritical technologies to maximise efficiency in the use of coal. While the adoption of these technologies can contribute to reducing carbon emissions, simultaneous investment in renewable sources is paramount.

Large-scale private funding, both domestic and foreign, will be required to support research and deployment of clean energy in the electricity, transportation, household, and manufacturing sectors. Enabling policy frameworks that attract financing and reduce the cost of capital will be crucial to sustain India's future in affordable, secure, and clean energy.

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ABBREVIATIONS

AAT: Advanced Automotive Technology
ACCESS: Access to Clean Cooking Energy and Electricity – Survey of States
AT&C: Aggregate Technical and Commercial
BAT: Best Available Technologies
BEE: Bureau of Energy Efficiency
BET: Battery Electric Truck
BF: Blast Furnace
BPCL: Bharat Petroleum Corporation Limited
CAGR: Compound Annual Growth Rate
CAPEX: Capital Expenditure
CBAM: Carbon Border Adjustment Mechanism
CCC: Carbon Credit Certificate
CC: Compound Cement
CCTS: Carbon Credit Trading Scheme
CEEW: Council on Energy, Environment and Water
CCS: Carbon Capture and Storage
CCU: Carbon Capture and Utilization
CCUS: Carbon Capture, Utilization and Storage
CF: Clinker Factor
CO: Carbon Monoxide
CO2: Carbon Dioxide
COP: Conference of the Parties
DBTK: Direct Benefit Transfer for Kerosene
DCPC: Department of Chemicals and Petrochemicals
DBTL: Direct Benefit Transfer of LPG Subsidy
DDUGJY: Deen Dayal Upadhyaya Gram Jyoti Yojana
DISCOM: Distribution Company
DRI: Direct Reduced Iron
DST: Department of Science and Technology
EAF: Electric Arc Furnace
ECR: Effective Carbon Rate
EOR: Enhanced Oil Recovery
EV: Electric Vehicle
FAME: Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
FID: Final Investment Decision
GCCA: Global Cement and Concrete Association
GDP: Gross Domestic Product
GHG: Greenhouse Gas
GPPP: Green Public Procurement Programme
HAP: Household Air Pollution
ICE: Internal Combustion Engine
ICM: Indian Carbon Market
IF: Industrial Furnace
IHDS: Indian Human Development Survey
IMEC: India Methanol Economy Coalition
IOCL: Indian Oil Corporation Limited
IPDS: Integrated Power Development Scheme

JSL: Jindal Stainless Limited
LC3: Limestone Calcined Clay Cement
LED: Light Emitting Diode
LT LEDS: Long-Term Low Emissions Development Strategies
LPG: Liquefied Petroleum Gas
MNRE: Ministry of New and Renewable Energy
MoS: Ministry of Steel
MoEFCC: Ministry of Environment Forest and Climate Change
MRV: Monitoring, Reporting, and Verification
MSW: Municipal Solid Waste
NAC: Non-Attainment Cities
NAAQS: National Ambient Air Quality Standards
NBCI: National Biomass Cookstoves Initiative
NCAP: National Clean Air Programme
NDC: Nationally Determined Contribution
NEDO: New Energy and Industrial Technology Development Organization
NGHM: National Green Hydrogen Mission
NPIC: National Programme on Improved Cookstoves
NSSO: National Sample Survey Office
OPC: Ordinary Portland Cement
OPEX: Operating Expenditure
PAT: Perform, Achieve, and Trade
PBS: Public Bicycle Sharing
PDS: Public Distribution System
PFC: Power Finance Corporation
PLFS: Periodic Labour Force Survey
PLI: Production Linked Incentive
PM E-Drive: Prime Minister E-Drive Scheme
PMUY: Pradhan Mantri Ujjwala Yojana
$PM_{2.5}$: Particulate Matter
PNG: Piped Natural Gas
PPC: Portland Pozzolana Cement
PSC: Portland Slag Cement
RE: Renewable Energy
REC: Rural Electrification Corporation
RGGVY: Rajiv Gandhi Grameen Vidyutikaran Yojana
RoW: Right-of-way
RTS: Rooftop Solar Scheme
SCMs: Supplementary Cementitious Materials
SEC: Specific Energy Consumption
SECI: Solar Energy Corporation of India
SIGHT: Strategic Interventions for the Green Hydrogen Transition
SMR: Steam Methane Reforming
TBSU: Technical Backup Support Unit
TCO: Total Cost of Ownership
UCA: Unnat Chulha Abhiyan
UDAY: Ujwal DISCOM Assurance Yojana
UJALA: Unnat Jyoti by Affordable LEDs for All
WHRS: Waste Heat Recovery System

UNITS

BU: Billion Units, where 1 BU equals 1,000 Gigawatt-hours (GWh), the equivalent of 1 TWh
MT: Million Tonnes
MTOE: Million Tonnes of Oil Equivalent
MTPA: Million Tonnes Per Annum
MU: Million Units, where 1 MU equals 1 GWh or 1,000 MWh.
TPD: Tonnes per day
1 crore = 1 crore = 10 million
1 crore = 100 lakh (where 1 lakh = 100,000)
Indian Rupee INR 100 = EUR 1.06 = USD 1.16 on 19 March 2025

1. REFORMING INDIA'S ELECTRICITY MIX

India has pledged to have 500 gigawatts (GW) of its power generation capacity (50% of its total) from non-fossil fuel sources by 2030. As of 31 December 2024, the country's total electricity generation capacity stood at 462 GW, with 217 GW (47%) originating from non-fossil fuel sources. Consequently, a substantial gap exists between the current non-fossil fuel capacity and the 500 GW target by 2030. To achieve this objective, a substantial acceleration in investments is necessary to add approximately 300 GW within the next six years. The government has recognised this challenge and has unveiled a plan to annually add 50 GW of renewable capacity.[1]

Table 1.1 - Installed power capacity (by fuel) as of 31 December 2024

Category	Installed Power Capacity (GW)	% Share of Total
Fossil fuels (coal, gas and diesel)	245	53
Non-fossil fuels, of which	217	47
- Renewable (including hydro)	209	45
- Nuclear	8	2
Total	**462**	**100**

Source: India's Central Electricity Authority

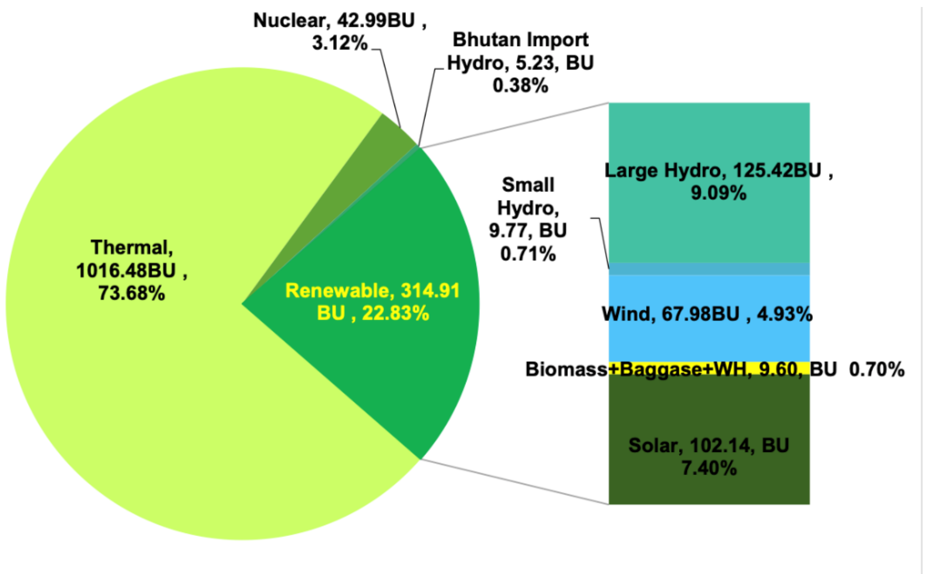
This recent buildup of low carbon capacity notwithstanding, the generation of electricity remains heavily dependent on fossil fuels. Thermal plants using fossil fuels generate about 75% of the total power produced (Figure 1.1), making it a significant source of greenhouse gas (GHG) emissions and air pollution. Thermal power plants largely rely on coal, a significant portion of which is imported, raising challenges on energy security in a fragmented geopolitical context. India's low electricity prices, while beneficial for consumers, limit revenue for clean energy investments. The financial viability of state-run electricity distribution companies (DISCOMs) remains a concern, with persistent losses impacting the scope for reforms.

1.1 The electricity mix is becoming gradually cleaner

India has made significant progress in renewable energy (RE) installed capacity, with renewables including hydroelectricity now representing a significant share of the country's electricity mix (Table 1.1). The gap between fossil fuels and alternative sources continues to narrow, with the latest data from the Central Electricity Authority indicating a RE-based electricity generation capacity of 209 GW, accounting for 45% of the country's total installed capacity. Within this segment, solar power contributes the most at 47%, followed closely by wind energy (23%) and hydro (25%). India now ranks fourth globally in terms of installed renewable energy capacity and aims for 500 GW of non-fossil fuel sources by 2030 (i.e. solar, wind, hydro and nuclear). This represents a pivotal moment in India's energy transition, highlighting its growing reliance on low-carbon energy and its commitment to climate goals.

The increase in installed electricity capacity has led to higher power generation, which reached 1734 BU/TWh in FY2023-24 and 1380 BU/TWh during April-December 2024 (Figure 1.1). Between 2017-18 and 2023-24, conventional generation based on fossil fuels increased by 294 BU/TWh (69% of additional generation), renewable generation (excluding hydro) has increased by 87 BU/TWh (29%) and the remainder came from hydro.[2] As a result, the share of renewables including hydro has risen from 17% to 21% of total generation during this period and increased further to reach 23% during April-December 2024[3] (Figure 1.1).

Figure 1.1 – India's Energy Generation During April-December 2024 (1380 BU/TWh)

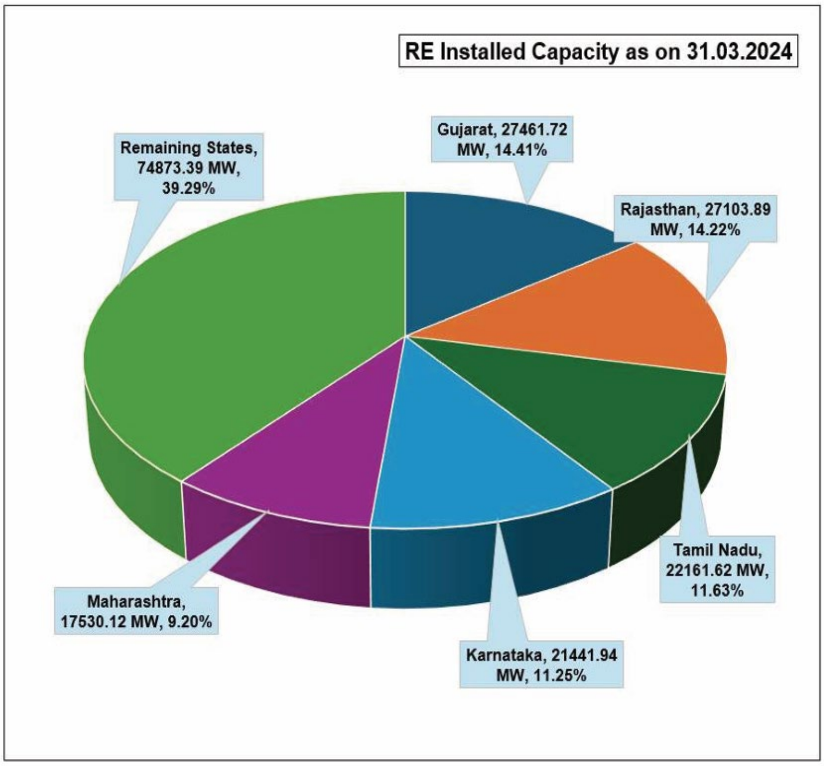


Source: India's Central Electricity Authority

(in this figure, 1 BU = 1TWh)

Five states account for more than 60% of the total installed RE capacity in the country as on 31 March 2024 (Figure 1.2).[4] Rajasthan leads in solar power with its high intensity solar radiation and vast desert stretches providing favourable conditions for the installation of solar plants.[5] Gujarat's natural advantage with abundant sunshine, strong winds and vast coastline along with favourable policies explain its dominance in both wind and solar power.[6] The southern states of India such as Tamil Nadu and Karnataka are endowed with strong winds due to their proximity to the mountains of the Western Ghats, providing ideal conditions for wind farms.[7]

