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Decomposition Analysis of Carbon Dioxide Emissions from the Electricity Generation Sector of India with a Policy-focused Approach and Evaluation of Scope for Raising Nationally Determined Contribution Ambitions for 2030

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ABSTRACT

This paper uses the Log Mean Divisia Index to decompose and analyze carbon emissions from electricity generation sector in India for the period 2014 to 2023. The overall carbon emissions grew by more than 558 Million tonnes during the period of study. The activity effect arising out of the growth in the Gross Domestic Product (GDP) has been the primary driver of growth in carbon emissions. The energy intensity of generation from thermal sources has also contributed significantly to the increase in emissions. The electricity generation intensity of the GDP is the biggest driver of emissions reduction. The falling share of thermal electricity in overall electricity generation also leads to some reduction of carbon emissions. The fuel mix effect is relatively insignificant. The emission factor remains unchanged during the period of study and has no effect on emissions. The study also analyses scenarios where different generation mixes lead to different levels of emissions reduction and uses them to analyze the scope for India to increase its NDC target of emission intensity reduction of the economy by 45% by 2030, assuming that other sectors of the GDP can achieve similar reductions. Based on the analysis in this study, it is found that India can consider enhancing its NDC target for emission intensity reduction to 55% by 2030, compared to 2005 levels, which could further influence the 2035 targets under its NDC 3.0.

Keywords: Carbon Emissions, Electricity Generation, Indian Electricity Sector, LMDI Analysis, Index Decomposition, Energy Transition
JEL Classifications: Q01, Q42, Q43, Q48

1. INTRODUCTION

Acknowledging the exacerbating issue of climate change due to anthropogenic Greenhouse Gas (GHG) emissions, 195 countries adopted the Paris Agreement in 2015, with the stated goal of restricting the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit this increase to 1.5°C above pre-industrial levels (United Nations Framework Convention on Climate Change [UNFCCC], 2025). At existing emission rates, there is a 50% chance that global warming will exceed 1.5°C by 2030 (Global Carbon Budget, 2024). This is deeply concerning as IPCC reports over the years have already warned about catastrophic effects of breaching the 1.5 degrees threshold. In 2024, total GHG emissions stood at 53.2 Gigaton carbon dioxide equivalent (Gt CO_2eq) (excluding Land Use, Land Use Change and Forestry (LULUCF)) and fossil carbon dioxide (CO_2) emissions (~39.6 Gton) comprised ~74.5% of all GHG emission (Crippa et al., 2025). The electricity generation sector alone was responsible for about two-fifth of the total fossil CO_2 emissions (Statista, 2024). CO_2 emissions from electricity generation therefore assume high priority when it comes to climate change mitigation strategies.

In 2024, India accounted for about 8% of global energy-sector CO_2 emissions (Aggarwal et al., 2025) As per the International Energy Agency (IEA, 2025), the power sector alone accounts for more than half of India's energy sector carbon emissions, which makes it the most important sector for decarbonization. Further, as India strives to increase the electricity penetration of its economy, the importance of this sector is set to increase in the time to come. In its first Nationally Determined Contribution (NDC) submitted to the UNFCCC, India had pledged to achieve about 40 per cent cumulative electric power generation capacity from non-fossil fuels by 2030 but achieved the target nine years ahead of schedule in 2021. It had also pledged to reduce the emissions intensity of its Gross Domestic Product (GDP) by 33-35% by 2030 from 2005 level, which it achieved eleven years in advance in 2019. India's updated NDC, submitted in 2022, inter-alia, laid down the following commitments- (i) Achieving about 50% installed electricity capacity from non-fossil fuel sources by 2030 and (ii) Reducing Emissions Intensity of its GDP by 45% by 2030, from 2005 level. With sustained policy emphasis on achieving a timely energy transition, the 50% non-fossil fuel sources-based installed capacity target was achieved in June 2025 (Press Information Bureau, India, 2025a) India is also well-positioned to achieve the emissions intensity reduction target well before time.

India, while following a multi-pronged strategy for energy sector decarbonization encompassing energy access, energy efficiency and energy transition, has put particular emphasis on universal electrification and the decarbonization of its electricity generation sector by introducing several power sector reforms and setting ambitious targets for and renewables-based electricity generation capacity deployment. This policy push is particularly evident since 2014 with the launch of the Rooftop Solar Program, Solar Parks scheme, Deendayal Upadhyay Gram Jyoti Yojana (DDUGJY) for rural electrification, and Integrated Power Development Scheme (IPDS) for strengthening the sub-transmission and distribution networks in urban areas (Press Information Bureau, India, 2021). 2015 was a crucial year during which India submitted its first NDC commitments and announced an ambitious target of achieving 175 GW of renewables based installed capacity by 2022 (Press Information Bureau, India, 2015), along with a wide range of supporting measures. Several new policies and initiatives have continued to be implemented since then even as existing targets have been enhanced in several cases. It is against this background that it becomes necessary to analyze the actual impact of these policies and programs on the carbon emissions from electricity generation sector. Crucial insights can be obtained by investigating the key drivers of carbon emissions from the sector and their effects over the years following the post 2014 policy impetus. This study therefore uses the Logarithmic Mean Divisia Index (LMDI) to decompose CO_2 emissions from the electricity generation sector in India over the period 2014 to 2023, to analyze various driving factors for changes in carbon emissions from the sector during the period and identify policy implications arising therefrom. The study also considers certain generation mix scenarios in 2030 for compatibility with increasing the NDC target for reduction of emissions intensity of the GDP by different levels to identify an appropriate one that achieves emissions reductions as well as meets estimated electricity demand. LMDI is again used to decompose the emissions between 2023 and 2030 under the selected scenario to identify the drivers of emission changes anticipated in the future.

2. LITERATURE REVIEW

The Logarithmic Mean Divisia Index (LMDI) method has been demonstrated by Ang et al. (1998) to be a desirable decomposition method to factorize temporal changes in energy demand or resulting emissions. Ang (2004) further analyzed several decomposition methods and concluded that LMDI method is recommended for decomposition of energy consumption and emissions in most cases while other methods can be used in some specific situations. LMDI has been instrumental in helping researchers and policymakers to decompose available energy related data to analyze the contribution of various factors like activity, structure, energy intensity, emission factors etc. to the evolution of energy consumption and energy emissions over a certain period of time.

De Freitas and Kaneko (2011) used LMDI to study the carbon emissions from energy use in Brazil between 1970 and 2009, and found that economic activity and population growth were predominantly responsible for changes in carbon emissions. Jeong and Kim (2013) decomposed the Greenhouse Gas emissions from Korea's manufacturing sector between 1991 to 2009 and observed that the structure effect and intensity effect both contributed significantly to reduction in emissions while activity effect was responsible for the net increase in emissions. Chen et al. (2018) used LMDI decomposition and decoupling analysis to evaluate various drivers of carbon emissions in member countries of the Organization for Economic Cooperation and Development (OECD) and found that the total carbon emissions for OECD countries decreased between 2001 to 2015, driven primarily by improvements in energy intensity, supported by decrease in CO_2 emission intensity of fossil energy and the optimization of energy consumption structure. Zhang et al. (2013) used LMDI to decompose carbon dioxide emissions from electricity generation in China from 1991 to 2009 and found that economic activity effect was primarily responsible for increase in carbon emissions whereas generation efficiency effect significantly reduced carbon emissions. He et al. (2022) used the LMDI method to decompose carbon emissions from electricity industry in China from 2005 to 2019 into nine factors and found that economic growth was the dominant driver of increase in emissions while power consumption intensity, energy intensity of thermal power generation and power mix were the main suppressors of emissions growth, though with much smaller magnitudes as compared to the economic growth. They further used K-means cluster analysis to classify China's provinces into four groups to provide targeted strategies for controlling carbon emissions from electricity industry.

Nag and Parikh (2005) used the Arithmetic Mean Divisia Index to examine the drivers of emissions in the power sector in India by studying their impact on emissions per unit of power consumption, or the emission coefficient of power consumption and also provided baseline emissions for the sector till 2015. Based on the data for the period 1974 to 1998, they found that the generation mix effect and the energy intensity effect were the two most important indicators of the emission coefficient of power consumption and should be targeted by policies. Their research used AMDI as it was considered simpler in implementation. They assumed that since their decomposition used annual time-series data, the results would be similar to those obtained using LMDI, and that the problem of residuals was also less likely in their study.

Considering LMDI based studies on India in recent times, Pillai (2019) used LMDI to measure energy productivity in the Indian state of Kerala by decomposing changes in energy consumption with respect to electricity and petroleum consumption. Ortega-Ruiz et al. (2020) used LMDI to analyze the main drivers of carbon emissions in India between 1990 and 2016, and found that economic growth effect was the main driver of increase in emissions while energy intensity was mainly responsible for a decrease. Liu et al. (2024) analyzed the drivers of energy related carbon emissions in India at national and regional levels from 2013 to 2021 using LMDI while including a population distribution effect. Their research showed that economic output effect was the major driver for increase in emissions, energy intensity and industrial structure effects led to decrease in emissions and the population distribution effect reduced emissions in sparsely populated regions. Karnik (2025) used LMDI to analyze the determinants of carbon emissions from energy use in India for the period 2011 to 2021. Her research too showed economic activity effect being the primary driver of increase in emissions, while energy intensity effect led to highest reduction of emissions. Jain and Rankavat (2023) used LMDI to decompose transport sector carbon emissions from 2001 to 2020 and found that economic effect was the biggest driver of increase in transport sector emissions while energy performance effect has the biggest impact on reducing emissions. Jain (2023) used LMDI to estimate energy savings resulting in India during 2011 to 2019, due to improvements in each of the following- primary energy intensity, the energy intensity of the electricity supply, final energy intensity, and manufacturing energy intensity. She decomposed the energy consumption in electricity sector into consumption effect, generation intensity effect and transmission & distribution intensity effect. Consumption effect was found to be driving energy consumption increase while generation intensity effect and transmission & distribution intensity effect were responsible for a reduction in energy consumption, resulting in saving of around 57 million tonnes of oil equivalent (Mtoe) of primary energy.

