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Small States, Big Impact: A Review of Rising Greenhouse Gases Emission from the Energy Sector in India

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Abstract: Emissions of greenhouse gases (GHGs) are a prime concern that needs our attention, not only in megapolitan states but also in developing small states. The increase in GHGs-emission could lead to severe climate change scenarios and global warming. In India, it is measured that the energy sector (68.7%) accounts for a significant GHGs-emission, followed by agriculture (19.6%), industry (6.0%), land use change and forestry (3.8%), and waste sector (1.9%). This article aims to investigate temporal changes and trends in greenhouse gases (GHGs) emissions in the energy sector of India. We have used GHGs-emission as Carbon dioxide (CO_2) equivalent and compared the top per capita emitting states *versus* their total emissions and vice versa. Most of this increase has occurred in small states, where urbanisation, population growth, and economic expansion have been significant factors. Odisha and Maharashtra were listed as top-emitting states releasing more than 240 million tonnes of carbon dioxide equivalent ($MtCO_2e$), mainly through industrial energy and electricity-related emissions, respectively, followed by Chhattisgarh, Gujarat, Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, and West Bengal. In contrast, Chhattisgarh was recorded as the top per-capita emitting state, followed by Odisha. Among all the states studied, Lakshadweep has shown a significant trend in GHGs per capita reduction, while the other shows an increasing trend due to a lack of robust and effective legislation. This review will help to seek the attention of policymakers and the government towards the increasing emissions from the small states which are emerging in day to day life.

Keywords: GHGs; Energy; Urbanisation; Per-capita emissions; CO_2 equivalent.

Introduction

India, as a developing country, ranks third globally in greenhouse gas (GHGs) emissions, holding significance to climate change (CAIT, 2021). Its dense population and agroeconomic nature exacerbate the climate change impacts, driven by global warming (Griggs et al., 2002). The majority of emissions originate from agricultural and industrial sectors, with emerging sub-sectors also contributing significantly (Lamb et al., 2021). In 2015, India was among the early adopters of the Paris Agreement, aiming to limit global temperature rise to below 2°C, ideally 1.5°C (Savaresi, 2016). The agreement operates on a 5-year cycle, with countries submitting nationally determined contributions (NDCs) (Maljean-Dubois, 2016). Since then, 197 countries, including India, have ratified the agreement, necessitating regular updates of GHG-emission inventories (Eggleston et al., 2006). India, as a non-Annex-I country, commits to building its national inventory and reporting biennial updates to the United Nations Framework Convention on Climate Change (Government of India, 2015a).

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India, recently submitting its third biennial report in 2021, hosts four major biodiversity hotspots and abundant natural resources. Climate change poses increasing threats to the country's flora and fauna, driven by rising GHG emissions due to its vast and growing population. Severe climatic impacts include rising sea levels, changing monsoon patterns, storms, flooding, drought, biodiversity loss, and extreme water stress (Gupta et al., 2021). These factors negatively impact socioeconomic progress, particularly affecting the agriculture-dependent population. Previously, authors have reviewed the status of annual emissions of significant GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from the different sources combined and measured the emissions per capita in a million tonnes of carbon dioxide equivalent ($MtCO_2e$). The energy sector accounts for 70% of India's total GHGs-emissions, with coal dominating electricity generation (IEA, 2021). Energy consumption has grown steadily since 2000, with coal, oil, and biomass meeting 80% of the demand. Coal alone contributes 55% to the nation's electricity, with renewable sources making up 23%, hydroelectric dams 13%, and gas 7% (Kumar and Majid, 2020). Factors influencing GHGs production from water storage tanks include carbon and nutrient levels, soil type, rainfall, and land use (Kumar and Sharma, 2015). India ranks fifth globally in hydropower potential, with small and large hydropower projects contributing significantly (Singh, 2020). The country's per capita energy consumption and emissions are nearly half of the global average (Pata and Kumar, 2021). India's recovery from the COVID-induced recession witnessed rapid energy expansion, necessitating substantial infrastructure development to meet growing needs (IEA, 2021). The country's urban population growth could soon surpass China's, requiring infrastructure equivalent to Europe's power grid to sustain energy demands over the next two decades.