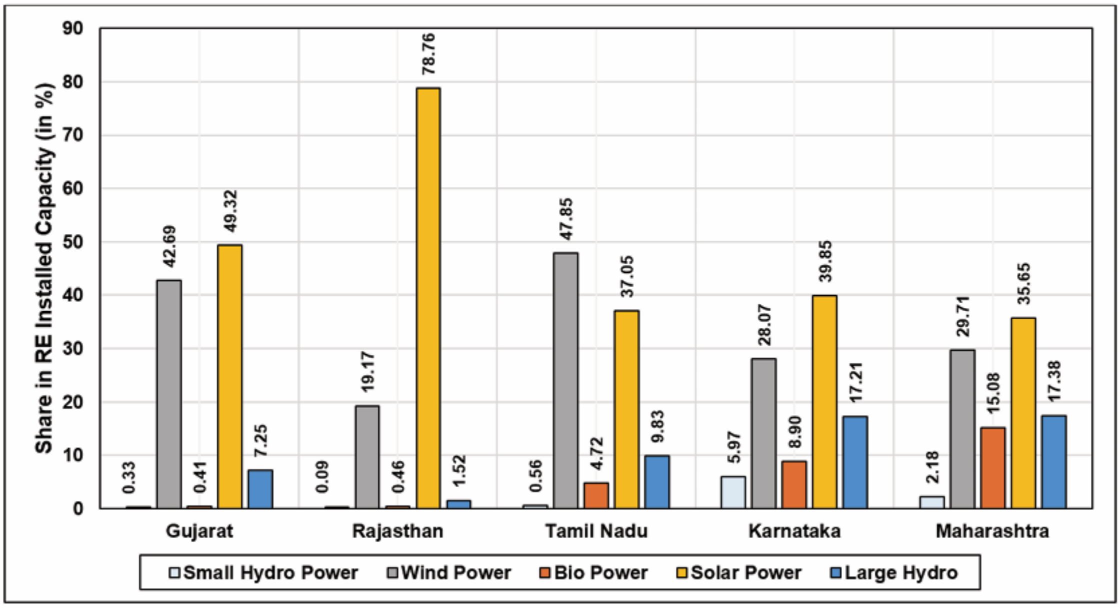
Figure 1.2 – Locations of RE generation capacity[8]



Source: Renewable Energy Statistics 2023-24. Ministry of New and Renewable Energy.[9]

Despite these encouraging trends, the continued dominance of coal is the stark reality of India's energy mix. Coal reserves are concentrated in the eastern states of Jharkhand, Chhattisgarh and Odisha and are the lifeline of some of the poorest communities in the country.[10] A Brookings Institute report of 2019 discusses how the coal industry is 'knit into the fabric of the Indian economy'.[11] Apart from providing employment for nearly 4 million people, the coal industry is also a significant source of revenue for both the central and state governments.[12] For the Indian Railways, the freight revenues from transporting coal are used to subsidize passenger transport.[13] Vice versa, for power plants located far from the mines, transport comprises a substantial portion of the coal price.[14]

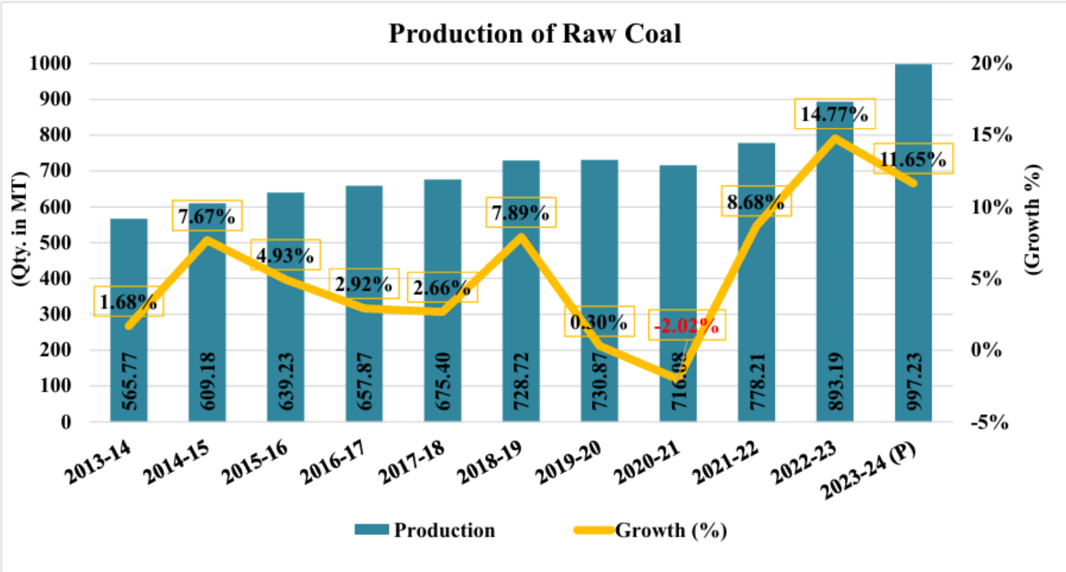
Figure 1.3 - Shares of RE sources in top 5 RE installed capacity states (on 31 March 2024)[15]



Source: Renewable Energy Statistics 2023-24. Ministry of New and Renewable Energy[16]

In addition to socio-economic factors, energy security concerns—brought into sharp focus during the onset of the Ukraine war in 2022—have encouraged the government to continue its traditional reliance on domestic coal, rather than encouraging a shift to gas-fired power plants, which would be cleaner but would depend on a resource that is increasingly imported. Since 2014, electricity demand in India has surged by about 51%, with peak demand rising from 136 GW in 2013–14 to 243 GW by September 2023.[17] These pressures partly explain the continued increase in the domestic production of coal (Figure 1.3) and the additional 4 GW of coal-fired power capacity in 2023, the highest annual growth since 2019.[18]

Figure 1.4 – Increase in raw coal production



Source: Ministry of Coal, Government of India, Production-of-Raw-Lignite-coal.xlsx

The government's Economic Survey of 2024-25 emphasizes the criticality of coal and mining to power the Indian economy.[19] It points out the imperative of coal as an energy source given the low availability of natural gas reserves in the country at 0.7% of the global reserves.[20] In recognition of balancing the priorities of energy security and climate commitments, India has adopted clean technologies to reduce the GHG emissions from the mining of coal. By mid-2024, India had installed 65.3 GW in supercritical units and 4,2 GW in ultra-supercritical units.[21] Furthermore, NTPC and BHEL are developing an 0.8 GW AUSC technology-based power plant, which is expected to cut emissions by 11% compared to existing supercritical plants.[22]

1.2 Policy initiatives to support renewable energy

To support the growth of solar power required to meet the pledge of 500 GW in non-fossil fuel electricity, the Government of India has launched the Production-Linked Incentive (PLI) Scheme under the National Programme in High-Efficiency Solar PV Modules. Solar PV manufacturers are selected through a transparent process for receiving the incentives. The Ministry of New and Renewable Energy (MNRE) is the implementing agency which will determine the amount of incentive based on sales achieved and other performance criteria.[23] With an allocation of INR 24,000 crores,[24] this initiative aims to achieve domestic manufacturing capacity of Gigawatt scale in high-efficiency solar PV modules.[25]

While the PLI Scheme incentivizes the scaling up of domestic production, the imposition of a 40% customs duty on solar PV modules and 25% on solar PV cells is aimed at further promoting domestic goods compared to imported products. Likewise, the reintroduction of the Approved List of Models and Manufacturers of Solar Photovoltaic Modules (ALMM) in March 2024 is intended to ensure that only approved manufacturers can supply solar PV modules for government schemes and projects including those for sale of electricity to central and state governments.[26] The Ministry of New and Renewable Energy

(MNRE) has however conditionally exempted all eligible projects commissioned up to 31 March 2024 from procuring the solar PV modules from the ALMM list.[27]

The Pradhan Mantri (PM) Surya Ghar Muft Bijli Yojana, announced in the 2024 Interim Budget, aims to install rooftop solar plants, providing 1 crore/ 10 million households with up to 300 units (generally 1 kWh) of free electricity each month. During the Budget presentation in July 2024, the Finance Minister highlighted the scheme's remarkable success, with over 1.28 crore/12.8 million registrations and 14 lakh/1.4 million applications received during FY 2023-24.[28] Additionally, the central government recently approved the development of 50 solar parks with a combined capacity of 37.5 GW.[29] India has also made significant strides in wind energy, with installed capacity increasing from 349 GW in 2015 to 1,017 GW in 2024, further bolstering the country's renewable energy portfolio.[30]

The Government also launched the PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan) scheme in March 2019, which has been scaled-up in January 2024 with the objective to promote the use of solar energy in the agriculture sector.[31] Different components under this scheme facilitate the installation of renewable power plants, de-dieselization of existing grid-connected agriculture pumps and the installation of stand-alone solar power agriculture pumps.[32] PM-Kusum is seen as a game changer for the agriculture sector as it seeks to enhance farmers' income, increase energy security, phase out diesel in agriculture and lower environmental pollution.

The government has introduced several policy initiatives to boost private investment in renewable energy.[33] Key measures include attracting foreign direct investment (FDI) and enhancing infrastructure to streamline operations across the entire supply chain—spanning generation, transmission, and delivery of clean energy nationwide. In addition to the existing provisions for 100% FDI under the automatic route, setting up of a Project Development Cell, development of ultra mega renewable energy parks, increasing substation capacity, among others, are all designed to facilitate foreign investment into renewables. These efforts have been successful with the Department of Promotion of Industry and Internal Trade (DPIIT) latest report stating FDI equity inflows of INR 126,161 Crores/USD 146 billion into the non-conventional energy sector between April 2020 to September 2024 (last four financial years (FYs) and six months of current FY, i.e. September 2024.[34] Additionally, efforts to expand the transmission network—such as laying new transmission lines, increasing substation capacity, and waiving interstate transmission charges on wind and solar power sales—are aimed at ensuring the smooth, cost-effective delivery of clean energy to end consumers.[35]

Small developers of solar and wind power have been supported by feed-in tariffs decided by respective State Electricity Regulatory Commissions (SERC). This ensures that states/Union Territories (UTs) can procure solar power at competitive prices from suppliers who are unable to qualify for the competitive bidding process.[36] Tax incentives are also made available to boost domestic production of clean energy. Solar power plants enjoy accelerated depreciation of 40% (plus an additional rate of 20% in the first year) as against the regular depreciation rate of 15% for plant and machinery.[37] Similar tax benefits are also available to encourage the power sector to adopt energy saving devices. A higher depreciation rate of 40% has been available since the Assessment Year 2018-19 (FY 2017-18) on the installation of new equipment such as specialized boilers and furnaces, systems for monitoring energy flows, waste heat recovery equipment and others.[38]

In addition, India has enacted a Carbon Credit Trading Scheme (CCTS).[39] This aims to develop the Indian Carbon Market (ICM) by pricing greenhouse gas emissions through the trading of Carbon Credit Certificates (CCCs) where each CCC represents the emission equivalent of one ton of carbon dioxide (tCO2e). The regulatory framework encompasses a mandatory compliance mechanism and a voluntary offset process. The high-emitting sectors such as iron and steel, aluminium, cement and others have been identified as obligated entities for transitioning to the compliance process for which detailed guidelines were released by the Bureau of Energy Efficiency (BEE) in July 2024.[40]

The voluntary mechanism, which complements the compliance framework, covers various sectors, including energy. This scheme allows non-obligated entities to earn Carbon Credit Certificates (CCCs) for emissions reductions achieved through eligible projects. Individuals and companies can register their projects for GHG emission, reduction or removal or avoidance for the issuance of CCCs upon fulfilment of eligibility conditions.[41] This process is to be monitored by the Bureau of Energy Efficiency under the Ministry of Power which will be guided by the National Steering Committee for Indian Carbon Market (NSCICM). Detailed regulations for the voluntary offset process are yet to be finalised though the Bureau of Energy Efficiency (BEE) has invited comments on the methodologies for adoption in the voluntary offset mechanism under the CCTS.[42]

Within this policy context, numerous domestic and foreign private players have invested significantly in the renewable energy sector. Reliance Energy has made a bold commitment to achieve net-zero by 2035 and reported energy savings of 5.28 million GJ in 2024.[43] The company is investing in sodium ion cell production, cost-efficient wind power generation, and green hydrogen production.[44] Additionally, it is developing the 5,000-acre Dhirubhai Ambani Green Energy Giga Complex in Jamnagar, Gujarat.[45]

The business conglomerates, TATA and Adani group of companies are other key investors in India's renewable energy sector. Recently, on September 30, 2024, TATA Power signed an MoU with the state of Rajasthan to invest INR 1.2 trillion over a decade in rooftop solar installations, charging infrastructure, and other clean technologies. Adani Green Energy Limited (AGEL) boasts a renewable portfolio of 8.4 GW across 12 states, cumulatively offsetting over 41 million tonnes of CO2 emissions.

In terms of green finance, India relies predominantly on domestic sources, with 83% of funding coming from within the country, and 66% of this being provided by the private sector.[46] International funding for clean energy is mainly sourced from private entities such as commercial financial institutions and FDI inflows, with public sources like Official Development Assistance (ODAs) making up the remaining 17%.[47] Although overseas funding for clean investments has increased from 15% in FY 2019-20 to 19% in FY 2021-22, it remains a small fraction of total FDI equity inflows between April 2020 and December 2024.[48]

The International Energy Agency estimates that India will require an annual financing of USD 160 billion up to 2030 to meet its net-zero commitment by 2070.[49] The Reserve Bank of India suggests that the country needs green financing equivalent to 2.5% of its GDP annually until 2030.[50] However, central and state government budgets have limited resources to contribute to this green transition. India does not have an explicit carbon tax, and fuel excise taxes cover only 54% of emissions.[51] From 2010 to 2017, a cess (earmarked excise tax) on coal production and imports was levied, with a portion allocated to renewable energy projects, but this was subsumed into the GST compensation cess in 2017.