Review of available literature indicates that several economy-wide and non-electricity sector-based studies exist for India. Some studies also examine certain aspects of the electricity sector at the national or provincial level. However, it seems that since Nag and Parikh‘s 2005 study, no comprehensive decomposition analysis of the national electricity generation sector has been conducted in almost two decades to specifically analyze the effects of various drivers on the carbon emissions from the sector while identifying causes and policy implications arising therefrom. Such research is highly desirable to evaluate the actual impact of concerted policy initiatives for universal electricity access and transition to clean sources of electricity, particularly over the last decade. This analysis could enable policymakers to evaluate the achievements and shortcomings of existing policies, and accordingly refine these policies or develop new ones to align the electricity sector transformation with evolving national priorities and energy landscape.

Several studies have also analyzed NDC as well as Net-Zeo pathways for India. Vishwanathan et al. (2023) used modelling tools to evaluate enhanced NDC and climate compatible pathways for India and assess the socio-technical, financial and macro-economic implications of such pathways. Their findings, inter-alia, suggested that India‘s emissions intensity reduction would range between 45 and 55% in 2030 relative to the 2005 level, even in the baseline scenario. Das et al. (2025) examined several scenarios for India‘s Net zero emissions by 2070 target using the Global Change Analysis Model (GCAM) and found that while achieving Net Zero emissions by 2070 would require additional policy interventions on part of the Government, particularly focusing on carbon pricing, power pricing reforms, fiscal support for clean technologies, energy efficiency and behavior changes, the emission intensity of the energy sector could decreases by 48-57% by 2030, compared to 2005 level. Most studies have found India‘s 2030 NDC target of 45% reduction in emissions intensity of the GDP compared to 2005 level to be easily achievable. This study tries to estimate emission reduction targets specifically for the electricity generation sector under enhanced reduction targets for the overall GDP and develop generation mix scenarios to look for compatibility of emissions under each scenario with the enhanced emission reduction targets. Using electricity generation as a representative sector (accounting for the highest share in energy emissions), overall NDC targets could be considered for upgrades based on achievements possible under this sector.

3. MAJOR POLICIES AND MEASURES FOR THE INDIAN ELECTRICITY SECTOR

The main foundation for market and structural reforms in the electricity sector in India was laid down by the Electricity Act of 2003. The National Solar Mission was launched in 2010 to promote solar power deployment. In 2011, Renewable Purchase Obligations (RPOs) were introduced to mandate distribution utilities to purchase a certain fixed percentage of their power procurement from renewable sources, along with the provision of trading in Renewable Energy Certificates (RECs) to account for the non-uniform distribution of renewable sources (Shereef and Khaparde, 2013). Initial policies for wind power generation (Mizuno, 2015) as well as biomass-based electricity generation (Ravindranath and Rao, 2015) had already been initiated in the country way back in the 1980s. However, till 31st March 2014, the total installed electricity generation capacity stood at about 249GW with nuclear and renewable sources accounting for only about 80 GW and the rest being predominantly coal-based thermal power generation capacity. Out of the renewable sources, Large Hydro power accounted for about 40 GW, Wind Power for about 21 GW and Solar for about 3 GW, among others (Press Information Bureau, India, 2025b).

From 2014 onwards, a number of programs and schemes were launched with a view to transform the national power landscape focusing on energy access as well energy transition. The Deen

Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY), launched in 2014 to promote rural electrification and improving the quality of power supply to such areas, achieved 100% village electrification by April 2018 while the Integrated Power Development Scheme (IPDS) was also launched in 2014 in order to strengthen urban sub-transmission and distribution networks while also promoting smart metering, Real Time Data Acquisition, and Information Technology enablement related works (Press Information Bureau, India, 2021). The Rooftop Solar scheme was launched in the same year to promote rooftop solar deployment with provisions for Central Financial Assistance for domestic sector (Press Information Bureau, India, 2015) revamping it significantly through the PM Surya Ghar: Muft Bijli Yojana (PMSGMBY) in 2024. In a major development in 2015, India announced a target of achieving 175 GW of renewables-based capacity by 2022 and revised its solar deployment target from 20 GW to about 100 GW during the same period (International Energy Agency, 2021). The UJWAL Discom Assurance Yojana (UDAY) was launched in 2015 to turn around the operational and financial performance of state-owned Power Distribution Companies (DISCOMs) (Press Information Bureau, India, 2021). India also initiated Green Energy Corridor (GEC) projects in 2015 to create dedicated transmission infrastructure for integrating renewable power, often dispersed and with its issue of variability, with the national grid (Press Information Bureau, India, 2015). Renewable Purchase Obligations (RPOs) trajectories were progressively notified in 2016, 2018 and 2021 for the years to follow. In 2022, the trajectory was notified till 2029-30, with the total RPOs in 2029-30 specified to be an ambitious 43.33% (Ministry of Power, India, 2022). The Pradhan Mantri Sahaj Bijli Har Ghar Yojana (SAUBHAGYA) scheme, launched in 2017 to achieve universal household electrification, was hailed by the International Energy Agency as the fastest expansion of access in the global history of power. The Revamped Distribution Sector Scheme (RDSS) was launched in 2021 as a Reforms-based and Results-linked scheme to reduce distribution to reduce the AT&C losses to pan-India levels of 12-15% (Press Information Bureau, India, 2021). The Scheme for Harnessing and Allocating Koyala Transparently in India (SHAKTI) policy was also introduced in 2017 (and amended from time-to-time for further improvements), to provide a transparent way of allocation of coal to the electricity generation sector by ensuring better accessibility to coal through a wide range of measures (Ministry of Coal, India, 2025). India has also mandated biomass co-firing in coal power plants since 2021. The latest policy notified in November 2025, mandates coal-based thermal power plants in the National Capital Region (NCR) to blend, by weight, 5% biomass pellets and an additional 2% of biomass pellets or torrefied charcoal made from Municipal Solid Waste (MSW) with coal from FY 2025. For coal-based thermal plants in other regions of the country, the mandate is to co-fire 5%, by weight, of either biomass pellets or torrefied MSW charcoal from FY 2025 (Kumar, 2025). Initiatives like Real Time Market, Green Term Ahead and Day Ahead Markets, Green Energy Open Access and waiver of Inter-state transmission charges have focused on strengthening the green electricity market and providing price-competitiveness signals. (Press Information Bureau, India, 2023a). A wide range of other sector-specific targeting and enabling initiatives like Production Linked Incentives to promote domestic Solar manufacturing, Solar Parks scheme to provide a plug and play model for large-scale solar projects deployment, PM-KUSUM scheme for solarization of grid-connected agricultural pumps and the export-oriented National Green Hydrogen Mission targeting 5 Metric Million Tonnes (MMT) of green hydrogen production capacity while focusing on domestic use primarily as an energy carrier and feedstock (Press Information Bureau, India, 2025b); and launch of the Nuclear Energy Mission targeting 100 GW of nuclear based generation capacity by 2047 (Press Information Bureau, India, 2025c) have also been contributing to the transformation of the electricity generation sector, which is consistently shifting towards more non-fossil fuel sources based installed capacity.

In addition to the ones listed above, a large number of initiatives and schemes to improve energy efficiency are being implemented by the Bureau of Energy Efficiency (BEE), established in 2002 under the Energy Conservation Act of 2001. The most notable among these, from an industry point of view, has been the Perform, Achieve and Trade (PAT) scheme introduced in 2012 to reduce Specific Energy Consumption (SEC) in industries that are energy-intensive through a market-based mechanism that provides for trading of certification of energy savings achieved in excess of allotted targets. Thermal Power Plants have been included in six of the seven PAT cycles till date (Bureau of Energy Efficiency, India, 2023). Energy efficiency schemes are expected to play a key role in reducing electricity demand, thereby enabling India to pursue its energy transition targets, with the possibility of cutting down on coal-based capacity earlier than would seem likely based on stated expansion plans (Press Information Bureau, India, 2024).

However, coal based thermal power continues to be the mainstay of the electricity generation and is expected to remain so, at least in the near future, even as renewable capacity additions have continued to increase steadily. A renewed focus on energy security, resulting from the energy supply chain disruptions due to the COVID19 pandemic and other geopolitical tensions, has sustained the reliance on thermal power predominantly based on coal (relatively abundant domestically). In spite of this, India actively continues to implement ambitious energy transition and energy efficiency policies. A list of some major policies for the electricity sector and their likely impacts on drivers of emissions (detailed in section 4) is available in Table 1.