This article provides an overview of India's emerging energy sub-sectors and their contribution to GHGs-emissions. It discusses significant GHGs and their current concentrations in the atmosphere, drawing on recent Intergovernmental Panel on Climate Change (IPCC) and national reports. Additionally, it highlights state-wise emissions inventory data from various climate change action plans. It examines the emissions trends of top per capita emitting states relative to their total emissions, focusing on emerging sub-sectors. The article underscores the evolving landscape of emissions sources, previously overlooked but now significant contributors to state emissions.

Methodology and Data Base

This study employed a systematic literature review guided by the PRISMA 2020 statement (Page et al., 2021) to investigate the concentrations and temporal trend of potent GHGs in India, focusing on CO_2, CH_4, and N_2O and identifying major contributing states and subsectors within the energy domain.

Search Strategy and Data Sources

Relevant publications were retrieved from a comprehensive set of scientific databases, including Web of Science, Scopus, Google Scholar, Research Gate, and Springer Link, alongside official websites of international and governmental organisations such as the IPCC, the GHG Platform of India, the Centre for Study of Science, Technology and Policy, the World Resources Institute India, Climate Data Explorer, the Council on Energy Environment and Water, Ministry of New and Renewable Energy, Ministry of Environment, Forest and Climate Change, Central Electricity Authority, International Energy Agency, etc. The search strategy employed specific keywords and Boolean operators tailored to the study objectives (e.g., "CO_2 emission AND India", GHGs-emission AND Energy sector "GHGs mitigation NOT carbon capture," etc.).

Data Extraction and Analysis

Peer-reviewed articles, grey literature, reports, and legislative documents published between 2005 and 2018 were screened to extract data on GHGs-emission in India, particularly within the energy sector. The data included information on GHGs concentration, trends, sectoral contributions, and potential mitigation strategies. This data was then subjected to rigorous analysis to reveal temporal trends in GHGs-emission and identify the states and subsectors responsible for significant emissions. The analysis aimed to provide insights into the factors driving India's GHG emissions and inform potential mitigation strategies. The review helped to identify the states emerging as major emitters and the possible causes of their emission trends, in order to assist the government and policymakers in taking appropriate actions and regulatory changes to address the emissions.

GHGs-Emission and Sources

GHGs, such as CO_2, CH_4, and N_2O, constitute the majority of emissions, with CO_2 being the most dominant, despite CH_4 and N_2O being potent

contributors to global warming (Myhre et al., 2014). Each gas has varying radiative properties and global warming potentials (GWPs), with CO_2 having a GWP of 1, while CH_4 and N_2O have GWPs of 28 and 273, respectively, over a 100-year period. The lifetimes of CH_4 and N_2O are approximately 11.8 ± 1.8 and 109 ± 10 years, respectively, while CO_2's lifetime varies due to its exchange between different Earth systems (IPCC, 2023).

Anthropogenic activities since the Industrial Revolution have significantly increased atmospheric CO_2 concentrations, reaching 424 ppm in 2023, with annual increases occurring at a rapid rate (GML, 2023). CO_2 emissions stem largely from fossil fuel combustion, cement production, and deforestation (Xi-Liu et al., 2018). CH_4 concentrations have also risen sharply, primarily due to anaerobic decomposition and anthropogenic sources like coal mining, energy production, and agriculture (Kweku et al., 2018). According to the World Meteorological Organization, the atmospheric concentration of CH_4 has increased more than two and a half times from the pre-industrial level to the present, reaching approximately 1900 ppb in 2023 (GML, 2023). Similarly, N_2O concentrations have increased, mainly from natural and anthropogenic sources such as soil nitrogen compounds and industrial activities (Kweku et al., 2018; Jain et al., 2016). The estimated atmospheric concentration of N_2O in 2023 is 336.6 ppb, approximately 125% higher than the pre-industrial level (GML, 2023).

Major Emission Sectors in India

According to the GHG Platform-India and IPCC, the 2006 report states that the main sectors of GHGs-emission are industry, energy, waste sector, agriculture, and Land Use Change and Forestry (LUCF) (Eggleston et al., 2006) (Table 1). In India, it is measured that the energy sector (68.7%) accounts for a major portion of GHGs-emission than from agriculture (19.6%), industry (6.0%), LUCF (3.8%), and waste sector (1.9%) (Climate Links, 2019).