This highlights the need to attract private capital, both domestic and foreign, to invest in clean energy. Policy measures have created a favourable investment climate and boosted investor confidence in green investments. The government has signalled its commitment through the issuance of its first sovereign green bond in early 2023. However, achieving substantial private investments in renewable energy requires critical elements such as data transparency, public-private partnerships, mandatory reporting standards, and standardized taxonomies.[52]

1.3 Low electricity prices weigh on distribution companies

In India, the State Electricity Regulatory Commissions (SERCs) set the tariff rates of each state based on factors like cost of generating and distributing electricity, fuel prices and operational expenses. The average residential electricity price in India, at USD 0.07 per kWh, is among the lowest in the world.[53] However, political economy considerations hinder a comprehensive reform of pricing policies that would ensure heavy users pay their fair share for electricity consumption. Political parties try to appease their electoral bases, primarily the agriculture sector, by providing free power, bill waivers and subsidized electricity.[54] This not only limits revenue streams but also reduces the fiscal capacity of states to finance the clean energy transition through domestic resources.[55]

Private Indian companies have entered the power sector after the introduction of de-licensing in power generation through the landmark Electricity Act of 2003 ('The Act'). Hereafter, any company can operate and maintain a power generating station without a license except for certain restrictions on the generation of hydro and nuclear power.[56] The Act also marked a major step in the reform of the power sector through the unbundling of the State Electricity Boards (SEBs) into distinct entities looking after generation (GENCOs), transmission (TRANSCOs) and distribution (DISCOMs). The private sector subsequently invested primarily into power generation and now accounts for just over half of installed capacity.[57] While the generation sector thrived, the state-controlled TRANSCOs and DISCOMs have struggled to attract private investment. The transmission segment is controlled by the central public sector enterprise Power Grid Corporation of India while distribution is controlled by distribution companies (DISCOMs) of individual states.[58] Poor financial health, inefficient processes, and corruption allegations have delayed private sector investment into these companies.

State-owned DISCOMs enter into Power Purchase Agreements (PPAs) with power generation companies for purchasing power to supply to the consumers within their distribution network. Expensive PPAs amidst escalating coal prices and other conditions raise cost of inputs while irregular tariff revisions, unpaid dues from schools, municipal corporations and other public bodies and delay in the release of state subsidies have resulted in revenue shortfall.[59] To meet this financial gap, DISCOMS rely on short-term costly loans to purchase power, adversely affecting electricity prices disproportionately particularly for smaller consumers.[60,] Yet, the paper also highlights that out of 36 states and Union Territories (UTs), 27 offer subsidized power and without these state government subsidies, the tariffs would increase by 40% every year for 9 years assuming the current level of losses and subsidies persist.[61]

The indebtedness of state DISCOMs is a chronic problem and a primary hurdle for providing affordable electricity to low-income households. Successive governments have used bailouts to address this issue, but these remained ad hoc measures and DISCOMs accumulated a debt of INR 6.84 lakh crores in FY 2023–24.[62] In a major departure from direct financial assistance, the Ujwal Discom Assurance Yojana (UDAY) scheme provided incentives for DISCOMs in the form of an increased supply of cheaper domestic coal and a reduction in interest burden by requiring respective state governments to take over 75% of the outstanding debt of their DISCOMs. It also sought to enforce fiscal discipline by setting operational benchmarks such as reducing aggregate technical and commercial losses (AT&C) by 15% up to FY 2018-19, compulsory smart metering, and others.[63]

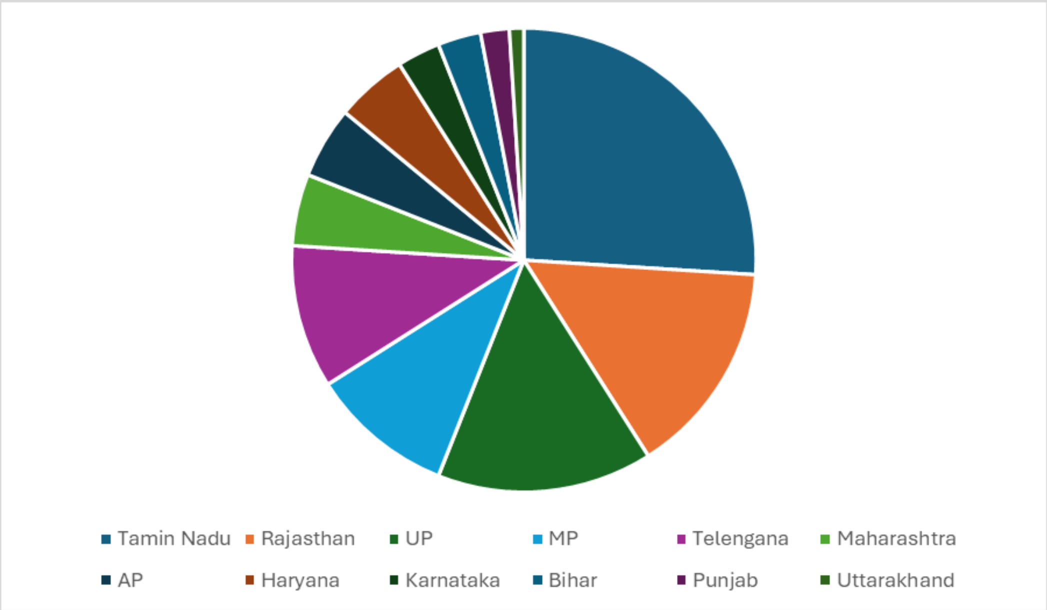
UDAY marked a definite improvement over earlier schemes, but the poor performance of DISCOMS has continued, thus resulting in unreliable power supply and operational inefficiencies such as high Aggregate Technical & Commercial (AT&C) losses. The government has responded by re-introducing a monetary assistance scheme, namely the Revamped Distribution Sector Scheme (RDSS) initially launched in 2021-22 and a second phase planned in 2026-27.[64] This is envisaged as a 'Reforms-based' and 'Results-linked' scheme to improve operational efficiency and financial sustainability of the DISCOMs. These bailouts all sought to provide financial aid to states conditional upon enactment of long-overdue reforms but were unsuccessful in addressing the structural gaps in the functioning of the DISCOMs. By financial year 2022-23, public electricity distribution companies had accumulated losses totalling INR 6.77 lakh crores with average annual increases of 10% since 2015-16.[65] The state-wise break-up of loss figures reveals that the accumulated DISCOM losses of 6 states together accounted for more than 75% of the national aggregated losses.[66]

The existing problems of DISCOMs have been exacerbated by recent changes in technology and policy. RE power sources are modular and scalable, with advances in technology and market forces gradually driving down costs.[67] The Green Energy Open Access Rules of 2022 reduced the renewable energy access limit from 1 megawatt to 100 kilowatts, allowing small consumers to request green energy from distribution companies (DISCOMs), who have become obligated to procure and supply it.[68] The availability of options particularly for non-subsidized consumers who make timely payments further erodes DISCOM revenues and places additional strain on providing subsidies to other groups.[69]

The DISCOMs need to completely rethink their current role and pricing strategies to overcome these multiple challenges. At present state DISCOMs are solely positioned as suppliers of electricity for all users within their distribution network. With the availability of alternative options and migration of consumers, their role as supplier of electricity will be restricted to servicing of small consumers who lack the capacity to purchase power directly from non-DISCOM sources.[70] Apart from electricity supply, DISCOMs will continue to provide banking and standby services for other suppliers but will have to improve their financial viability through unbundling and resetting of tariffs. Most importantly, the DISCOMs will be responsible for the planning of network expansion and management to reduce outages, accidents and provide a reliable power supply.[71] This transformation from DISCOMs to NETCOMs will require close collaboration between the centre and state governments and is the urgent need of the hour.

Figure 1.5 - State-wise accumulated DISCOM losses

(% of national aggregate)

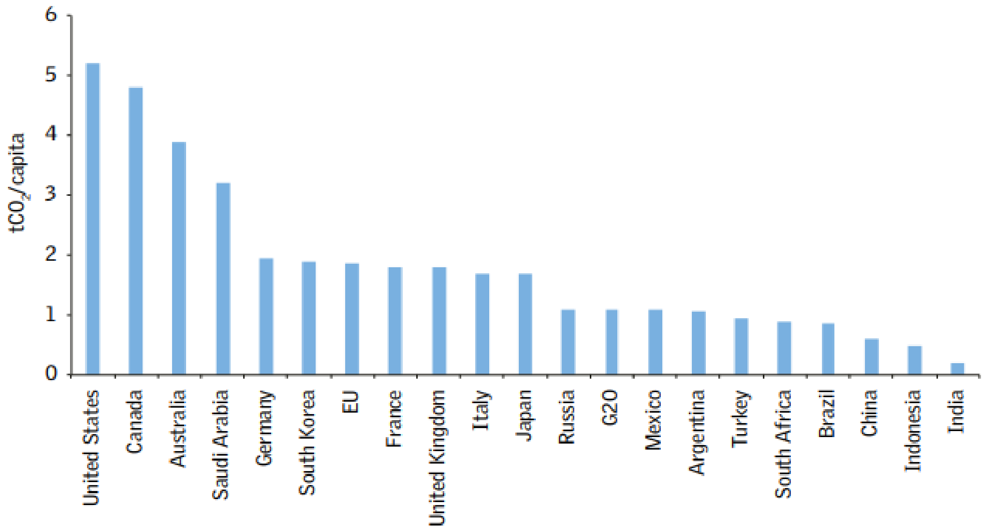


Source: Analysis of data from the Performance Report on Power Utilities (PFC, 2024) [72]

2. RETHINKING MOBILITY IN INDIA

The transport sector in India is a major consumer of fossil fuels and a contributor to GHG emissions, and local air pollution. In 2022, the sector's energy consumption was 4.7 exajoules, representing approximately 15% of the country's final energy use.[73] At 0.22 tCO2e/year in 2018[74], India's per capita emissions from the transport sector is substantially lower than the G20 average of 1.13 tCO2e/year but its growth (excluding aviation) is one of the highest among the G20 (Figures 2.1 and 2.2 below).[75] The transport sector relies currently on imported crude oil and refined car fuels, which might create issues of energy security, while shifting to electric vehicles would rely on domestically energy sources. In all these transformations, making transport affordable for all population groups will be essential, with specific objectives of promoting electric two-wheelers and mass transit systems.

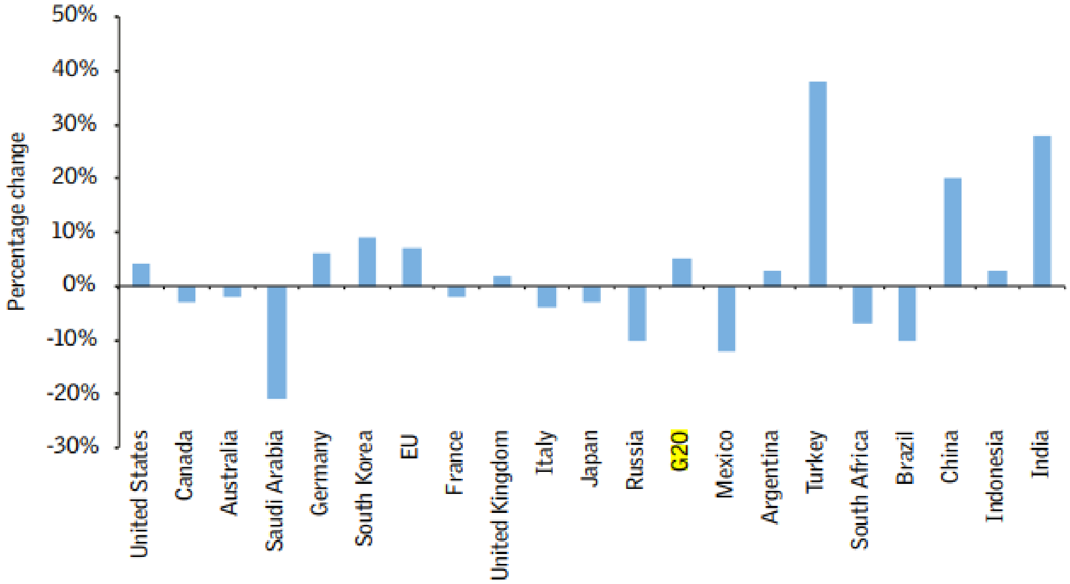
Figure 2.1 - Per capita transport GHG emissions in G20 countries



Source: Enerdata 2019; World Bank 2019

Transport sector emissions grew 241% from 95 Mt CO2 in 2000 to 324 Mt CO2 in 2022.[76] Apart from GHG emissions, the transport sector also contributes to air pollution from particulate matter leading to severe air quality and associated health hazards. In 2023, the capital Delhi was the most polluted city in the world with dangerous levels of particulate matter (PM) 2.5.[77] In a 2020 study, Niti Aayog published the trends in transport sector emissions between 1990 and 2020 to highlight that road transport was primarily responsible for high emission figures, contributing to more than 90%of the total CO2 emissions.[78]

Figure 2.2 - Per capita transport GHG emissions in G20 countries (% change)

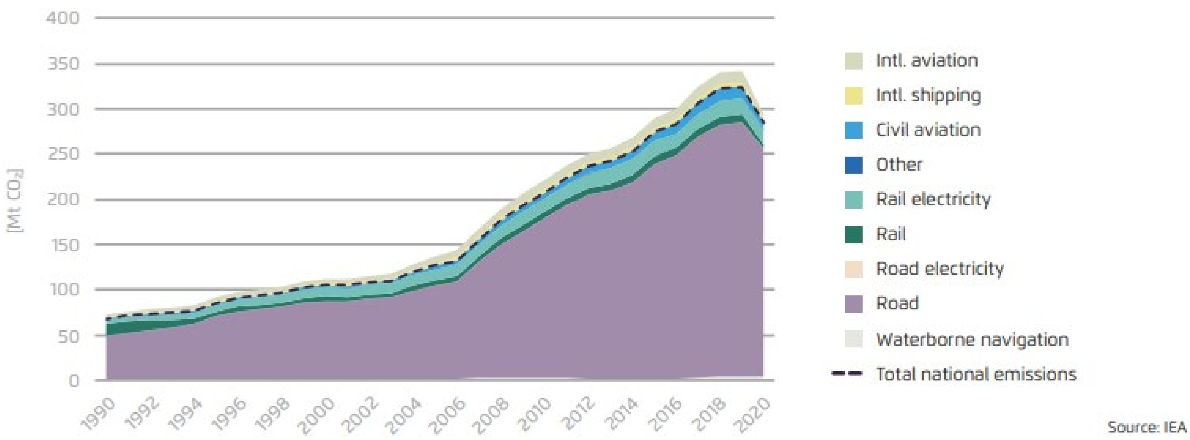


Source: Enerdata 2019; World Bank 2019

Given India's rapid urbanization and its vast road network, the rapid adoption of public transport particularly in the urban areas can have ripple effects on emissions reduction, traffic decongestion and air quality improvement.[79] The Economic Survey of 2024-25 argues for public transportation as an efficient alternative for viable energy transition.[80] The Indian government has been actively investing in urban public transport through the expansion of city bus services and the Mass Rapid Transport System (MRTS) or the metro. Among states and UTs, Delhi is a role model in the successful implementation of the metro system. Going forward the expansion of the metro network, the rationalisation of prices and improving last-mile connectivity can enable other cities to provide affordable public transport in urban areas.