In summary, the installed electricity generation capacity in India increased from about 276 GW in Financial Year (FY) 2014 to about 442 GW in FY 2023. The total generation increased from 1105 Billion units (BU) (1 unit = 1 kilowatt-hour, kWh) in FY 2014 to 1734 BU in FY 2023. Though renewables-based generation almost doubled between FY 2014 and FY 2023, its overall share in total generation increased marginally from 17.2% to 20.7% during this period (Ministry of New and Renewable Energy, India, 2024). This indicates that fossil fuels, mainly coal, form the bedrock of power generation. The total installed generation capacity and total generation are expected to rise to about 777 GW and 2440 BU respectively by FY 2029-30 (Central Electricity Authority, India, 2023). While renewables are expected to account for about 64% of the total capacity in 2029-30, fossil fuels are expected to be responsible for about 56% of the total generation around

Table 1: Some major policies/programs for electricity generation sector in India since 2014 and their impact

Policy/Program	Effect impacted, (nature of impact: + or -)	Broad objectives
Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) (2014)	Electricity Generation Intensity effect (+)	Universal electrification
NDC targets for non-fossil fuel based installed electricity capacity (2015 and 2022)	Production Structure effect (-)	Increase the share of non-fossil fuels-based generation capacity and reduce emissions intensity of the GDP
Solar Parks scheme (2014)	Production Structure effect (-)	Facilitate large scale solar power projects
Rooftop Solar Program (2014 and 2024)	Electricity Generation Intensity (-) and Production Structure effects (-)	Promote Rooftop solar installation by households
Integrated Power Development Scheme (IPDS) (2014)	Electricity Generation Intensity effect (-)	Strengthening of urban sub-transmission and distribution networks, enabling of IT and smart grid technologies
Ujwal DISCOM Assurance Yojana (UDAY) (2015)	Electricity Generation Intensity effect (-)	Improving the operational & financial efficiency of the State Power Distribution Companies
Green Energy Corridor scheme (2015)	Production Structure effect (-)	Establishing an intra-state transmission system for nation-wide renewable energy projects
Perform, Achieve and Trade scheme- Cycles II to VII (2016-2022)	Activity effect (-), Electricity Generation Intensity effect (-) and Energy Intensity effect (-)	Reducing the specific energy consumption (SEC) in highly energy-intensive industries including thermal power plants
Renewable Purchase Obligations trajectories (2016, 2018 2021)	Production Structure effect (-)	Promoting renewable power by mandating power utilities to purchase a certain percentage of their total power requirements from renewable energy sources
Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya scheme) (2017)	Electricity Generation Intensity effect (+)	Universal electrification
Scheme for Harnessing and Allocating Koyala Transparently in India (SHAKTI) policy (2017)	Production Structure effect (+), Fuel mix effect (+), Energy Intensity effect (-)	Transparent allocation of coal to power sector
Real Time Market (2020), Green Term Ahead Market (2020), Green Day Ahead Market (2021), Green Energy Open Access Rules (2022)	Production Structure effect (-)	Promoting the green electricity market and providing competitive price signals
Production Linked Incentives (PLI) scheme for Solar and Advanced Chemistry Cells (2021)	Production Structure effect (-)	Boosting the renewable energy and energy storage ecosystem by achieving self-sufficiency in domestic manufacturing
CEA Smart Metering regulations (2021, 2022)	Electricity Generation Intensity effect (-)	Improving financial health of state DISCOMs and facilitating demand side management
National Green Hydrogen Mission (2023)	Activity effect (-), Emission factor effect in furure(-)	Decarbonization of hard-to-abate industrial sectors
Nuclear Energy Mission (2025)	Production Structure effect (-)	Scaling up nuclear power generation capacity to 100 GW by 2047
Energy efficiency programs by Bureau of Energy Efficiency (ongoing)	Activity effect (-), Electricity Generation Intensity effect (-) and Energy Intensity effect (-)	Promoting energy-efficient appliances and behavioral changes, Financing demand side management programs

that time- indicating that the exiting gap between renewables-based installed capacity and actual generation from this capacity will shrink but still be significant. India's upcoming policies are likely to be aligned with its long-term target of achieving energy independence by 2047, even as it pursues achieving Net Zero emissions by 2070.

4.DATA SOURCES AND RESEARCH METHODOLOGY

4.1. LMDI decomposition for 2014-2023

4.1.1. Data sources

In India, the Financial Year, abbreviated as FY, starts from 1st April and ends on 31st March of the subsequent year. For instance, FY 2014, inter-changeably written as FY 2014-15, covers the period from 1st April 2014 to 31st March 2015. Majority of the data published by the Government of India and its agencies follow the financial year format instead of the calendar year. The focus of this research has been to obtain relevant data regarding fuel consumption and fuel-type based generation from established Government sources only to ensure reliability of data quality.

This research analyses electricity generation emissions over a period of 10 years starting from Financial Year (FY) 2014 to FY 2023. It utilizes annual fuel consumption data by electricity producer plants in India, obtained from annual energy balances for Financial Years 2014 through 2023, sourced from the Ministry of Statistics and Program Implementation (Ministry of Statistics and Program Implementation, 2025a) of the Government of India. For the purpose of this study, we consider only carbon emissions from the combustion of fossil fuels. In this context, electricity generated from nuclear energy, hydro power and other renewable sources is considered to be carbon free. The Energy balance data provide details of energy consumption for coal, oil products, and natural gas for electricity generation for this study.

The annual data for electricity generation from various fossil fuels and other clean sources of energy for the same period have also been sourced from MoSPI (Ministry of Statistics and Program Implementation, India, 2025b). The data is available for coal, diesel, gas, Hydro, nuclear and renewable sources. Bituminous coal is predominantly used in power generation and is used as the standard reference for coal in this study, with any difference in emission factors compared to other types used in relatively very smaller quantities assumed to not have any significant effect on emissions; Diesel is the primary oil product (Ministry of Statistics and Program Implementation, 2025b) used for power generation while natural gas is itself used. Carbon Dioxide Emission factors for these fuels were obtained from the Inter-Governmental Panel on Climate Change (IPCC)_s 2006 Guidelines for National Greenhouse Gas Inventories. The GDP data (based on constant 2015 USD prices) for the period of study were sourced from the World Bank. Table 2 lists source-wise electricity generation related data as well as GDP data at constant 2015 USD prices sourced from World Bank for each financial year while Table 3 lists the financial year-wise data for consumption of fossil fuels for generation, both tables using Peta Joules as the unit. Table 4 lists the IPCC carbon emission factors used for the calculation of CO_2 emissions, which are further tabulated in Table 5.

4.1.2. Methodology

This research uses Log Mean Divisia Index (LMDI) for Index Decomposition Analysis of carbon dioxide emissions from the electricity production sector of India from Financial Year (FY) 2014-15 to FY 2023-24. The carbon emissions (C) from electricity generation can be expressed through the following Kaya identity:

$$C = \sum C_f = \sum GDP \times \frac{Q}{GDP} \times \frac{Q_{th}}{Q} \times \frac{Q_f}{Q_{th}} \times \frac{E_f}{Q_f} \times \frac{C_f}{E_f}$$

- GDP: Gross Domestic Product
- Q: Total electricity generation
- Q^{th}: Total thermal electricity generation
- Q_f: Thermal electricity generation from fuel type f
- E_f: Consumption of fuel type f
- C_f: Emissions from fuel type f

Following the above Kaya identity, this study uses the additive LMDI decomposition to decompose carbon emissions from electricity generation into the following six effects:

$$\Delta C = Ct - C0 = \Delta Cact + \Delta Cegi + \Delta Cps + \Delta Cfm + \Delta Cei + \Delta Cemf$$

Where:

$\Delta Cact$– Activity effect: Changes in emissions due to changes in GDP levels

$\Delta Cegi$– Electricity generation intensity effect: Changes in emission due to changes in electricity generation per unit of GDP.

ΔCps– Production structure effect: Changes in emissions due to changes in the share of thermal generation in overall electricity generation.

ΔCfm– Fuel mix effect: Changes in emissions due to changes in the share of different fossil fuels in thermal electricity generation.

ΔCei – Energy intensity effect: Changes in emissions due to changes in energy intensity of electricity generation from different fossil fuels

$\Delta Cemf$– Emission factor effect: Changes in emissions due to changes in emission factor of different fossil fuels.

The formulas used for calculating the above effects are listed below:

$$\Delta C_{act} = \sum_f L(C_{f,t}, C_{f,0}) \cdot ln \frac{GDP_t}{GDP_0}$$

$$\Delta C_{egi} = \sum_f L(C_{f,t}, C_{f,0}) \cdot ln \frac{Q_t / GDP_t}{Q_0 / GDP_0}$$

$$\Delta C_{ps} = \sum_f L(C_{f,t}, C_{f,0}) \cdot ln \frac{Q_{th,t} / Q_t}{Q_{th,0} / Q_0}$$

$$\Delta C_{fm} = \sum_f L(C_{f,t}, C_{f,0}) \cdot ln \frac{Q_{f,t} / Q_{th,t}}{Q_{f,0} / Q_{th,0}}$$

$$\Delta C_{ei} = \sum_f L(C_{f,t}, C_{f,0}) \cdot ln \frac{E_{f,t} / Q_{f,t}}{E_{f,0} / Q_{f,0}}$$

$$\Delta C_{emf} = \sum_f L(C_{f,t}, C_{f,0}) \cdot ln \frac{C_{f,t} / E_{f,t}}{C_{f,0} / E_{f,0}}$$

Where the Logarithmic mean weight ($C_{*f,+}$, $C_{*f,0+}$) is calculated as:

$$L\left(C_{\{f,t\}}, C_{\{f,0\}}\right) = \frac{\left(C_{\{f,t\}} - C_{\{f,0\}}\right)}{\left(\ln C_{\{f,t\}} - \ln C_{\{f,0\}}\right)}$$

- $C_{\{f,t\}}$ = Carbon emissions from fuel type f in year t
- $C_{\{f,0\}}$ = Carbon emissions from fuel type f in base year.

Table 2: Source wise electricity generation (PJ) and GDP for each Financial Year (FY)

FY	Coal	Oil	Gas	Nuclear	Hydro	Renewable	Total	Thermal share	GDP (bn USD 2015, constant)
2014	3007.05	5.67	147.87	129.97	465.28	264.83	4020.66	0.79	1,947.8
2015	3223.22	1.98	169.64	134.69	436.96	236.81	4203.30	0.81	2,103.6
2016	3398.48	1.44	176.73	136.50	440.56	293.57	4447.29	0.80	2,277.3
2017	3551.73	1.25	180.75	138.05	454.04	366.62	4692.44	0.80	2,432.0
2018	3680.15	0.77	179.40	136.13	485.62	456.33	4938.41	0.78	2,589.0
2019	3579.11	0.72	174.39	167.30	560.77	498.01	4980.30	0.75	2,689.2
2020	3533.19	0.81	183.40	154.90	541.08	530.09	4943.48	0.75	2,533.8
2021	3882.89	0.77	129.66	169.60	545.86	615.28	5344.06	0.75	2,779.3
2022	4255.55	1.47	85.99	165.10	583.56	732.79	5824.45	0.75	2,990.8
2023	4661.47	1.44	112.67	172.57	482.59	813.01	6243.75	0.76	3,265.7

Table 3: Fossil fuel consumption (in PJ)

FY	Coal	Oil	Gas
2014	9,070.61	49.854	414.162
2015	9,402.75	37.716	420.714
2016	9,716.62	34.272	448.77
2017	10,597.8	31.29	464.688
2018	11,226.7	35.658	463.806
2019	11,240.7	36.834	428.064
2020	10,227.9	32.298	420.966
2021	12,370.1	36.246	394.59
2022	13,719	37.506	316.722
2023	15,022.8	29.988	352.8

Table 4: IPCC carbon emission factors (in Kilo tonne/PJ)

Fuel	Carbon emission factor
Coal	94.6
Oil	74.1
Gas	56.1

Table 5: CO_2 emissions from source (Kton)

FY	Coal	Oil	Gas	Total
2014	858,080.1	3694.2	23234.5	885,008.8
2015	889,500.2	2794.8	23602.1	915,897.0
2016	919,191.9	2539.6	25176.0	946,907.4
2017	1,002,549.6	2318.6	26069.0	1,030,937.2
2018	1,062,044.3	2642.3	26019.5	1,090,706.1
2019	1,063,371.4	2729.4	24014.4	1,090,115.1
2020	967,557.6	2393.3	23616.2	993,567.1
2021	1,170,210.7	2685.8	22136.5	1,195,033.0
2022	1,297,821.9	2779.2	17768.1	1,318,369.2
2023	1,421,154.0	2222.1	19792.1	1,443,168.2

And in other terms, subscript t indicates the value in year t and subscript 0, indicates values in the base year of calculation.

Since the emission factors prescribed by IPCC for the fossil fuels considered in this study have not undergone any changes between 2014 to 2024, the emission factor effect is effectively zero. Therefore, this study decomposes the carbon dioxide emissions from India's electricity generation sector into the other five effects only, namely- Activity effect, Electricity Generation Intensity effect, Production Structure effect, Fuel mix effect and Energy Intensity effect.

4.2. 2030 NDC evaluation for raising ambition

4.2.1. Data sources and methodology

India's updated NDC, submitted in 2022, inter-alia, laid down the following commitments- i) Achieving about 50% installed electricity capacity from non-fossil fuel sources by 2030 and ii) Reducing Emissions Intensity of its GDP by 45% by 2030, from 2005 level.

With sustained policy emphasis on achieving a timely energy transition, the 50% non-fossil fuel sources-based installed capacity target was achieved in June 2025. As per India's BUR 4, its gross domestic product (GDP) emission intensity reduced by 36% by 2020 compared to 2005 levels. In view of the rapid reductions achieved and the decarbonization efforts getting stronger, it is very likely that India will achieve 45% reduction in emissions intensity well before 2030. This leaves India with an opportunity to increase its ambition in the subsequent update of its NDC, which the current study tries to quantify.

This study uses the data for total GHG emissions and GHG emissions per capita in 2005, 2015, 2020 and 2023 from the European Database for Global Atmospheric Research (EDGAR)'s 2025 report (Crippa et al., 2025) to calculate GDP data used by EDGAR in this report, since ―WB (2025), data of GDP PPP, (constant 2017 international $) (expressed in 1000 US dollar, and adjusted to the Purchasing Power Parity of 2017) for 1990-2024, World Bank, July 2025‖ used by EDGAR could not be traced online. The GDP numbers for above mentioned years were used to project the GDP value in 2030. Assuming 45% reduction in emissions intensity in 2030, emissions intensity was calculated for 2030, which was multiplied with the projected GDP in 2030, to get the GHG emissions level in 2030 based on the 45% reduction target. One point worth noting here is that the data available from EDGAR and calculated based thereon is effectively for a calendar year, rather than financial year used for FY 2014-2023 analysis. However, it is expected that the variation arising due to replacement of the first 3 months of the subsequent year with those in the current/base year would not lead to any significant changes that could disrupt the calculations or results. Further, the use of a single period decomposition instead of the time—series decomposition, would further minimize any possible mis-reading of decomposition results.

This study assumes three possible upgrades to the NDC target-

i) NDC Upgrade 50- Increasing the emission intensity reduction target to 50% by 2030
ii) NDC Upgrade 55- Increasing the emission intensity reduction target to 55% by 2030
iii) NDC Upgrade 60- Increasing the emission intensity reduction target to 60% by 2030.

The Emissions Intensity of GDP (EIGDP) for different years and scenarios, compatible emission levels for each scenario and additional GHG emission reductions needed, compared to 2023 levels, are tabulated in Table 6.

Further, the share of carbon emissions in GHG emissions was calculated using EDGAR data, which was subsequently used together with the 2023 electricity generation emissions data calculated by this study to calculate the share of electricity generation sector in total carbon emissions in India. The calculated values are given below in Table 7:

Using the share of CO_2 in total GHG emissions and share of electricity generation in total CO_2 emissions, the emission reduction targets under NDC Upgrade 1-3 Scenarios are broken down into assumed targets for emission reductions from the electricity generation sector as follows:

Electricity generation emissions target=Total GHG reduction target * 71.67% (CO_2 share in total GHG emissions) * 47.88% (share of electricity generation in CO_2 emissions)

Table 6: EIGDP in NDC scenario, various NDC Upgrade scenarios and GHG emission reductions needed

Year	EIGDP (kg CO_2eq/1000 USD)	Emission (Mton)	GDP (USD trillion)	GHG reduction needed compared to 2023 (Mton)
2005	471.12	2111.74	4.48	-
2015	384.20	3310.46	8.62	-
2020	333.48	3461.05	10.38	-
2023	314.46	4206.33	13.38	-
2030-NDC	259.12	4172.80	16.10	-33.53
NDC Upgrade 50	235.56	3793.46	16.10	-412.87
NDC Upgrade 55	212.00	3414.11	16.10	-792.22
NDC Upgrade 60	188.45	3034.77	16.10	-1171.56

Table 7: Shares of electricity sector in CO_2 emissions and CO_2 in GHG emissions in 2023

Parameter	Emissions (Mton), shares (%)
India GHG	4,206.3
India CO_2	3,014.5
CO_2 share	71.67%
Electricity emissions 2023	1,443.2
Electricity share in CO_2	47.88%

Table 8: Carbon emission reduction targets for electricity generation (compared to 2023)

Year	GHG reduction target (Mton)	Electricity CO_2 reduction target (Mton)
2023	NA	NA
2030-NDC	−33.53	−11.50289586
NDC Upgrade 50	−412.87	−141.6581138
NDC Upgrade 55	−792.22	−271.8133317
NDC Upgrade 60	−1,171.56	−401.9685497

The CO_2 reduction targets thus calculated are available in Table 8.

Separately, four different scenarios were created to reflect possible changes in the overall electricity generation mix in 2030. The estimates for source-wise generation are arrived at by assuming different levels of changes in the generation from each source, taking the generation data from 2023 as reference. Emissions factors were assumed to remain unchanged from 2023. The four scenarios based on electricity generation mixes assumed in this study are detailed in Table 9. For oil generation, which is assumed to be negligible, for the sake of LMDI decomposition, a very small non-zero value for oil-based generation is assumed.

The electricity generation data for each scenario, based on assumptions made therein, and the original data for the reference year (2023 in this case, as it is the latest year for which actual data is available) are tabulated below in Table 10.

Energy Intensity values for generation from each fossil fuel were assumed to improve by 10% in 2030, considering that technological improvements could lead to similar improvements by 2030. The energy intensity values for 2023 and the assumed values for 2030 are listed in Table 11.

The consumption of fossil fuels for generation under each scenario calculated by multiplying the generation value with the energy intensity value, is given in Table 12.