Rail transport presents an energy-efficient mode for both passenger and freight traffic and is a viable alternative for decongesting the road sector. It accounts for only a 3% share in passenger transport energy use for a 25% share in passenger transport activity.[81] Similarly, in 2020, the inland freight transport energy use amounted to 9% compared to an activity share of close to 30%.[82] Metro services are operational in many Indian cities but integration with other modes of local transport hinders a seamless experience for the daily commuter.

Figure 2.3 - Transport sector emissions by subsectors



Source: [Towards Decarbonising Transport - Taking Stock of G20 Sectoral Ambition (niti.gov.in)]

2.1 Policies promoting electric mobility

India is a net importer of oil but has abundant coal and renewable sources. To improve energy security and reduce oil dependence in the wake of geopolitical crisis, the government is incentivizing research and adoption of electric vehicles. Internal Combustion Engine (ICE) vehicles not only increase fuel imports but also contribute significantly to GHG emissions and atmospheric pollution. Notably, India is home to more than 40 of the world's 50 top polluted cities in 2023, making the reduction of tail-pipe emissions a critical health priority for the government.[83]

Decarbonization can ensure simultaneous progress towards environment, social and economic goals. The Avoid-Shift-Improve (ASI) framework focusses on avoidable motor travel, encourages shift to less carbon intensive modes of transport and the improvement of energy efficiency of vehicles. [84] Innovations in low carbon transport technologies can spur local economies and create employment while mitigating the effects of climate change. Encouraging the use of non-motorized transport (NMT) can contribute to healthier and livable cities. The ASI approach ensures the attainment of climate goals, tackling of air pollution and sustainable growth.

T**he Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME – I and II) schemes have been instrumental in driving EV adoption in India, with sales crossing the 1 million unit mark in FY 2022-23**.[85] FAME II has been superseded by the PM e-drive scheme that was announced in September 2024 with an outlay of INR 10,900 crore targeted, inter alia, towards the purchase of 2 and 3-wheelers, ambulances, e-trucks and e-buses, as well as investments into charging stations.[86] By providing direct subsidies to consumers, the government is committed towards lowering the price barrier to make EVs a more affordable choice for Indian buyers.[87]

The government is promoting 'Make in India' for the automotive sector through the Production Linked Incentive (PLI) scheme. With a substantial budget of INR 25,938 crores, the scheme provides financial incentives for domestic manufacturing of Advanced Automotive Technology (AAT) products and attracts investments into the automotive manufacturing supply chain.[88] The Ministry of Heavy Industry is the nodal ministry for implementing the scheme that is open to both existing automobile manufacturers as well as new players. This initiative has garnered positive feedback, and its success is expected to contribute towards strengthening the domestic manufacturing of environment friendly vehicles in India.[89]

Table 2.1 – Comparison of government EV promotion schemes

Parameters	FAME I	FAME II	PM e-Drive
Period	2015-19	2019-24	Sep 2024 for 2 years
Budget	INR 795 crores	INR 10,000 crores (later increased to 11,500 crores)	INR 10,900 crores
Subsidy provided	Electrification of 465 e-buses	Subsidized the purchase of 24.79 lakh e-2Ws, 3.16 lakh e-3Ws, and 14,028 e-buses.	To subsidize e-2W, e-3W, e-buses, trucks and ambulances. To support 88,500 EV charging sites. Cars and SUVs are not covered.

In addition to the PM e-Drive and PLI schemes, the central government offers further support measures for purchase of EVs. The Goods and Services Tax (GST) on electric vehicles has been lowered to 5% and the Ministry of Road Transport and Highways (MoRTH) has announced an exemption from permit requirements for battery-operated vehicles.[90] The latest Budget presented in July 2024 furthermore proposed customs duty exemptions on 25 critical minerals such as lithium used for the manufacture of batteries for EVs.

Subnational governments also offer many tax benefits and concessions for the purchase of EVs as well as the manufacture of EVs, auto components, and ancillary industries. A total of 28 states and Union Territories (UTs) have already notified EV policies.[91] These include tax exemptions such as on payment of road tax, registration charges, and State Goods and Service Tax (SGST) reimbursements.[92] Scrapping and retrofit incentives for replacing older polluting ICE vehicles with EVs are offered in Delhi and Telangana. Purchase subsidies may be offered in the form of price reductions and rebates as in Delhi and Maharashtra and concessional access to financing as in Bihar and Uttar Pradesh.[93]

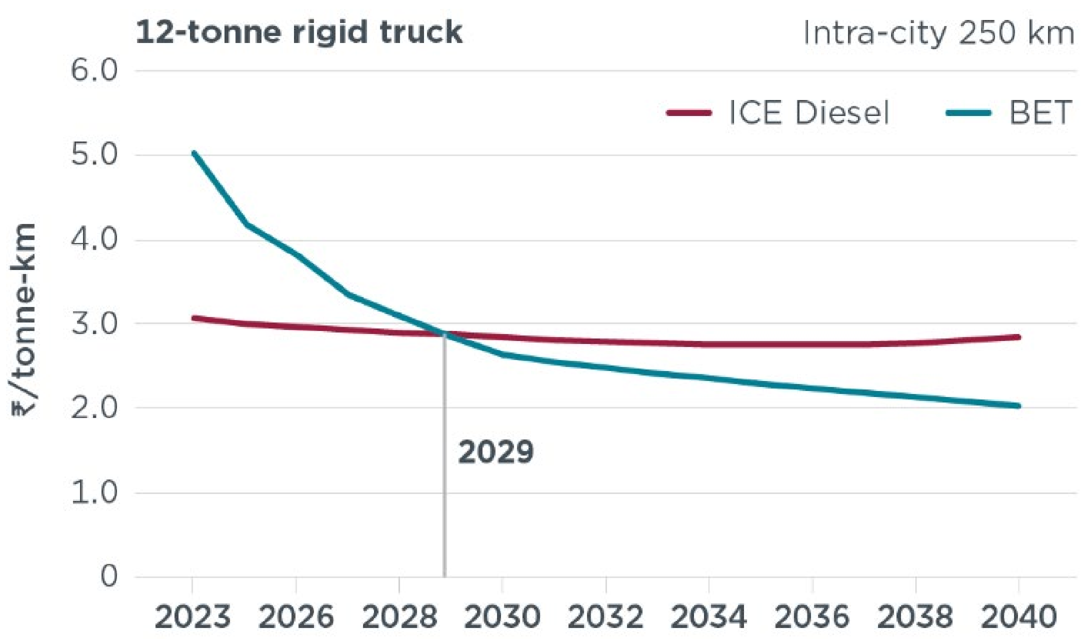
India's EV market accounted for 5% of total vehicle sales between October 2022 and September 2023 and is expected to achieve 40% penetration by 2030.[94] The current adoption rate is particularly strong in the 2-wheeler and 3-wheeler category. Among 4-wheelers, EV sales has gained traction and reached 90,432 in FY 2024 (up from 1204 in FY 2018 and nearly double of 47,499 in FY 2023).[95] Though the initial purchase costs of electric cars are higher, their lower fuel and maintenance costs makes them a preferred option over longer ownership duration. Table 2.2 below compares the total cost of running the TATA NEXON, a popular EV launched in 2020 with its ICE versions (both petrol and diesel).

Table 2.2 – Comparison of price and maintenance cost of EV vis-à-vis ICE cars [96]

Parameter	Electric	Petrol	Diesel
Ex-showroom price	Tata Nexon EV INR 1,449,000	Tata Nexon petrol INR 1,249,990	Tata Nexon diesel INR 1,389,990
5 YR Fuel or Battery Cost	INR 44,321	INR 330,805	INR 223,305
5 YR Maintenance cost[97]	INR 15,000	INR 24,093	INR 31,358
Total Cost of Running (over 5 yrs) 12000 KM	INR 1,758,321	INR 1,834,888	INR 1,814,653

For freight transport by road, India relies mostly on medium and heavy-duty trucks that comprise only 3% of total vehicles but contribute 44% of the road transport pollution.[98] However**,** the decarbonization of heavy-duty vehicles (HDVs), such as long-range trucks, poses greater challenges.[99] Despite the proven efficiency of battery electric trucks (BETs) and lower TCO, the higher initial purchase price has hindered their uptake and deployment.[100] About 80% of truck owners in India operate a small fleet of less than 10 trucks and cost is an important factor which deters them from moving to EVs.[101] An ICCT study compares the TCO of BETs and diesel trucks and projects that upfront costs for BETs will fall to 1.2-1.4 times the cost of ICE diesel trucks by model year (MY) 2040 in the 12 tonne segment.[102]

Figure 2.4 - TCO Projections and cost parity of a 12-tonne BET and an ICE diesel truck



Source : Total cost of ownership parity between battery-electric trucks and diesel trucks in India - International Council on Clean Transportation

The availability of charging infrastructure is a critical driver of growth for the EV sector. Only 10% of the total incentive outlay under FAME-II was reserved for charging infrastructure.[103] As of February 2024, there were 12,146 public charging stations operational in the country as compared to 87,000 fuel stations.[104] The PM e-drive scheme is committed towards supporting the installation of 88,500 charging stations. An adequate number of accessible public charging stations will benefit two and three-wheeler owners to boost EV sales among this consumer segment.

The Ministry of Power has recently updated the guidelines for installing EV charging infrastructure through a notification released in September 2024. The proposals are directed towards improving the affordability and accessibility of the charging stations by providing subsidized land for charging stations and encouraging their installation at public spaces such as shopping malls, office complexes, and residential areas.[105] These measures are expected to benefit the EV owners and also allay common fears about 'range anxiety'.[106] The new revenue-sharing model assures the land owner INR 1 per kWh of energy purchased and the concessional land provided by the government ensures lower setup cost for the charging station owners.[107] The speedy implementation of these guidelines will expedite the adoption of these non-polluting means of transportation.

A gradual shift to EVs can contribute to decarbonization of passenger traffic but freight transport through polluting trucks presents a real challenge to achieving net-zero targets. The government is prioritizing low-carbon freight logistics through railways to address this issue. India's NDC commits the country to achieving a 45% mode share for rail freight until 2030.[108] The Dedicated Freight Corridor Corporation of India Limited (DFCCIL) is executing several projects including the Eastern and Western Dedicated Freight Corridors (DFCs) which span a combined length of 1766 miles.[109] The speedy completion of these corridors along with other proposed projects will ensure speed and efficiency in the movement of freight as well as achieving the NDC target of 457 million tonne reduction in CO2 emissions through building DFCs.[110]

Deep decarbonization' of the transport sector would require a holistic approach to reduction of emissions. Along with tank-to-wheel emissions associated with fossil-fuel based electricity generation and tail-pipe emissions from the operation of combustion engine vehicles, the creation of transport infrastructure such as roads also contributes to GHG emissions. A co-ordinated approach involving multiple stakeholders in policy planning and implementation is crucial to meet climate commitments and achieve NDC targets. In that context, environmental concerns around the end-of-life disposal of EVs and their batteries must also be addressed.[111] The use of metals like cobalt and nickel in Lithium-ion batteries poses danger to human health and other life forms and needs to be disposed of with utmost care and caution.[112] These safeguards are equally applicable during the production of these batteries.

2.2 Policies to shift the modal mix

The 'PM Gati Shakti' programme aims for multi-modal connectivity to various economic zones by integrating railways, roads, waterways, airports, and mass transport. Under the 'Gati Shakti' scheme Indian Railways has introduced energy-efficient 'Vande Bharat' trains and created warehouses for enhanced logistics management. Three economic corridors namely for (i) energy, mineral, and cement (ii) port connectivity and (iii) high traffic density, together comprising 434 projects have been identified under the PM Gati Shakti program.[113] The decongestion of rail routes is meant to increase efficiency in logistics management and encourage a modal shift in cargo movement away from high-polluting road traffic.