Table 9: Generation mix scenarios for 2030

Generation scenario	Assumption
2030 GenScen 1	Coal and Gas generation increases by 10% each; Hydro, Nuclear and Renewable generation increase by 50% each; Oil share is negligible
2030 GenScen 2	Coal and Gas generation remains the same as 2023; Nuclear generation increases by 75%, Hydro power by 50% and Renewable power by 100%; Oil share is negligible
2030 GenScen 3	Coal and Gas generation remains the same as 2023; Nuclear generation increases by 100%, Hydro power by 50% and Renewable power by 200%; Oil share is negligible
2030 GenScen 4	Coal generation decreases by 10%, Gas generation increase by 20%, Nuclear generation increases by 75%, Hydro power by 50% and Renewable generation by 300%; Oil share is negligible

Emissions factors used remain unchanged from the LMDI decomposition for FY 2014-2023. Carbon emissions under each scenario were calculated by multiplying fossil fuel consumption with respective carbon emission factors and changes in emission levels were also calculated compared to 2023 levels. These results are available in Table 13.

It can be seen that GenScen4 scenario achieves the highest reduction of carbon emissions from 2023 levels. The total generation under this scenario is also the closest to the optimal generation (~2440 BU or 8784 PJ) estimated by the Central Electricity Authority for FY 2029-30 (Central Electricity Authority, India, 2023) and the central estimates for electricity demand (2254-2533 TWh or 8114-9118 PJ) calculated by The Energy and Resources Institute (Spencer and Awasthy, 2018). Achieving reductions beyond this level seems highly unlikely since this scenario already assumes renewable power (non-hydro) growing by 300%, nuclear power and hydropower growing by 75% and 50% respectively along with coal-based generation decreasing by 10% and gas-based generation increasing by 20% to ensure sufficient grid stability in adverse situations. The assumptions under this scenario, though ambitious, are sufficiently realistic to achieve, assuming concerted policy-led progress ahead, primarily focusing on translating renewables-based capacity to renewables-based generation. It is fair to assume that other energy sub-sectors would achieve their share of reductions too, given that emissions intensity reduction targets for four energy-intensive sectors-aluminum, cement, chlor-alkali, and pulp and paper- have already been notified

Table 10: Source wise electricity generation (PJ)

Year	Coal	Oil	Gas	Nuclear	Hydro	Renewable	Total	Thermal share (%)
2023	4,661.47	1.44	112.67	172.57	482.59	813.01	6,243.75	0.76
2030 GenScen 1	5,127.61	0.00	123.93	258.86	723.89	1,219.51	7,453.81	0.70
2030 GenScen 2	4,661.47	0.00	112.67	302.00	723.89	1,626.01	7,426.04	0.64
2030 GenScen 3	4,661.47	0.00	112.67	345.15	723.89	2,439.02	8,282.19	0.58
2030 GenScen 4	4,195.32	0.00	123.93	302.00	723.89	3,252.02	8,597.17	0.50

Table 11: Energy intensity values for fossil fuel

Year	Coal	Oil	Gas
2023	3.22	20.77	3.13
2030 (10% improvement)	2.90	18.69	2.81

Table 12: Consumption data for fossil fuels (PJ)

Year	Coal	Oil	Gas
2023	15,022.77	29.99	352.80
2030 GenScen1	14,872.54	0.00	349.27
2030 GenScen 2	13,520.49	0.00	317.52
2030 GenScen 3	13,520.49	0.00	317.52
2030 GenScen 4	12168.44	0.00	349.27

under the compliance mechanism of the Carbon Credit Trading scheme. Targets for five other sectors are expected to be notified by the end of 2025 (Internation Carbon Action Partnership, 2025). Adoption of Electric vehicles and cleaner substitutes for aviation mad maritime transport, Rooftop solar scheme, energy conservation codes and energy efficient appliances and usage in residential and commercial sectors, as well as gradual expansion of compliance component of the Carbon Credit Trading System to cover the entire energy sector are expected to accelerate emissions-intensity reduction of the energy sector, which alone accounts for more than three-fourth of the total GHG emissions. As per shares available in India‘s 4th Biennial Update Report (Ministry of Environment, Forest and Climate Change, India, 2024) submitted to the United Nations Framework Convention on Climate Change, carbon dioxide accounted for more than 97% of all GHG emissions from energy sector. For other sectors of the GDP, India is pursuing a wide range of initiatives, which are outside the scope of this study.

GenScen 1 scenario fails to achieve any significant emissions reduction, compared to the actual 2030 NDC based sectoral target and it fails to achieve desirable generation levels too. While GenScen 2 and GenScen 3 scenarios achieve similar emission reductions compared to 2023, GenScen 3 scenarios achieves a substantially higher electricity generation level, which is equally important to meet estimated electricity demand. While this could be a feasible scenario under low electricity demand growth, since GenScen 4 achieves higher emission reductions with reasonable additional ambition, while generating enough electricity to meet projected demand, this study assumes it to be an ideal target scenario for 2030 for enhancing its NDC target. Upon comparison, it is seen the carbon emissions reductions achieved under this generation scenario (272.4 Mt) are almost identical to the electricity generation carbon emission targets under NDC Upgrade 55 scenario (271.8Mt). Based on this observation and assuming achievements in electricity generation (largest emitter) could be replicated in other sectors, this study suggests that in line with its sustained climate ambition, India can upgrade its emissions intensity target to 55% by 2030 from the existing 45% target, at the time of submission of its NDC 3.0, expected soon. The target for 2035 in NDC 3.0 could be influenced by the actual enhancement in the 2030 target. In the results section, this study uses LMDI to analyse the major drivers of changes in emissions for the period 2023 to 2030 (under GenScen4 scenario).

5. RESULTS AND DISCUSSION

5.1. LMDI Decomposition for 2014-2023

Figure 1 shows the overall change in carbon emissions from the electricity generation sector between FY 2014 to FY 2023. The carbon emission increased from about 885 Million tonnes in FY 2014 to about 1443 Million tonnes in FY 2023. This is a net increase of more than 558 Million tonnes CO_2 over the entire period. The emissions have increased steadily except for FY 2019 when they showed some stagnation and for FY 2020, when they decreased due to the COVID19 induced lockdown. The result of the LMDI decomposition of individual effects is contained in Table 14.

Table 14 lists individual effects on change of carbon emissions between the financial years mentioned in the column titled ―Period‖. As is evident from the decomposition results tabulated above, Activity effect has been the single most significant contributor to increase in CO_2 emissions from India‘s electricity sector during the period of study i.e. FY2014-FY2023. It has resulted in an increase in emissions by 568 Million tonnes during the study period. It is on the expected lines since the Indian GDP grew from about 1.95 trillion USD (Constant 2015 prices) in 2014 to about 3.27 USD (Constant 2015 prices) in 2023. Figure 2 depicts the levels of GDP in each financial year and the activity effect during relevant intervals. In line with India‘s economic growth, the total electricity generation also increased from about 4020 PJ in 2014 to about 6243 PJ in 2023. Thermal generation also increased from about 3160 PJ to about 4774 PJ during the same period, which explains the increase in emissions. The only reduction of emissions due to activity effect is observed between FY2019 to FY2020,

Table 13: Carbon Emissions (Kton) in reference year and various scenarios; Reductions needed in Mton

Year	Coal	Oil	Gas	Total	Reduction from 2023 achieved (Mton)
2023	1,421,154	2,222.11	19,792.08	1,443,168.23	0
2030 GenScen1	1,406,942.5	0.138	19,594.15	1,426,536.79	−16.63
2030 GenScen 2	1,279,038.6	0.138	17,812.87	1,296,851.64	−146.31
2030 GenScen 3	1,279,038.6	0.138	17,812.87	1,296,851.64	−146.31
2030 GenScen 4	1,151,134.8	0.138	19,594.15	1,170,729.07	−272.43

Table 14: LMDI decomposition of CO_2 emissions from electricity generation in India from 2014 to 2023 (All effect values in $KtCO_2$)

Period	ΔAct	ΔEGI	ΔPS	ΔFM	ΔEI	ΔTotal
2014-2015	69,259.67	−29,263.50	24,377.53	−3,890.28	−29,595.22	30,888.21
2015-2016	73,882.19	−21,333.79	−3,961.84	−557.29	−17,018.81	31,010.46
2016-2017	64,976.30	−11,945.65	−10,554.06	108.34	41,444.84	84,029.77
2017-2018	66,327.16	−12,143.78	−18,819.65	−93.72	24,498.89	59,768.89
2018-2019	41,417.38	−32,206.40	−39,602.65	−110.33	29,911.07	−590.94
2019-2020	−61,958.56	54,232.19	−2,534.80	−1,338.70	−84,948.15	−96,548.03
2020-2021	100,907.75	−15,893.68	−1,443.54	8,959.54	108,935.84	201,465.92
2021-2022	92,076.72	15,996.53	−8,953.00	7,475.62	16,740.33	123,336.21
2022-2023	121,321.23	−25,402.20	35,091.47	−2,215.24	−3,996.27	124,798.99
Total	568,209.82	−77,960.29	−26,400.54	8,337.96	85,972.53	558,159.48

Figure 1: Annual carbon emissions from electricity

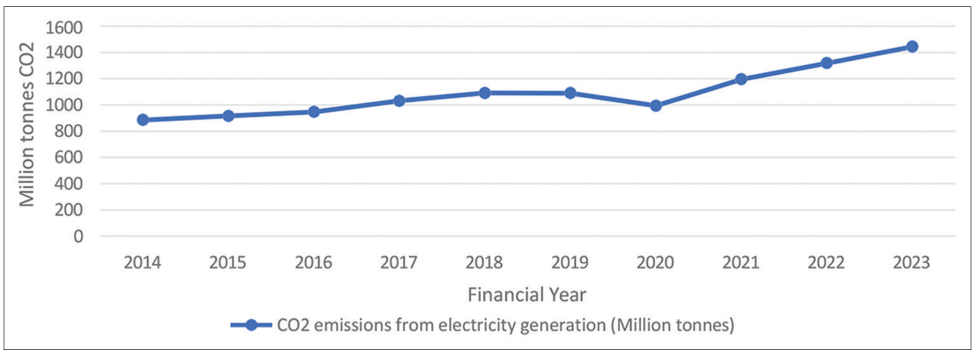
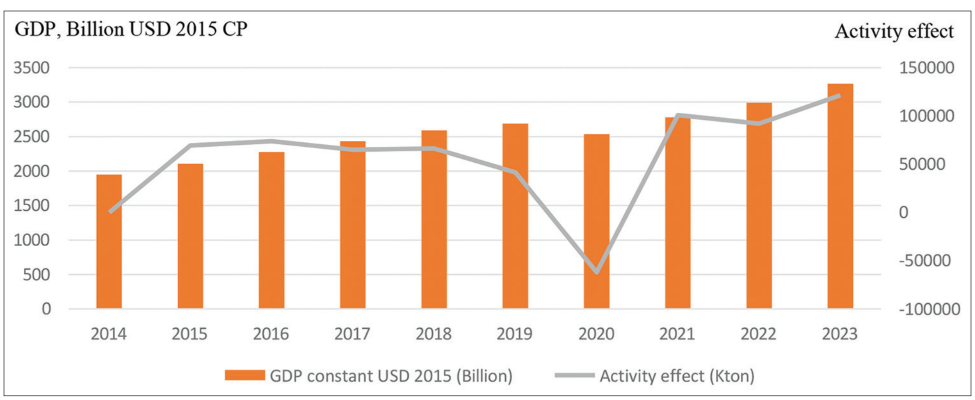


Figure 2: Activity effect versus GDP



which resulted from negative GDP growth in FY 2020 due to the COVID-19 induced nationwide lockdown and related economic disruptions. The sharp increase between FY2020-FY2021 can be attributed to the strong economic rebound post COVID-19. The overall increase in Activity effect could be attributed to several Government policies and initiatives like the Make in India Scheme to attract Foreign Direct Investment (2014), Digital India Mission to improve digital infrastructure(2015), Sagarmala Project for ports-led industrialization(2015), Bharatmala Project to improve road connectivity (2017), National Infrastructure Pipeline to develop world-class infrastructure (2019), Production Linked Incentives schemes for key sectors (2020), the Prime Minister Gati Shakti Master plan for improvement of multimodal connectivity, logistics efficiency (2021) and significant capital investment outlays in annual union budgets.

Electricity Generation Intensity effect is found to be the single largest contributor to a decrease in carbon emissions between

FY 2014 to FY 2023. The effect is negative for most time-series intervals, owing to a steeper growth in the GDP as compared to electricity generation over annual time intervals as well as through the entire period of study. A major exception is the period between FY 2019 and FY 2020, which saw the GDP shrink more than the relatively smaller reduction in electricity generation in FY 2020 during the COVID19 pandemic, resulting in an increase in emissions. The effect was also positive during FY 2021 to FY 2022, owing to an increase in total electricity generation growth coupled with a decrease in the GDP growth rate. DDUGJY and Saubhagya schemes for universal electrification and improving living standards have led to an increase in electricity demand and hence, electricity generation too in order to meet this demand. However, policies conducive to economic development have resulted in GDP growth across sectors, even those dependent majorly on primary fuels rather than electricity. The resultant effect is a gradual improvement in electricity generation intensity per capita with only some years as exceptions. A comparison of the Electricity Generation Intensity effect and Electricity Generation Intensity (Generation/GDP) levels over different financial years is given in Figure 3 below.

The Production Structure effect (thermal electricity share in total electricity production) is negative for the overall period of study as well over most of the annual intervals, indicating its role in decreasing of sectoral emissions. It is positive for the period from FY 2014 to FY 2015 due to a drop in clean electricity generation coupled with an increase in the production of thermal electricity. This was due to a significant year-on-year decrease of 6% (South Asia Network on Dams, Rivers and People, 2016) in hydropower generation caused by lesser rainfall experienced in some regions of the country coupled with an increase in electricity demand which was likely met with by increased thermal power generation. A similar trend is seen between FY 2022 and FY 2023, primarily caused by a 16% drop in hydropower generation in FY 2023 due to low rainfall levels leading to lowest reservoir levels in 5 years (Reuters, 2024). The effect for other annual periods remains negative, in line with the growth of renewables-based generation and an overall decline in the share of thermal power during these periods. The decrease is notable for FY 2019 over FY 2018 due to a decrease in thermal power share by almost 2.8%. The ambitious non-fossil fuel based installed capacity targets, Solar Parks scheme, Rooftop Solar scheme, Renewable Purchase obligations and other programs for the promotion of renewable energy-based production capacity have been instrumental in the gradual reduction in the share of thermal generation. Figure 4 plots the Production Structure effect for each annual interval against the share of thermal electricity in total generation for each financial year.

The Fuel mix effect, though overall positive for the entire period from FY 2014 to FY 2023, is relatively insignificant. It is generally negative and low in magnitude for most intervals. However, for the periods from FY 2020 to 2021 and 2021 to 2022, it leads to relatively significant positive values due to an overall increase in share of coal in thermal power production. It could be attributed to the post-COVID19 demand recovery, met most likely through domestic coal in view of its relatively ready availability and thermal power‘s reliability. Even as India has implemented an ambitious energy transition and in 2022, set a target of increasing

Figure 3: EGI effect versus EGI

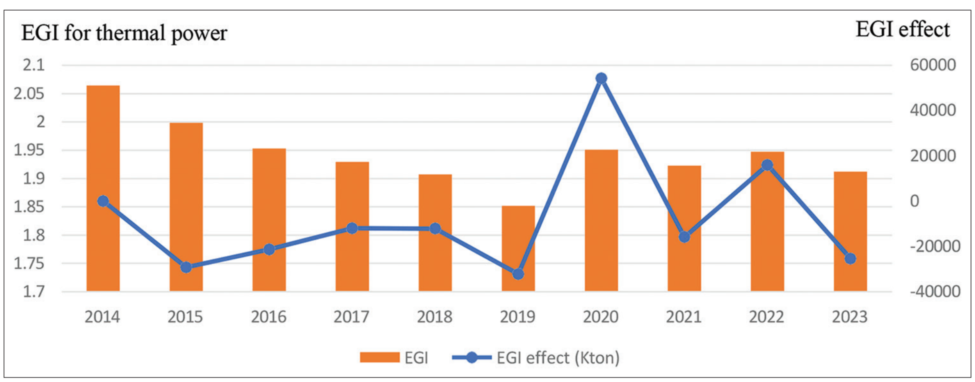


Figure 4: PS effect versus Share of thermal electricity

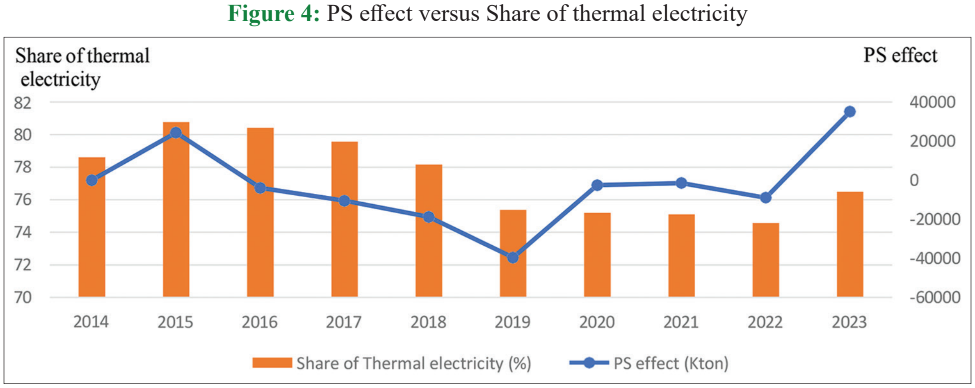
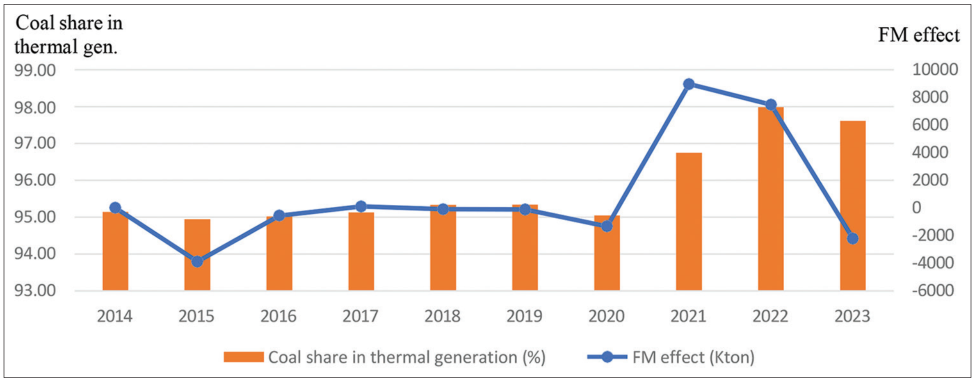


Figure 5: FM effect versus Coal share in thermal generation



the share of gas in its energy mix to 15% by 2030, gas-based power generation has remained consistently low during the period of this study. Targeted policies for shifting from coal-based generation capacity to relatively cleaner gas-based capacity are highly unlikely at the moment. Oil is likely to play no role in generation in a span of few years. Fuel mix is, therefore, not expected to have a major effect on reduction of emissions in the electricity generation sector in the near future. A comparison of the Fuel Mix effect and the share of coal in thermal generation is provided in Figure 5.