India has an extensive river network, but the modal share of water transport is below 2%.[114] The NDC commits the country to increase the share of freight transport by inland waterways and coastal shipping to 5% by 2030.[115] A concerted push from the government with funding provided by the World Bank has resulted in the increase of the freight share using waterways from 55.47 million tonnes in 2016-17 to 133 million tonnes in 2023-24.[116] For coastal shipping, licensing relaxations can be introduced and port facilities need to be upgraded, for tapping the full potential of this eco-friendly mode of transportation.[117]

Rapid expansion of the metro rail network and investment in faster and cleaner trains can give a boost to efficient mass-transit systems in urban areas. Since the inaugural Kolkata metro in 1984, the metro construction now extends to 20 plus Indian cities with the proposed addition of routes covering more than 1000 km.[118] The expeditious completion of these projects will facilitate sustainable and eco-friendly connectivity in urban areas. A detailed study of the working of the metro rail in three Indian cities, namely Delhi, Nagpur and Bengaluru has highlighted the popularity of the metro particularly among young and middle class commuters.[119] The high-income strata prefer to use their personal vehicles owing to last mile challenges in metro access, while the poor are 'priced out' from using the metro.[120] The findings are based on a post-pandemic survey of 7200 metro users (Nagpur: March 2022, Delhi: October 2022, Bengaluru: March 2023).

The affordability of tickets is an issue for low-income groups. The lower trip cost for Delhi commuters may be one of the reasons along with an extensive metro network for the higher passenger traffic compared to the other two cities covered in the study. Ticket prices need to be competitive for the metro to be financially viable and alternate financing options can be explored based on international best practices. Advertising revenues, leasing out of metro land, granting 'pouring' and other rights to specific brands can generate funds that can be used to subsidize fares for metro riders with incomes below specific thresholds.[121]

The last-mile connectivity to the metro is serviced through various modes such as motorized auto-rickshaws, non-motorised cycle rickshaws or commuters travelling by foot or bicycles. These feeder services are fragmented and non-standardized contributing to congestion at stations and bus terminals thereby dissuading many from availing these facilities. Park-and-ride facilities are underdeveloped and contribute to traffic jams at entry and exit points of metro stations.

Non-motorised transport (NMT) in India comprising, walking, cycling and use of cycle rickshaws has a higher adoption rate than in other developed countries. An early study (Pai, 2007) pointed out that in Indian cities with a population of more than 1 million, non-motorized modes of commuting accounted for more than 25% of passenger trips whereas the comparable figure for London (with a population then of 6.6 million) was about 14%. These figures are now declining in view of concerns around road safety standards and lack of adequate infrastructure to support NMT.[122]

Options such as Uber's two and three-wheeler services, Uber Moto and Uber Auto respectively are gaining popularity for last mile connectivity. According to the 2024 Uber India Economic Report, these services are projected to generate economic activity of INR 36,000 crores (approximately USD 4.2 billion) in 2024.[123] This can support both enhanced mobility and economic growth.

To decongest the transport sector and achieve net-zero emissions, a comprehensive approach should combine a continuation of policy interventions through subsidies, tax incentives, technology innovations and private sector participation. The infrastructure for public transport should be strengthened through capacity addition and addressing of first and last mile connectivity challenges. Lowering the price barrier can make city buses and metro trains affordable for the average commuter. This can create an ecosystem for the adoption and use of energy-efficient modes of transport.

Table 2.4 – Summary of metro statistics

		Delhi	Bengaluru	Nagpur
N (sample size)		3,000	1,800	2,400
Trip cost	Mean	6	13	7
	Median	0	0	0
Trip distance (km)	Mean	2	2	3
	Median	1	1	1
Age (%)	<18	2	1	3
	19-25	43	50	68
	26-35	37	39	17
	36-50	15	9	9
	51-60	2	0	2
	60+	0	1	0
Income	< 5,000	0	3	2
	5,001-10,000	2	8	7
	10,001-20,000	32	22	35
	20,001-40,000	43	37	36
	40,001-60,000	19	20	13
	60,001-80,000	4	6	5
	80,001100,000	0	2	1
	Above 100,000	0	2	1
Access to vehicle %	Yes	43	61	43
	No	57	39	57

2.3 Centre-state coordination to tackle air pollution from vehicular traffic

The Centre's policy initiatives must be complemented by local and state efforts. India's rapidly expanding urban population is expected to reach 814 million by 2030.[124] Providing affordable mobility options to their citizens will be vital for India's cities. Enhancing air quality will also be critical. The National Clean Air Programme (NCAP) provisions city-specific targets for 102 non-attainment cities (NAC) that have fallen short of the national Ambient Air Quality Standards (NAAQS) for 5 consecutive years. A preliminary review by the Council on Energy, Environment and Water (CEEW) revealed that transport and road dust management together accounted for 50% of these cities' clean air action plans.[125]

A city-centric approach can be siloed and ineffective especially while dealing with high levels of air pollution. An airshed-management focus involving inter-state authorities in target-setting and monitoring can create better impact in achieving ambient air quality in main city centers and suburban areas.[126] The World Bank is working with state governments to introduce state-wide Air Quality Action Plans and a regional airshed action plan for the Indo-Gangetic plains involving seven states and Union Territories (UTs) where the concentration of population and pollution is densest in this region.[127]

The deterioration of air quality is highest in the capital Delhi and National Capital Region (NCR) prompting the judiciary to mandate urgent action.[128] A ban on diesel vehicles more than 10 years old and other vehicles more than 15 years old within Delhi and NCR has been introduced through orders passed by the National Green Tribunal, NGT (2014/2015). This order was subsequently reinforced by the apex court, The Supreme Court of India (2018) which also mandated the scrapping of these older vehicles.[129] Similar interventions are needed across other cities and regions experiencing high pollution levels.

3. ENERGY CHALLENGES FACED BY HOUSEHOLDS

The household sector is pivotal in India's transition to sustainable energy practices. As consumers of electricity and cooking fuels like biomass and Liquefied Petroleum Gas (LPG), Indian households significantly drive energy demand, which continues to rise with urbanization and improved living standards. In 2022-23, the domestic sector accounted for 26% of total electricity consumption.[130] This demand, largely met through reliance on fossil fuels, contributes to air pollution and carbon emissions.[131] However, recent government initiatives, technological advancements, and evolving consumer behaviours present opportunities for both urban and rural households to adopt cleaner and more affordable energy sources, fostering a more inclusive energy future for India.

Differentiating between urban and rural India in household energy consumption is essential due to their distinct energy needs, consumption patterns, environmental impacts, and policy implications. The 2011 Census of India revealed significant contrasts: back then, 87% of rural households were relying on biomass for cooking, compared to 26% in urban areas, while only 12% of rural households were using LPG or Piped Natural Gas (PNG), versus 65% in urban areas.[132] For lighting, 55% of rural households were using electricity and 43% were utilizing kerosene, compared to 93% and 7%, respectively, in urban households.[133] Given that rural India accounts for nearly two-thirds of the population, access to electricity and modern energy solutions remains limited, with a continued reliance on traditional fuels. In contrast, urban households benefit from better infrastructure, ensuring greater access to modern energy sources like electricity and LPG. These disparities underscore the need for targeted government interventions to bridge the urban-rural energy divide.

While these numbers have changed over the last decade, the key message remains the same: the distinction between urban and rural India is critical. More recent surveys such as the National Sample Survey Office (NSSO) 76th Round (2018), Periodic Labour Force Survey (PLFS), Indian Human Development Survey (IHDS), and Access to Clean Cooking Energy and Electricity – Survey of States (ACCESS) by CEEW and project specific government reports— provide updated statistics, and valuable insights into household energy trends. However, while these sources capture evolving dynamics, they may not match the extensive demographic reach and granularity of the 2011 Census, which remains an essential reference point.

3.1 Encouraging cleaner cooking stoves

Cooking remains the highest energy-consuming activity in both rural and urban households.[134] Cooking consumes nearly four times more energy than non-cooking activities like lighting, water heating, and space heating.[135] While biomass fuels have traditionally been the primary energy source for cooking, many households now practice fuel stacking—using multiple fuels based on cost, availability, and convenience.[136] Biomass remains a significant component of this mix, particularly in rural areas and urban slums.[137] This widespread use of biomass fuels, which when burned inefficiently in traditional stoves, releases harmful pollutants linked to severe health risks.[138] A study conducted in rural India compared emissions from traditional solid fuel stoves, improved biomass stoves, and LPG stoves, finding that LPG stoves emitted over 90% less particulate matter ($PM_{2.5}$) and carbon monoxide (CO) than biomass stoves.[139] A study in rural Maharashtra, found that women using biomass fuels for cooking had higher rates of respiratory issues, including chronic bronchitis, compared to those using cleaner fuels. Similarly, a recent study in Haryana highlighted that residential biomass cooking significantly impacts women's health, with prolonged exposure increasing the risk of severe health conditions.[140] These studies consistently demonstrate that LPG stoves emit significantly lower levels of harmful pollutants compared to traditional biomass stoves, highlighting the health benefits of transitioning to cleaner cooking fuels.

To address the issues related to biomass use, the MNRE introduced the National Programme on Improved Cookstoves (NPIC) in 1984.[141] This programme aimed to promote efficient stove models in rural and semi-urban areas to reduce indoor air pollution and related health risks.[142] Between 1983 and 2002, over 35 million cookstoves were distributed across India under the NPIC, and a network of 21 Technical Backup Support Units (TBSUs) was established in various states to conduct region-specific research and develop improved cookstoves.[143] The programme was discontinued in 2002 due to various challenges, including unrealistic approaches without considering geographical conditions, cooking preferences, economic viability, and other inputs from end-users.[144]

Similarly, the National Biomass Cookstoves Initiative (NBCI), launched in 2009, aimed at developing efficient wood-burning stoves to offer rural and semi-urban households a cleaner alternative to biomass cooking without switching to LPG.[145] The initiative was phased out in 2017 due to issues such as limited stove functionality, reliance on electricity in areas with poor access, reduced quality despite subsidies, and competition from cheaper local alternatives. These challenges, combined with continued indoor air pollution and inadequate maintenance infrastructure, undermined its effectiveness. Building on NBCI's lessons, the Unnat Chulha Abhiyan (UCA) was introduced in 2014 to distribute improved cookstoves to rural households.[146] The programme had a budget of USD 39 million and a goal of 2.75 million stoves to be distributed by 2017 but reached only a fraction of its target. The initiative was further sidelined by the introduction of new LPG schemes, which diverted attention and resources.

The use of kerosene has traditionally been promoted through government subsidies and distribution schemes, particularly for low-income households that rely on kerosene for cooking and lighting. However, the focus has recently shifted away from kerosene towards promoting cleaner alternatives like LPG and electricity. Schemes like the Kerosene-Free Delhi Scheme and Direct Benefit Transfer for Kerosene (DBTK) aimed to reduce kerosene usage and prevent misuse.[147] The Indian government also gradually reduced the allocation of subsidized kerosene through the Public Distribution System (PDS) in several states, reflecting a policy shift towards promoting cleaner fuels.[148] The reduction in kerosene quotas was intended to encourage the adoption of LPG and electricity.

India has explored solar energy for cooking since the 1980s, with initiatives like box-type solar cookers promoted by the MNRE to reduce reliance on traditional fuels.[149] Despite challenges such as high costs, cultural resistance, weather dependency, and longer cooking times, solar cooking programs have been integrated into broader initiatives like the UCA. Solar water heaters also emerged as a sustainable alternative for household needs, including cooking.[150] In 2023, the Surya Nutan programme, launched by Indian Oil Corporation, introduced a portable, rechargeable solar stove that addresses some earlier limitations, such as reliance on direct sunlight.[151] While solar cooking has found success in community kitchens, barriers like upfront costs have limited household adoption, with LPG remaining the preferred choice. Increased awareness, technological advances, and government incentives are seen as critical for wider uptake.

The Direct Benefit Transfer of LPG Subsidy (DBTL), introduced in 2013, improved efficiency by depositing subsidies directly into beneficiaries' bank accounts.[152] The "Give it Up" campaign launched in 2015 encouraged 10.5 million affluent households to relinquish subsidies, saving over INR 21.6 billion (USD 247 million) annually.[153] Building on these gains, the Pradhan Mantri Ujjwala Yojana (PMUY), launched in 2016, provided free LPG connections to families below the poverty line, empowering women and expanding access to clean cooking fuel.[154] By March 2023, active domestic LPG consumers rose from close to 15 crore in 2014 to more than 31 crore, with LPG coverage increasing from 62% in 2016 to 104% in 2022.[155] The 2024-25 Union Budget allocated INR 9,000 crore (USD 1 billion) to PMUY for further expansion and INR 1,500 crore (USD 240 million) to subsidize fuel costs under DBTL.[156] In addition to promoting LPG, the Indian government is actively supporting the expansion of PNG in urban areas.[157] PNG presents a more economical option than LPG due to its domestic production. According to the MoPNG, the coverage of PNG has grown significantly, expanding from 66 districts in 2013-2014 to 630 districts in 2022-2023, along with a four-fold increase in household PNG connections during the same period.[158]

India's dependence on imported LPG exposes households to rising costs, making affordable alternatives crucial. India's heavy reliance on imported LPG—which accounts for nearly 50% of domestic consumption—leaves the country vulnerable to global price volatility, directly impacting household energy affordability.[159] To mitigate this dependence, the government has been promoting PNG as a cheaper and more reliable domestic alternative, particularly in urban areas. However, PNG access remains limited, with infrastructure expansion progressing slowly, restricting its reach primarily to metropolitan regions. As LPG prices continue to rise, urban consumers, especially those without PNG access, face increasing financial strain, highlighting the need for diversified and sustainable cooking fuel options to ensure energy security and affordability.