Energy Intensity effect is the second largest contributor to carbon emissions increase during FY2014-FY2023. From FY 2014 to 2015 and subsequently FY 2016, intensity effect is negative, primarily due to a decrease in the energy intensity of production from coal. Possible reasons for this could include improving thermal efficiency of coal-based power plants and improved average calorific value of coal (Central electricity Authority, India, 2024), strengthened further by adequate availability of coal during this period due to higher production by Coal India Limited (J.M. Baxi Group, 2018). Between FY 2019 and 2020, there is a sharp decline due to decreased energy intensity of coal-based production. This could be due to the fall in electricity demand during the COVID 19 pandemic, which would have resulted in more of high-efficiency generation being used to supply to the grid. The effect is also negative for FY 2023 due to slight decreases in energy intensity of all three fossil fuels-based production, primarily due to adequate coal stock availability (Press Information Bureau, 2023b) and improvement in Plant Load factor for coal-based plants (Ministry of Power, India, 2023). For the rest of the periods studied, the effect remains positive. Notably, there is a huge jump of 108,935 ktCO_2 in FY 2021 due to an increase in energy intensity of production for all three fossil fuels. This could be attributable to the increased electricity demand due to the economic rebound post the COVID19 pandemic leading to sourcing of power from less-efficient plants too, addition of eight thermal power plants with a capacity of 4,485 MW in 2021-22 (Pande et al., 2022). At the sectoral level, initiatives promoting improved coal allocation to the power sector, phasing down of old/inefficient capacity and increasing Plant Load Factors could have a bearing on energy intensity. Figure 6 shows the relationship between the Energy Intensity (EI) effect for annual intervals and the overall energy intensity of thermal production for each financial year.

Table 15: Contribution of individual effects to the total effect on carbon emission

Effect	ΔAct	ΔEGI	ΔPS	ΔFM	ΔEI	ΔTotal
Contribution toΔTotal (%)	101.80	−13.97	−4.73	1.49	15.40	100.00

The total effect on carbon emissions between FY2014-FY2023 is an increase of about 558.2 Million tonnes of CO_2. The nature and magnitude of contribution of individual effects to the total effect is given below in Table 15.

5.1.1. Key insights from results for 2014-2023

Activity effect alone is equal to about 102 % of the net increase in emissions, indicating that Government policies have been able to spur economic growth over the years, but the growth has been fairly carbon-intensive, even though emissions-intensity of the GDP has decreased steadily. Electricity Generation Intensity effect is equal to about (-)14 % of the net increase in emissions, pointing to a relatively slower growth in electricity generation (and demand) as compared to the national GDP, thereby indicating that electrification of the economy is a work in progress. Production Structure effect is equal to about (-) 4.7% of the net emissions increase, confirming a decrease in the share of thermal electricity generation due to ambitious energy transition policies, but at a relatively slower pace than expected. The Fuel mix effect is equal to ~1.5% of total emissions increase, confirming that coal has continued to be the fossil fuel of choice for power generation in India. The Energy Intensity effect is about 15.4% of the total effect, implying that a considerable share of old/inefficient plants continue to be operated, even as new more-efficient plants have been added to the fleet. While the emission factor effect had no impact on carbon emissions due to no change in the fuel-specific emission factors prescribed by IPCC during the period of study, it can be expected to play a major role in driving down emissions in the years to come through technological advancements, especially Carbon Capture, Utilization and Storage (CCUS) technologies. While CCUS viability is awaited, Biomass co-firing mandates can be increased and cofiring with Green Hydrogen can be explored.

5.2. LMDI Decomposition for 2023-2030 (GenScen4)

In Section 4.2, it was found that GenScen 4 scenario of generation mix in 2030, was compatible with projected electricity demand as well as compatible with emissions reductions required under the

Figure 6: EI effect versus Thermal power EI

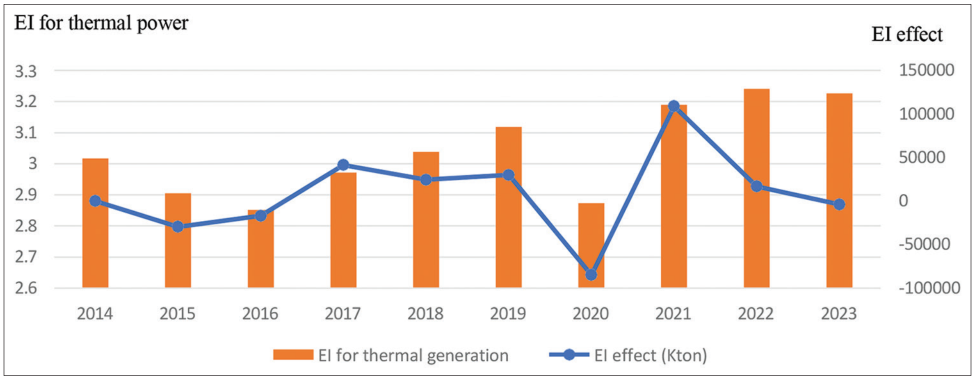


Table 16: LMDI decomposition of emissions under 2030 GenScen4 scenario compared to 2023

2023-2030 GenScen 4	Activity effect	EGI effect	PS effect	FM effect	EI effect	Total effect
Value	241,498.98	174,734.00	−546,928.38	−4,635.09	−137,108.67	−272,439.16

scenario where the emissions intensity related NDC target could be enhanced to 55% from the existing 45%. The result of LMDI decomposition of emissions change from 2023 to 2030 GenScen 4 is given below in Table 16.

Under the GenScen 4 scenario, carbon emissions from the electricity generation sector in India would decrease by more than 272 Million tonnes. As evident from the decomposition, both the Activity effect and Electricity Generation Intensity (EGI) effect would strongly drive an increase in emissions, accounting for an increase by more than 241 Million tonnes and 174 Million tonnes of carbon emissions respectively. This is different from FY 2014-2023 decomposition where EGI effect causes a net reduction in emissions. The Production Structure effect is the single biggest inhibitor of emissions, with its magnitude (546 Million tonnes) greater than both GDP effect and EGI effect combined. Fuel mix effect is insignificant, because of the share of coal in thermal generation remaining more or less the same. Energy Intensity (EI) effect also leads to significant avoiding of emissions to the tune of 137 Million tonnes. Emission factor has no effect since emission factors have been assumed to remain the same as in 2023.

In view of the results, it is seen that the bulk of reductions in 2030 (under the GenScen 4 scenario or similar scenarios) would come from an increase in the share of non-fossil fuels in generation to about 50% of total generation. Energy Intensity improvements (assumed to be 10% in 2030 compared to 2023) are likely as old plants are shut down and new more efficient plants become operational, leading to a decrease in emissions. The significant and positive GDP effect indicates that policies would need to continue to evolve, in order to try and decouple economic growth and emissions. The positive value for EGI effect indicates that growth in electricity generation is expected to outpace the growth in GDP. Deployment of CCUS technologies can lead to an effective decrease in emission factor and hence, lead to decrease in overall emissions and the emission factor effect can become prominent in the years to come, though this study has not taken it into account for FY 2030.

6. POLICY IMPLICATIONS

Based on the findings of the LMDI decompositions and India‘s stated priorities, this study proposes the following four policy approaches that India would need to adopt to efficiently reduce carbon emissions from electricity generation, while acknowledging the impact of certain policies on multiple effects of the LMDI analysis:

1) The Activity effect due to GDP growth is the single largest driver of emissions growth from the electricity sector between 2014-2023. India‘s GDP is expected to grow at a decent rate till 2030 and even beyond. In this context, it is important to decouple economic growth from electricity generation emissions. This could be done through market mechanisms that create incentives for all sectors of the economy to reduce their emissions, by shifting from fossil fuels to other cleaner alternatives or electricity sourced from non-fossil fuels as and when possible, and by enhancing energy efficiency. The PAT scheme is being implemented for highly energy-intensive industries in India to this effect. The rate-based India Emission Trading System (ETS), based on performance benchmarks for emissions intensity under the Carbon credit Trading Scheme, is being built on the PAT scheme with the first phase starting from 2026. This market can be expected to accelerate the GDP- emissions decoupling. Thermal power plants are currently not included in the nine sectors to be covered in the first phase. The ETS coverage needs to be expanded to include thermal power plants, with ambitious benchmarks set for them since the electricity generation sector is the single largest source of carbon emissions from energy use in India.
2) Electricity generation is expected to grow at a faster rate than the GDP between 2023 to 2030 if India were to target a generation mix similar to the one proposed in GenScen4 scenario of this study. The trend was opposite for 2014 to 2023. In order to reduce emissions attributable to the electricity generation intensity effect, even as GDP growth continues, reducing electricity demand through improvements in the overall energy efficiency of end-use applications is crucial. Existing energy-efficiency schemes run by the BEE under the

National Mission for Enhanced Energy Efficiency (NMEEE) need to be strengthened. High-impact policies targeting demand side management could include strengthening and stricter time-bound implementation of the Energy Conservation codes for residential and commercial buildings, inclusion of more categories of appliances under the Standards and Labeling Program with provisions for mandated phasing out of inefficient but widely-used appliances, incentives for accelerated adoption of decentralized renewable energy applications implementation of Time-of-Use pricing and, large scale implementation of Smart meters coupled with Internet of Things and Artificial Intelligence for efficient electricity usage, to name a few. Rationalization of electricity tariffs is another separate measure that would be needed in India to promote efficient use of electricity. This could be made more effective by including provisions for annual reviews and revisions along with phasing out of subsidies, thus ensuring an organic process.