Expanding access to clean cooking fuels requires a multi-pronged approach. Enhancing affordability through targeted subsidies can make LPG refills more accessible for low-income households.[160] Strengthening distribution networks with mobile units, smart metering, and improved logistics can ensure timely LPG access and curb black-market sales.[161] Raising awareness via ASHA workers and community campaigns can promote LPG adoption by highlighting health risks of biomass use.[162] Given rising biomass reliance, advancing improved cookstoves with better efficiency and pollution control is key to reducing health risks while maintaining a renewable energy option.[163]

In summary, the Indian government is dedicated to enhancing access to clean and affordable cooking fuels, with a strong focus on LPG subsidies. These efforts are part of a broader strategy to move away from traditional biomass and improve clean and sustainable cooking options. The MNRE and MoPNG are driving this transition by fostering research, supporting new business ventures, and exploring innovative financing mechanisms.

3.2 Enhancing electrification: government strategies for inclusive access

Ensuring electricity access for households across the country has been a key focus for India's government. To that end, it launched the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) scheme in 2005, followed by the Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) in 2015, and the Saubhagya Yojana scheme in 2017.[164] Saubhagya aimed to provide free electricity connections to both rural and disadvantaged urban households, achieving near 100% household electrification by March 2022.[165] Unlike earlier schemes focused on infrastructure, Saubhagya emphasized direct household connections. Urban infrastructure has been enhanced through the Integrated Power Development Scheme (IPDS),[166] launched in 2014, while the Unnat Jyoti by Affordable LEDs for All (UJALA) programme[167], started in 2015, distributed over 360 million LED bulbs, saving 47 billion kWh annually and reducing CO2 emissions by 38 million tons. The Gram UjALA program, launched in 2021, continues to promote energy-efficient LEDs in rural areas, further advancing energy sustainability.[168]

Although the Saubhagya scheme significantly expanded electricity connections across India, structural challenges continue to hinder affordable and consistent household electricity access. While the scheme provided free connections, it did not subsidize ongoing electricity bills, leaving many poor households vulnerable to disconnection.[169] Aware of this financial burden, some households opted out, making the reported electrification progress less comprehensive than it appears. Additionally, implementation efforts often overlooked households with illegal connections rather than regularizing their access, leading to an undercount of actual rural electrification and perpetuating unsafe, unauthorized electricity use.[170] To ensure affordable and consistent electricity access, the government can introduce targeted subsidies for low-income households and implement prepaid smart meters to allow flexible payments. Regularizing illegal connections through affordable plans can improve grid integration, while off-grid solar solutions can enhance access in remote areas

3.3 Technological innovations are driving cleaner energy adoption

In India's household sector, technological innovations are profoundly shaping the transition to cleaner energy. Solar technology has seen significant advancements, including the development of high-efficiency photovoltaic cells and next-generation solar panel designs. These innovations have made rooftop solar systems increasingly accessible and efficient for both urban and rural homes, allowing households to generate their own clean electricity and reduce reliance on grid power and fossil fuels. Additionally, advancements in energy-efficient technologies, such as smart thermostats and intelligent home energy management systems, are optimizing household energy use. These technologies not only enhance the performance of energy-efficient appliances, like LED lighting but also provide real-time monitoring and control of energy consumption, leading to further reductions in energy usage and operational costs.[171]

In the realm of energy storage, breakthroughs in battery technology, including advancements in lithium-ion and emerging solid-state batteries, are making solar energy storage more viable. These innovations enhance the reliability of solar home systems by providing consistent power supply even during periods of low sunlight.[172] The deployment of smart meters and advanced grid management technologies is revolutionizing energy consumption patterns. Additionally, the integration of these technologies with digital platforms supports better energy management and enhances grid reliability.

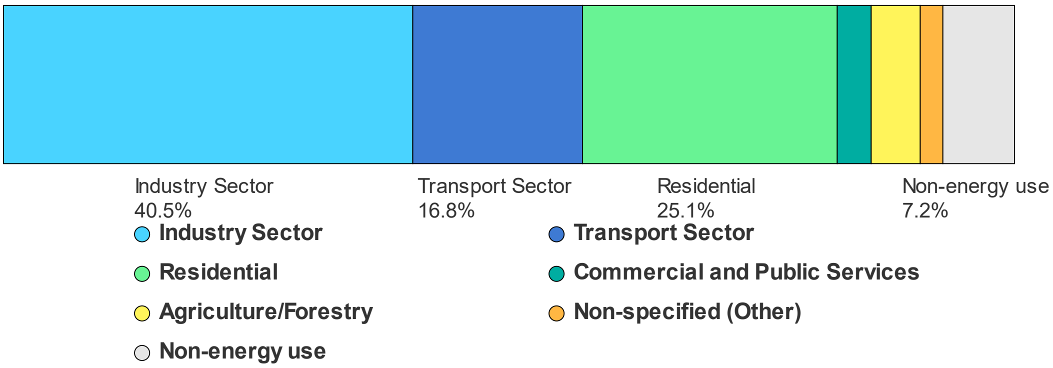
India's household energy transition has witnessed transformative progress, yet challenges remain in ensuring universal access to clean and affordable energy. The widespread adoption of LPG connections has significantly reduced reliance on traditional biomass, improving indoor air quality and health outcomes. Simultaneously, the rapid expansion of electricity connections, coupled with the deployment of efficient LED lighting, has brought affordable and sustainable energy to even the most remote areas, enhancing livelihoods and economic opportunities. However, high costs and limited accessibility continue to hinder clean energy adoption, particularly in rural regions. The way forward lies in accelerating the integration of solar and other renewable energy sources, fostering technological innovation, and strengthening support systems to ensure a more inclusive and sustainable energy transition.

4. INDIA'S MANUFACTURING SECTOR ENERGY USE

India's industrial sector, a key contributor to economic activity and employment, is also a major energy consumer, **accounting for approximately 41% of the country's total energy use** (Figure 4.1). Energy consumption by the industrial sector has steadily increased, driven by economic development. Domestic coal accounts for the bulk (37%) of the sector's energy use, followed by biofuels and waste (29%) and electricity (19%).[173] Other sources, such as imported natural gas and petroleum products, also play a role in meeting industrial energy demand. This diverse mix highlights the challenge faced by the sector to transition toward affordable, secure and clean energy sources.

Figure 4.1 – Industry is the largest energy consumer in India

(Final energy consumption in India, 2022)

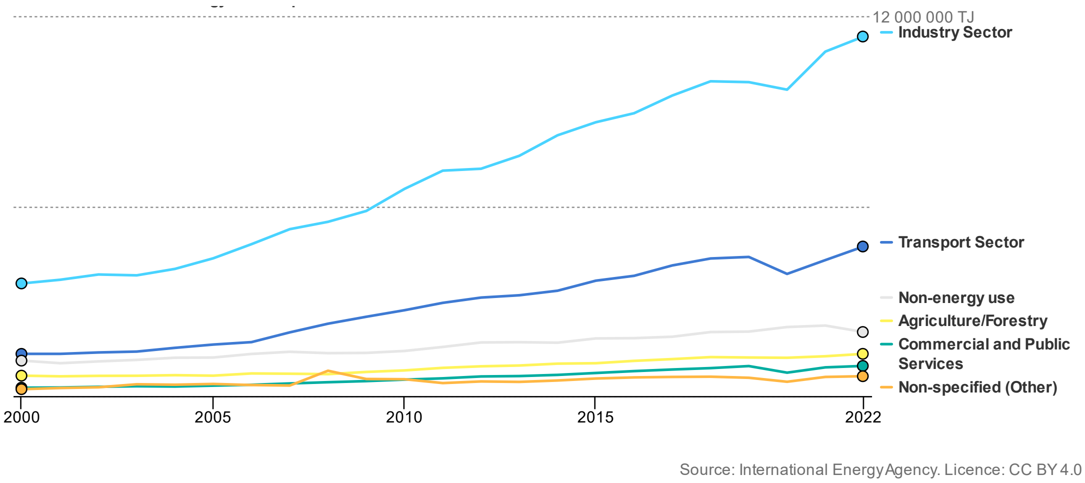


Source: International Energy Agency. Licence: CC BY 4.0

Among the manufacturing industries, steel, cement, and chemicals stand out in terms of their energy intensity and significant GHG emissions. These industries are often classified as "hard-to-abate" due to their reliance on energy-intensive processes, high-temperature heat requirements, and the chemical reactions involved in production, which generate substantial emissions. These sectors face the dual challenge of growing demand alongside increasing environmental pressures. Globally, these sectors account for 66% of industrial CO_2 emissions and 20% of total emissions, making their decarbonization essential for achieving the country's climate targets.[174] Within India's industrial sector, iron and steel are the most energy-intensive industries, consuming 15.2% of the total energy. This is followed by the chemicals and petrochemicals industry at 4.6% and the construction sector at 1.1%.[175] Challenges such as aging infrastructure, coal dependency, and slow adoption of low-carbon technologies highlight the need for investments in energy efficiency, process innovation, and technologies like carbon capture.

Figure 4.2 – Industrial energy consumption is rising fast

(Evolution of energy final consumption by sector)



Source: International Energy Agency

4.1 Steel sector

India's steel sector is a major contributor to energy consumption and emissions. Iron and steel production accounts for about one-fifth of the nation's industrial energy consumption, utilising 70 million tonnes of oil equivalent (Mtoe), of which 85% comes from coal.[176] As the second-largest producer of crude steel and consumer of finished steel globally, the steel sector is highly energy-intensive, relying on coal and electricity to power processes like heating, cooling, melting, and solidification. Energy-intensive technologies such as blast furnaces and basic oxygen furnaces dominate production, requiring significant thermal energy. Moreover, the steel sector in India is poised for substantial growth, with the National Steel Policy, 2017, aiming to increase annual production capacity from the current 120 million tonnes (MT) to 300 MT by 2030.[177] Notably, India's steel industry contributes 12% of the country's total GHG emissions, and emissions from this sector are projected to increase almost 2.5 times by 2030 underscoring its role in making India the fourth-largest emitter globally.[178]

Decarbonizing India's steel sector is critical not only for meeting its net-zero 2070 target but also for maintaining competitiveness in the face of global carbon regulations like the EU's Carbon Border Adjustment Mechanism (CBAM). Efforts to reduce emissions in the steel sector are essential to place India on a trajectory toward its net-zero 2070 goal while adapting to the evolving international regulatory landscape. The European Union's CBAM, set to impose a tariff on carbon emissions from steel imports beginning in 2026, will align these tariffs with the carbon price paid by EU producers in the carbon market.[179] Indian steel, with an average emissions intensity of 2.55 tonnes of CO_2 per tonne in 2022—much higher than the global average of 1.85 tonnes—faces significant challenges.[180] Without proactive decarbonization, Indian steel exports to the EU could decline by as much as 58% by 2030 under the CBAM scenario, compared to a no-CBAM baseline.[181] Addressing these challenges is essential for India's long-term economic and climate strategies.

To achieve deep decarbonization in the Indian steel sector, policies must drive the adoption of green hydrogen and Carbon Capture and Storage (CCS) technologies for primary production while enhancing energy efficiency and boosting scrap recycling in the secondary sector. The primary sector, which accounts for 60% of India's crude steel production, relies heavily on the Blast Furnace (BF) route using coke and the coal-based Direct Reduced Iron (DRI) route.[182] In contrast, the secondary sector, responsible for 40% of production, primarily recycles scrap steel through electric arc furnaces and induction furnaces.[183] However, India's limited scrap availability, driven by lower end-of-life scrap generation and reliance on imported scrap, hinders the sector's growth. A successful transition requires clean solutions like green hydrogen and CCS, affordable pathways through enhanced energy efficiency and recycling, and greater energy security by reducing dependence on imports - coal, gas or scrap, while integrating renewable energy into steel production.[184] This transition must also account for the socio-economic impact on communities in regions like Jharkhand, Odisha, and Chhattisgarh, where coal and steel production are central to local livelihoods.[185] Further this transformation hinges on strong government intervention, international collaboration, and innovation-driven strategies.[186]

While Carbon Capture, Utilization and Storage (CCUS) and green hydrogen offer promising pathways for decarbonizing the Indian steel sector, their effectiveness hinges on complementary measures and supportive policies. A scenario analysis by CEEW highlights that CCUS can play a significant role in reducing emissions when combined with energy efficiency improvements, renewable power integration, and fuel switching to alternatives like green hydrogen and biomass.[187] However, CCUS remains commercially unviable, and green hydrogen is cost-prohibitive without strong policy support.[188] The high capital investment required for CCUS infrastructure, operational costs of carbon capture and storage, and the energy-intensive nature of green hydrogen production, which depends on expensive renewable electricity, collectively drive up the cost of near net-zero steel production. To bridge this gap, India needs targeted policy interventions to reduce costs, develop infrastructure, and encourage industry adoption, thereby enabling successful decarbonization of the steel industry.[189]

To bridge the cost and infrastructure gap for near net-zero steel production, India has implemented targeted policies that enhance energy efficiency, support advanced technologies like green hydrogen, and promote sustainable practices such as scrap recycling, renewable energy integration, and circular economy initiatives. Key measures include the Perform, Achieve, and Trade (PAT) Scheme (2012), which led to energy savings of 5.5 MTOE and a CO_2 reduction of 20 million tonnes by 2020.[190] The adoption of Best Available Technologies (BAT) further reduced emissions intensity.[191] Collaborative initiatives, such as the 2016 partnership with Japan's New Energy and Industrial Technology Development Organization (NEDO) and the Steel Scrap Recycling Policy (2019), helped improve energy efficiency and reduce coal dependency.[192] More recent initiatives, like the Green Hydrogen Mission (2023), the Production Linked Incentive (PLI) scheme for specialty steel, and the Motor Vehicles Scrapping Rule (2021) to increase scrap availability, are pivotal in supporting low-carbon steel production.[193] Furthermore, at COP27, India's Long-Term Low Emissions Development Strategies (LT-LEDS) emphasized hydrogen adoption and renewable energy use in secondary steel production as essential pathways for reducing emissions, despite the challenge of high capital expenditure.