3) Ensuring energy security has been a high priority for India, particularly since the volatility of energy supply chains came to the fore in view of the COVID19 pandemic and geo-political tensions affecting the world since early 2020s. The persisting issues pertaining to intermittency and variability of renewable power necessitate the need to ensure adequate generation capacity from other sources in order to ensure grid stability and uninterrupted supply, at least in the near future. Hydropower has its own challenges associated with its possible environment impacts and the Central Electricity Authority (CEA) estimates only a marginal increase in hydropower capacity by FY 2029 in its optimal generation mix for 2029-2030 report. Nuclear power faces the problem of public acceptability and possible safety risks. While the Government has announced a Nuclear Energy Mission in the financial budget for the FY 2025-26 with a target of achieving 100 GW of nuclear based power capacity by 2047, a sharp increase in installed capacity by 2030 is unlikely. Natural gas, though cleaner than coal, poses the same old challenge of energy security for India since it imports almost all of its natural gas. So, India is expected to rely on a substantial coal-based generation capacity in 2030 and beyond. Even though new capacity additions of coal-based generation are expected to be of super-critical or ultra super-critical type, thereby leading to a decrease in carbon emissions due to the energy intensity effect, the residual carbon emissions would still be significant. Even in the highly ambitious GenScen4 scenario considered in this study for 2030, though coal-based generation is assumed to drop by 10% compared to 2023 level, it still accounts for about 4195 PJ or about 1165 BU of generation. Hence, to balance energy security needs with its energy transition ambitions, India would need to invest heavily in CCUS technologies to ensure economic viability for implementation in coal-based power plants as soon as practically possible. It can enable managing any shortfall in ambitiously enhanced non-fossil fuel-based generation targets by 2030 with coal-based generation without allowing emissions to increase, offering much needed flexibility to the power regulating agencies. While CCUS is awaited, coal co-firing with green hydrogen and biomass can also be a viable option for reducing emissions intensity, although at a smaller level than possible with CCUS. This provides scope for India to increase it biomass-cofiring mandates and explore mandates for co-firing with Green Hydrogen or its derivatives. The―Green terminology is very important here since India's national mission focuses only on green hydrogen. The above suggested policy measures would play a key role in inducing emission reductions through Emission Factor improvements.

4) A 10% energy intensity improvement in the 2030 GenScen4 scenario in this study leads to the avoidance of more than 137 Million tonnes of carbon dioxide emissions. Between 2014-2023, EI effect was responsible for an increase in emissions by 85 Million tonnes. Phasing out of old thermal plants and adoption of latest generation technologies available from time to time is the pressing need of the hour to realize intensity gains and reduce the energy intensity effect. A policy component targeting improvement of quality of domestic coal and enhancing higher-quality coal supply for the generation sector can also help in this regard. The inclusion of thermal power plants under the compliance mechanism of the Carbon Credit Trading System (CCTS) and notification of ambitious targets for the sector, expected soon, can really accelerate intensity effect driven reductions, by providing an enhanced incentive to the sector. Further, targeted Research and Development programs to devise more energy-efficient and less energy-intense coal-based generation technologies tailored to meet India-specific challenges need to be sponsored by the Government as other major economies continue to reduce their dependence on coal and would have little incentive to work on decarbonizing coal-based generation. This would be important in order to ensure that India can continue to use coal-based thermal power plants for strategic reasons.

5) The production structure effect is already contributing to reducing carbon emissions from electricity generation as the share of thermal power in total generation has reduced from FY 2014 to FY 2023. In the 2030 GenScen 4 scenario, this effect is the single largest driver of a decrease in emissions. This would imply a greater translation of installed capacity into actual generation from non-fossil fuels sources, particularly renewables. The shift from coal-based generation to renewables-based generation can be accelerated if Energy Storage Systems (ESS) achieve technology maturity and economic viability earlier than expected. Large scale deployment of ESS can help to achieve the true potential of renewable power while ensuring grid stability, therefore, reducing the need for expansion of coal-based capacities. While immediate focus is on Battery Energy Storage Systems (BESS), there is a need to pursue other emerging ESS technologies like Gravitational and Thermal Energy storage as well as Supercapacitors in medium-term. While pilots on various such technologies are already under implementation globally as well as in India, strategies to mobilize private capital and blended finance need to be developed to facilitate the large-scale investments needed for continuous R&D for more efficient and cost-competitive storage technologies as well as the simultaneous deployment alongside renewable power projects. Another likely problem currently faced by renewable power generation is the increasing mismatch

between the installed capacity and the infrastructure for its evacuation. A 2025 report (Sharma et al., 2025) suggests that more than 50 GW of the installed renewables-based generation capacity remained stranded across India as of June 2025 primarily due to issues related to availability of required transmission infrastructure and utilization of the existing one. A coordination committee of all relevant agencies may be put in place to hold stakeholder consultations and ensure quick redressal of any issues hampering renewable energy generation and supply.

6) Based on the findings and assuming that emission reduction in electricity generation sector would be fairly reflective of potential emission reductions achievable by other sectors (based on their own existing levels), this study recommends that India can consider enhancing its NDC target of reducing emissions intensity of its GDP by 45% by 2030 (compared to 2005 level) to a more ambitious one of 55% reduction. A more ambitious target would reinforce the energy transition currently underway and incentivize energy sub-sectors to decarbonize faster through the enhanced target in general, and specifically under the compliance mechanism under the Carbon Credit Trading System. The decarbonization of the electricity generation sector, in particular, will have positive spill-over effects in several other sectors which could intensify as the electrification of the economy is continually pursued. By accelerating the overall energy transition, India's Net Zero by 2070 target would, in all likelihood, come well within reach while achievement of ambitious targets now will provide a cushion in later stages where marginal abatement costs could be higher than current levels.

7. CONCLUSION

India's CO_2 emissions from the electricity generation sector have increased by over 558 Million tonnes between 2014 and 2023. The activity effect is the biggest driver of increase in carbon emissions from the electricity generation sector, consistent with high GDP growth rates clocked by India. Decoupling of the economy and emissions can lead to reduction of this effect. While electricity generation will be closely co-related to the projected significant growth in India's GDP in coming years, demand management techniques and energy efficiency policies can help reduce electricity demand growth, thereby creating the scope of accelerated reduction in electricity generation intensity. Energy Intensity effect has also led to increase in emissions, though at a much smaller scale as compared to activity effect. Retiring of old thermal units and transitioning to a fleet of plants based on new energy-efficient technologies can help bring down the energy intensity effect. Even then, CCUS deployment would be necessary to reduce emissions to align thermal electricity generation with energy transition and climate action targets. The fuel mix effect is responsible for a marginal increase in emissions, indicating that coal alone has been the main fossil fuel used for electricity generation over the study period. This is unlikely to change much in near future, primarily due to energy security considerations. Production share effect is the only driver responsible for reducing carbon emissions. However, in spite of the rapid growth in renewables based installed capacity between 2014 to 2023, the change in share of thermal power in overall electricity production has resulted in reducing carbon emissions by only about 26 Million tonnes, suggesting that renewables-based capacity additions are not translating into a commensurate increase in renewables-based generation. Technologies that support seamless renewable power integration with the grid need to be developed and promoted to address this issue. The emission factor effect, though having no effect, during the period of this study may have a significant impact in future as technological advancements to this end materialize.

In an ambitious scenario where, between 2023 and 2030, renewable generation grows by 300%, Nuclear and Hydro power grows by 75% and 50% respectively, coal-based generation drops by 10% while gas-based generation increases by 20%, while energy intensity for each fossil-fuel based generation improves by 10%, India could avoid 272 Million tonnes of carbon emissions from electricity generation by 2030. The scenario witnesses share of fossil fuels in total generation decreasing to about 50%, while building enough generation potential to match projected electricity demand with decent likelihood. In such a scenario, India is expected to reduce its emissions intensity of the electricity generation sector by up to 55% (compared to 2005 level). Following this benchmark, India can aim to reduce the emission intensity of its entire GDP by 55% by 2030, assuming other sectors would be able to achieve similar or even greater reductions based on their existing levels. This proposed ambition could turn into action if India updates its 2030 NDC target accordingly and provides necessary policy support for the wide range of actions needed. The target for 2035 in NDC 3.0 submission would depend significantly on the revision of the target for 2030.

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9. DECLARATION OF COMPETING INTEREST

The lead author of this study is a Section Officer in the Ministry of New and Renewable Energy of the Government of India. However, this study has been conducted by him entirely in his personal capacity as a Master's degree student at Hanyang University, where he is currently on study leave.

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