The National Green Hydrogen Mission (NGHM) stands as a pivotal initiative aimed at decarbonizing India's steel industry. Out of all the initiatives undertaken by the government, this is the most important, as it directly addresses the need to transition one of the most carbon-intensive sectors to cleaner energy alternatives. Under this mission, the Ministry of Steel has been allocated 30% of the pilot project budget, amounting to INR 14.66 billion (approximately USD 170 million), to promote the adoption of green hydrogen in steel production.[194] This allocation underscores the government's commitment to fostering sustainable practices within the steel sector. As part of this mission, the Solar Energy Corporation of India (SECI) launched two key tenders in July 2023 under the Strategic Interventions for the Green Hydrogen Transition (SIGHT) programme to reduce the cost of green hydrogen and make it viable.[195] The first tender targets 1.5 GW of capacity by scaling up domestic electrolyser manufacturing and advancing research in indigenous stack technology. The second tender focuses on producing 450,000 tonnes of green hydrogen annually through technology-agnostic and biomass pathways.[196]

India's Ministry of Steel (MoS) is promoting green steel through a star-rating system and the Green Public Procurement Programme (GPPP), while leveraging the CCTS under the Ministry of Environment, Forest and Climate Change (MoEFCC) to reduce emissions and comply with the EU's Carbon Border Adjustment Mechanism (CBAM). Under the Green Steel Mission, India's Ministry of Steel (MoS) is advancing the decarbonisation of the steel sector through a star-rating system that categorises green steel based on CO2 emissions per tonne of crude steel (tCO2/tcs): 3-star (2.2 to 2.0), 4-star (2.0 to 1.6), and 5-star (1.6 to 0.0). The GPPP, launching in 2026-27, mandates green steel usage in public projects, while PLIs and sustainable financing aim to offset high production costs. The MoS also plans to introduce 'green steel inside' labels and integrate green steel taxonomy into building codes. Complementing these efforts, the CCTS, launched by the MoEFCC in 2023, will allow carbon credit trading to further reduce emissions. These initiatives will reduce the carbon footprint of India's steel industry while enhancing competitiveness in global markets and supporting compliance with the EU's CBAM.

Private companies are taking significant steps toward decarbonization. Tata Steel commissioned a 5 tonnes per day (TPD) carbon capture plant in Jamshedpur in 2021,[197] while Jindal Stainless Limited (JSL) plans to establish a green hydrogen plant. JSW Steel has committed to investing in CCUS technologies and announced plans to use green hydrogen in steelmaking[198]. ArcelorMittal, in partnership with Nippon Steel India, has also pledged to explore low-carbon technologies, including hydrogen-based production processes.[199] However, scaling these innovations remains challenging due to high costs and infrastructure requirements.

Collaboration between industry, government, and academia has emerged as a critical driver of innovation in green technologies. For instance, the National Mission on Transformative Mobility and Battery Storage fosters partnerships to develop sustainable technologies.[200] JSW Steel has joined forces with research institutes to pilot hydrogen-based steelmaking, and Tata Steel collaborates with international organizations under the Mission Possible Partnership to accelerate net-zero steel initiatives.[201] To accelerate decarbonization, policies should focus on subsidies for green hydrogen, renewable energy expansion, and carbon pricing. Aligning these policies with private sector innovation will drive large-scale adoption of low-carbon technologies, ensuring competitiveness while moving toward net-zero emissions.

4.2 Cement sector

India's cement industry, the second largest globally after China, plays a critical role in infrastructure development but is also a significant contributor to CO2 emissions. With a production of 298 million tonnes in FY 2022 and 8% of the global installed capacity, the industry is projected to add 80 million tonnes of capacity by 2025.[202] The industry operates 210 large cement plants, 98% of which are privately owned, with 77 of these located in Andhra Pradesh, Rajasthan, and Tamil Nadu.[203] The sector's market size was 3,644.5 million tonnes in 2022 and is projected to reach 4,832.6 million tonnes by 2028, growing at a Compound Annual Growth Rate (CAGR) of 4.94%.[204] The cement industry accounts for 5.63% of the country's GHG emissions, driven by the energy-intensive process of removing carbon dioxide from limestone, a process known as calcination.[205] Nearly 56% of the total 0.66 tCO2/t cement produced is due to calcination of limestone in the kilns. Of the remaining emissions, 32% is due to the combustion of fuels for process-heating applications, while only 12% is due to electricity used for manufacturing.[206] [207] Decarbonizing India's existing cement production will require significant investment, amounting to USD 334 billion in capital expenses.[208] Additionally, it will incur an extra USD 3 billion annually in operating costs.[209] To mitigate its environmental impact, the industry is exploring solutions like alternative fuels, carbon capture technologies, and the use of blended cements, which are crucial for aligning with India's climate goals.[210] [211] [212] [213]

Decarbonizing India's cement industry is essential to curb emissions, align with global targets, and sustain economic competitiveness. Addressing emissions from cement production is crucial due to the industry's vast scale in India and its potential to surpass electricity sector emissions. Decarbonization is not only vital for combating climate change but also for maintaining global competitiveness and avoiding trade barriers like carbon border adjustments. Aligning with global initiatives, such as the Global Cement and Concrete Association's (GCCA) targets for a 20% reduction in CO2 per metric ton of cement and a 25% reduction per cubic meter of concrete by 2030, positions India as a leader in sustainable development.[214] The GCCA's goal of full decarbonization by 2050 further underscores the urgency of transitioning to cleaner energy sources and efficient processes, advancing both environmental and economic objectives.

The type of cement produced directly influences emissions intensity and is essential for decarbonization. Ordinary Portland Cement (OPC) is the most common, but blended cements like Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) are more sustainable.[215] [216] These types integrate industrial by-products such as fly ash and slag, which lower CO2 emissions. The shift to using blended cement can substantially reduce the environmental impact of cement production, making them a critical element in achieving the sector's decarbonization goals. Compound Cement (CC) can sequester CO_2 in the curing process. The table below highlights the typical composition of OPC, PPC, PSC, and CC cements, showcasing the varying proportions of raw materials used to achieve these environmental benefits.[217]

Table 4.1 – Composition of typical OPC, PSC, and CC cements (in %)

Constituents	Types of Cement			
	OPC	PPC	PSC	CC
Limestone/Clinker	95	65	40	45
Gypsum	5	4	3	5
Fly Ash	-	31	-	25
Slag	-	-	57	25

Source: Blended cement: Green, Durable and Sustainable, GCCA India, 2022.

*The constituents of blended cements taken based on the average fly ash and slag consumption in India

The cement sector in India is exploring multiple pathways to achieve significant reductions in carbon emissions while maintaining production growth to meet rising demand. These strategies as explained below are critical for aligning the sector with national and global climate goals.

Switching to blended cements like PPC, PSC, and CC offers significant emissions reductions and resource conservation compared to OPC. Reducing reliance on OPC is one of the most impactful ways to lower emissions in cement production. OPC is highly carbon-intensive, emitting approximately 0.842 tonnes of CO_2 per tonne due to its high clinker content.[218] Substituting OPC with blended cements such as PPC and PSC can significantly reduce emissions. PPC, which replaces a portion of clinker with fly ash (up to 35%), emits 0.582 tonnes of CO_2 per tonne—a reduction of nearly 30%. PSC, which uses granulated slag from steel plants, has even lower emissions at 0.381 tonnes per tonne.[219] CC, a newer variety, combines both fly ash and slag, offering additional reductions in CO_2.[220,221] Efforts to increase the content of these industrial by-products in cement are vital. For example, raising the fly ash content in PPC from 31% to 45% could cut CO_2 emissions by up to 17%.[222] Similar increases in slag usage for PSC would not only lower emissions but also conserve limestone reserves. However, realizing these benefits requires regulatory updates, such as increasing the maximum allowable fly ash and slag content in cement standards.

Transitioning to renewable energy and alternative fuels can substantially reduce the energy-related emissions of the cement industry. Energy consumption in cement manufacturing is heavily dependent on coal and pet coke, contributing significantly to CO_2 emissions. Transitioning to renewable energy sources like solar and wind, as well as adopting Waste Heat Recovery Systems (WHRS), can drastically reduce energy-related emissions. WHRS can capture and reuse heat generated during cement production, improving energy efficiency.[223] [224] [225] Biomass is another alternative fuel that can replace fossil fuels while reducing the carbon footprint. Increased government incentives and renewable energy mandates could accelerate this transition, supporting the industry in meeting its renewable energy targets. As per a study conducted by CEEW, the use of renewable energy, alternative fuels and raw materials can abate 13% of cement emissions.[226] However, alternative fuels are also more expensive than coal/petcoke, which are currently primarily used in the cement industry.

CCUS offers transformative potential for cement plants but requires significant investment and policy support to scale. CCUS is a transformative technology capable of capturing up to 90% of CO_2 emissions from cement plants.[227] Captured carbon can be stored underground or repurposed for industrial applications, such as producing construction materials. While CCUS shows immense potential, it remains cost-intensive and technologically challenging, requiring substantial investment and policy support. According to a study by CEEW, as much as 67% of emissions would need to be abated through carbon management techniques such as CCUS and carbon offsetting (afforestation).[228] But the cost is much higher than other alternatives. Achieving net-zero emissions in cement production will increase production costs, depending on the expense of implementing Carbon Capture and Storage (CCS) or Carbon Capture and Utilisation (CCU). The estimated cost rise ranges from 19% to 107%, reflecting the variability in technology costs and operational requirements for these carbon management techniques.[229] While CCS and CCU are critical for significant emissions reductions, their adoption will require balancing environmental benefits with the economic burden on the industry. Collaborative efforts between government, industry, and research institutions are crucial to scale this technology effectively. Additionally, the study also mentions the right-of-way (RoW) issue hindering the scaling up of CO2 transportation infrastructure needed for CCS in India.[230] Around 50% of cement plants lack access to natural gas pipelines, preventing them from adopting CCS, which relies on these pipelines for CO2 transportation. As a result, these plants are assumed to pursue CCU, specifically CO2-to-methanol production, which offers versatile applications.

Achieving net-zero cement emissions could raise prices by up to 107%, but cost-effective measures could reduce this increase to 19%, with a 32% reduction in emissions intensity. Transitioning to net-zero emissions in the cement industry requires a capital expenditure (CAPEX) of INR 25 lakh crore (about USD 290 billion) and an annual operating expenditure (OPEX) of INR 29,580 crore (about USD 3.4 billion).[231] While expensive methods like CCS and CCU could increase prices by 107%, adopting cost-effective measures could reduce cement costs by 3% while cutting emissions by 20%.[232] If CCS infrastructure is available to all plants, the cost increase could be reduced to 34%, and with CCS costs at USD 50 per tonne, the price rise would be limited to 19%, all while achieving a 32% reduction in emissions intensity.[233]

Fiscal incentives and more stringent regulations can significantly accelerate the adoption of sustainable practices within the cement industry. Economic tools such as carbon pricing, tax rebates, and subsidies for green technologies are crucial in motivating cement manufacturers to reduce emissions. In India, green premiums—additional revenue from selling low-carbon cement—offer an important opportunity to offset the increased costs associated with decarbonization, especially as global demand for sustainable materials grows. Reports from CEEW suggest that achieving net-zero emissions in cement production could increase costs by 19–107%, depending on the implementation of CCUS technologies.[234] Green premiums, therefore, help bridge this cost gap. Furthermore, policies from the Department of Science and Technology (DST) and the MoPNG are actively supporting the research and deployment of CCUS technologies, further driving the sector's transition to cleaner practices.[235] Green premium policy frameworks, as outlined by the Rocky Mountain Institute (RMI), aim to establish markets for low-carbon materials, ensuring financial viability for producers. These efforts highlight the need to balance decarbonization goals with economic feasibility in the cement sector. Companies adopting these technologies can earn carbon credits, which can be traded in both voluntary and compliance carbon markets. This provides a financial incentive to offset the costs of implementing cleaner technologies and encourages further investment in sustainable practices. By participating in carbon credit mechanisms, both the cement and steel industries can contribute to India's climate goals while tapping into the growing global demand for carbon offset solutions, positioning themselves as key players in the transition to a low-carbon economy.

The lack of a clear definition and standards for "green cement" highlights the need for labelling and policy support to achieve net-zero targets. Currently, there is no universally accepted definition of "green cement," creating ambiguity in its production and adoption. While some innovative companies have set benchmarks, such as achieving a carbon footprint at least 30% lower than ordinary cement, there is no consensus or standardization across the industry. This lack of clarity, combined with limited consumer awareness, underscores the importance of implementing clear labelling systems for green cement.[236] Additionally, integrating green public procurement policies could accelerate its adoption, making it a critical step toward achieving net-zero emissions by 2050.

Energy efficiency measures reduce energy consumption and enhance waste heat recovery, cutting costs and emissions in cement production. Energy efficiency in cement production involves reducing thermal and electrical energy use per unit output while maximizing waste heat recovery at each stage of manufacturing. Measures include upgrading kilns with preheaters and precalciners, using energy-efficient motors, optimizing grinding systems, and implementing waste heat recovery systems (WHRS) to reuse exhaust heat for electricity generation. These improvements lower operational costs and CO_2 emissions, though their impact is limited compared to transformative technologies like carbon capture. However, studies show that energy efficiency in cement production will have a limited effect on emission production at 9%.[237]

Clinker factor reduction cuts emissions by replacing clinker with Supplementary Cementitious Materials (SCMs) like fly ash and steel slag, enhancing sustainability and resource efficiency. Clinker factor (CF) reduction focuses on lowering the proportion of clinker in cement by incorporating supplementary SCMs such as steel slag, fly ash, and pozzolanic materials. Clinker production is the most energy-intensive and carbon-emitting phase of cement manufacturing, as it involves the calcination of limestone. By increasing the share of additives like fly ash (a by-product of coal combustion) and steel slag (a residue from steel production), CO_2 emissions can be significantly reduced. This approach also promotes resource efficiency and waste utilization in the cement industry. According to a study by CEEW, as much as 11% of emissions would need to be abated through reduction in clinker factor.[238] However, reducing the clinker factor is challenging due to supply chain limitations in sourcing additives like slag and fly ash. Mandatory use of blended cement in infrastructure projects would further support decarbonization efforts. These policies need to be complemented by a robust monitoring framework to ensure accountability and transparency.

Achieving net-zero emissions in the cement industry requires mandated efficient technologies, alternative materials and fuels, robust monitoring, and innovation-driven policies. To achieve net-zero emissions, several studies highlight the need to mandate energy efficiency technologies under the Indian Carbon Market (ICM) scheme. Key measures include using electric arc furnace (EAF) and Industrial Furnace (IF) slag, building supply chains for alternative fuels like biomass and Municipal Solid Waste (MSW), and establishing a robust Monitoring, Reporting, and Verification (MRV) framework for GHG monitoring.[239] Additionally, incentivizing renewable energy, developing CCS and CCU ecosystems, and fostering R&D for technologies like LC3 and kiln electrification are crucial steps.[240]

The Perform, Achieve and Trade (PAT) scheme run by the Bureau of Energy Efficiency (India), which is a market-based compliance mechanism to accelerate improvements in energy efficiency in energy-intensive industries, including cement was cited as one example of a mechanism at hand to achieve these goals.[241]

Policy instruments should champion profitable solutions for decarbonizing the cement industry, such as Limestone Calcined Clay Cement (LC3). Policies should also aim to remove barriers caused by economic disadvantages associated with fly ash (such as the cost of transportation in states with no fly-ash availability) and examine the role of substituting clinker with LC3. In technical terms, this material offers a realistic solution, because it is potentially available in viable quantities. Among the advantages of LC3 is that it saves up to 40% of CO2 emissions when compared to Portland cement.[242] There is a need for institutional support to make it more attractive to invest in green cement. There is also a need to strengthen the "polluter pays" principle to generate demand for greener alternatives. Furthermore, de-risking investments by building up sustainable climate finance is key to accelerating the speed of transition.

By adopting these measures, the cement industry can balance its production growth with the urgent need for decarbonization, contributing to India's broader climate commitments.

4.3 Chemical industry

India's chemical industry serves as a catalyst for economic growth. India's chemical industry, ranked sixth globally and third in Asia, is a cornerstone of its economic development.[243] With over 80,000 commercial products and projected growth of 13–14% in the next five years, the sector is expanding rapidly.[244] Rising demand, particularly for plastics, which is expected to reach 35 million tonnes by 2027-28,[245] has fuelled exports and attracted significant domestic and international investments. In 2019-20, exports of chemicals and petrochemicals (excluding pharmaceuticals and fertilizers) rose to approximately US$ 34 billion, accounting for 12.4% of India's total national exports, up from 9.2% in 2012-13.[246] The industry contributes approximately 10.5% to global foreign trade,[247] with government initiatives like 'Make in India' prioritizing its growth[248].

The chemical sector is a significant contributor to industrial CO2 emissions globally, with its reliance on energy-intensive production processes. It accounts for around 10-12% of global industrial emissions, with ammonia and petrochemicals being two of the largest contributors.[249] Ammonia production alone is responsible for roughly 1.8% of global CO2 emissions, primarily due to the energy-intensive Haber-Bosch process, which uses natural gas as a feedstock.[250] On the petrochemical side, ethylene and propylene production, together with the bulk of petrochemical output, contributes significantly to industrial emissions, with estimates suggesting ethylene production alone contributes over 0.8% of global CO2 emissions.[251]

The chemical sector directly contributes only around 4% to India's GHG emissions, a figure poised to rise with increasing demand for petrochemical products.[252] The petrochemical industry manufactures various chemicals derived from petroleum and natural gas, including ethylene, propylene, and methanol. These processes are energy-intensive and often involve high-temperature reactions powered by fossil fuels, leading to significant CO_2 emissions. Presently, India produces about 7 million tonnes of ethylene and 5 million tonnes of propylene, with 85% of ethylene production dependent on fossil fuels.[253] To meet the growing demand, projections indicate the need for 5 new cracker units by 2025 and 14 by 2040, potentially leading to a 30-40% increase in emissions over the next two decades without significant interventions.[254] Ammonia is primarily produced through the Haber-Bosch process, which synthesizes ammonia by combining hydrogen and nitrogen. The hydrogen is typically derived from natural gas via steam methane reforming (SMR), a process that emits substantial amounts of carbon dioxide (CO_2). In the ammonia sector, India stands as the second-largest global producer, accounting for approximately 6-7% of worldwide output. Ammonia production in India contributes around 20-25 million tonnes of CO_2 emissions annually.[255] With rising agricultural demand and increased use of nitrogen fertilizers, these emissions are expected to grow in tandem with production.

Green ammonia, produced by synthesizing nitrogen and hydrogen derived from water electrolysis powered by renewable energy sources, offers a promising pathway for decarbonizing the chemical industry. Traditional ammonia production relies on the Haber-Bosch process, which typically uses natural gas, resulting in significant CO_2 emissions. In contrast, green ammonia production emits no CO_2 during synthesis, thereby substantially reducing the carbon footprint associated with ammonia manufacturing. Implementing green ammonia not only aids in producing fertilizers with lower environmental impact but also serves as a potential energy carrier, facilitating the storage and transport of renewable energy. This dual functionality positions green ammonia as a critical component in the transition towards a more sustainable and low-carbon chemical industry.

India is actively promoting green ammonia through government policies and private sector investments. The National Green Hydrogen Mission, with an allocation of INR 19,744 crore (about USD 2.3 billion), aims to produce 5 million metric tonnes of green hydrogen annually. This initiative includes developing green hydrogen hubs to support large-scale production and utilization.[256] Several Indian companies are investing in green ammonia production. AM Green, a subsidiary of Greenko, has partnered with DP World to develop infrastructure for exporting 1 million tonnes per annum (MTPA) of green ammonia and 1 MTPA of green methanol.[257] Additionally, AM Green has reached a Final Investment Decision (FID) on a large-scale green ammonia project in Kakinada, aiming to produce 1 million tonnes annually by late 2026.[258] Larsen & Toubro (L&T) plans to invest INR 48,000 crore (about USD 5.6 billion) over the next decade to build six green ammonia production facilities at Deendayal Port, each with a capacity of 300 kilotonnes per annum.[259] ReNew Energy Global plc has partnered with Japan's JERA Co., Inc to evaluate a green ammonia project in India, projected to produce approximately 100,000 tonnes annually by 2030, with JERA having the right to offtake this green ammonia for Japan.[260] These efforts underscore India's commitment to reducing carbon emissions and becoming a leader in the global green energy market.

Green methanol, produced from renewable resources such as biomass or synthesized using green hydrogen and captured carbon dioxide, offers a promising pathway for decarbonizing the chemical industry. Its adoption can significantly reduce greenhouse gas emissions associated with chemical manufacturing processes. Methanol serves as a fundamental building block in the chemical industry, utilized in the synthesis of formaldehyde, acetic acid, and various plastics. Transitioning to green methanol enables the production of these chemicals with a substantially lower carbon footprint. Utilizing green methanol can cut carbon dioxide emissions by up to 95% compared to conventional fossil fuels, thereby contributing to the overall decarbonization efforts within the chemical sector.[261]

India is advancing green methanol initiatives to enhance energy security and reduce carbon emissions.[262] The government's 'Methanol Economy' program, led by NITI Aayog, aims to convert coal reserves and municipal solid waste into methanol, thereby decreasing oil imports and greenhouse gas emissions.[263] In the private sector, Ohmium International is collaborating with Indian organizations to establish the nation's first green methanol plant. This facility will produce green methanol by combining green hydrogen with CO_2 captured from the Singareni Thermal Power Plant.[264] Additionally, the Methanol Institute has formed the India Methanol Economy Coalition (IMEC) to unify Indian companies interested in developing the methanol economy, promoting methanol adoption for sustainability and energy security.[265] These initiatives underscore India's commitment to integrating green methanol into its energy and industrial sectors, fostering sustainability and energy independence.

Improving energy efficiency is a key strategy for decarbonizing the petrochemical industry, particularly by reducing specific energy consumption (SEC) in processes like steam cracking. In India, the Bureau of Energy Efficiency (BEE) has implemented the Perform, Achieve, and Trade (PAT) scheme to enhance energy efficiency in energy-intensive industries, including the petrochemical sector. In the petrochemical industry, the PAT scheme mandates specific energy consumption targets, encouraging companies to adopt measures such as optimizing heat exchangers, recovering waste heat, and enhancing the efficiency of pumps and compressors.[266] These initiatives not only contribute to energy conservation but also support India's broader goals of reducing greenhouse gas emissions and promoting sustainable industrial practices.

Implementing demand reduction strategies in the petrochemical industry, such as enhancing the collection, reuse, and recycling of plastics, can significantly minimize the production of virgin plastics and thereby reduce overall emissions. Research indicates that recycling between 2020 and 2050 could reduce emissions by 5.5 to 6.02 gigatons of carbon dioxide, equivalent to removing over one billion cars from the roads for a year.[267] Additionally, advanced recycling of post-use plastics can lower greenhouse gas emissions by up to 23%, offering a sustainable alternative to fossil-based plastic production.[268] In India, the Department of Chemicals and Petrochemicals (DCPC) is actively promoting Circular Chemistry to enhance sustainability and resource efficiency. Circular Chemistry focuses on extending the lifecycle of resources by maximizing their use, recovering, and regenerating materials at the end of their life.[269] This approach is crucial for managing toxic and hazardous industrial waste, which in India is increasing by 2% to 5% annually, with approximately 10% to 15% of industrial waste classified as hazardous.[270]

Electrification is emerging as a promising decarbonization strategy for the petrochemical industry. Conventional steam crackers, which burn fossil fuels for high temperatures, emit approximately 1.8 to 2 tonnes of CO2 per tonne of ethylene produced.[271] Electrified steam crackers powered by low-carbon electricity eliminate these emissions while maintaining the same process chemistry.

Carbon Capture and Storage (CCS) is a key emissions-reduction strategy in the petrochemical industry, utilizing methods like solvent-based absorption, membrane separation, and carbon dioxide mineralization to capture and store CO_2.[272] In India, Indian Oil Corporation Limited’s (IOCL) planned CCS project at Koyali refinery will transport captured CO_2 to ONGC's Gandhar oil field for Enhanced Oil Recovery (EOR).[273] Bharat Petroleum Corporation Limited (BPCL) also aims to integrate CCS into its operations as part of its net-zero strategy by 2040, reflecting India's commitment to decarbonizing the sector.[274]

The Indian petrochemical industry faces several challenges in adopting decarbonization technologies: implementing novel decarbonization technologies, such as electrified steam crackers and recycling methods, requires substantial capital investment; many technologies, including green hydrogen, are still in the developmental phase in India, necessitating significant efforts to make them commercially viable; the supply of uninterrupted renewable energy-powered electricity is crucial for process electrification and green hydrogen production, posing a key challenge; and there is a lack of streamlined markets for utilizing captured carbon and for recycled plastic products, with the higher cost of recycled plastics compared to virgin plastics hindering adoption.

Decarbonizing heavy industries is both a necessity and an opportunity for India to lead in sustainable industrial practices. A comprehensive approach is essential, starting with robust policy frameworks that enforce stringent emission standards and promote low-carbon technologies such as CCS, green hydrogen, and electrification. Financial incentives can ease the transition for industries, while capacity-building initiatives will equip the workforce with the skills to manage emerging technologies. Sector-specific strategies, including alternative materials in cement production and energy-efficient methods in steel manufacturing, are crucial for reducing emissions. With targeted investments, regulatory backing, and technological innovation, India can transform its industrial sector into a model of sustainable growth while contributing significantly to global climate action.

NOTES

[1] Government declares plan to add 50 GW of renewable energy capacity annually for next 5 years to achieve the target of 500 GW by 2030
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