Energy Sector

India's increasing population, urbanisation and industrialisation emphasise a higher demand for energy production in different states. It is the largest dominating economic sector (Figure 1), constituting various sub-sectors. According to the IPCC (2006) (Eggleston et al., 2006), guidelines on emission from the energy sector are classified as follows: 1A: Combustion of fossil fuels and biomass, 1A1: Energy industries - Manufacturing of solid fuels, petroleum refining, and electricity generating are all energy-related enterprises, 1A2: Manufacturing industries - Non-ferrous metals, cement, food and beverage, iron and steel, non-specific industries, textile/leather, etc., 1A3: Transportation - includes road, navigation, aviation, and railways, 1A4: Other sectors – includes commercial, agriculture/fisheries, residential, and institutional, 1B: includes fugitive emissions, 1B1: include emissions from coal mining activities, 1B2: include emissions from oil and natural gas.

The revised IPCC methodology (2006) was utilised to estimate emissions for this sector. According to emission inventory records, the energy sector contributes 54 to 56% of total annual emissions (MoEFCC, 2015). Official inventories indicate that electricity generation is the largest polluting category, accounting for 42-44% of emissions in the last decade (GHG Platform-India, 2017). However, according to the World Resources Institute's Climate Analysis Indicators Tool (CAIT, 2021), energy emissions increased by 115% in

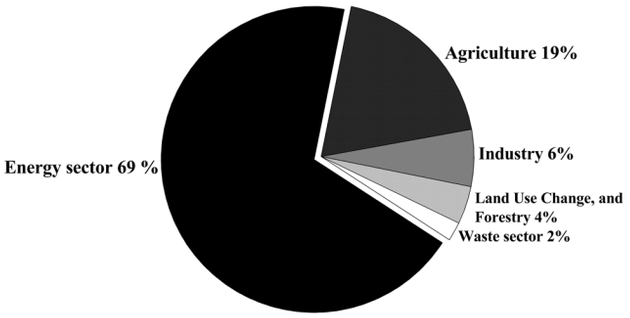

Figure 1: Sectoral share of emissions in India.

Table 1: Major GHGs-emission sector and sub-sectors in India

Sector	*Fugitive*	*Transport*	*Electricity*	*Others*
Sub-sector	Coal extraction and processing	Railways	Utility power plants	Agriculture
	Extraction of crude oil and natural gas, Refining and Distribution	Road	Non-utility (Industries) power plants	Residential
		Aviation		Commercial
		Navigation		Fisheries

Source: GHG Platform-India, 2017

2018 (~2455 $MtCO_2e$) from 2005 (~1141 $MtCO_2e$). International Energy Agency (IEA) data show that overall energy generation more than doubled between 1991 and 2018, with coal becoming dominant and hydropower less prevalent (IEA, 2021). Coal accounts for 74% of electricity output, while hydropower accounts for 11%, according to IEA figures (Figure 2). Emissions from coal and lignite-based power facilities have been steadily increasing, while emissions from other sources have decreased. The carbon intensity of Gross Domestic Product (GDP) decreased by 12% from 2005 to 2010. Emissions from coal-fired power plants increased by 7.8% from 2005 to 2018, contributing approximately 99% of total emissions. Emissions from gas-fired captive power plants increased at a Compound Annual Growth Rate (CAGR) of 2.5%, while emissions from diesel-fired captive power plants decreased at a CAGR of 4.14%. CO_2equivalent emissions for CH_4 and N_2O were computed using IPCC Assessment Report 6 (AR6) based on their global warming potential. Fuel combustion dominates emissions in the energy sector, followed by electricity, fugitive, and transport emissions, as shown in Table 2.

$MtCO_2e = MtCO_2$emissions * GWP of CO_2+MtN_2O emissions * GWP of N_2O + $MtCH_4$ emissions * GWP of CH_4

State-Wise GHGs Estimation

According to the IPCC, energy sector emissions comprise electricity generation, industrial energy use, transportation, fugitive (fuel production), and other sectors (residential, commercial, agriculture/fisheries). Each sub-sector is further divided into various divisions based on the activities within the sector. Electricity generation is the primary contributor to energy-related emissions, accounting for 83% in 2018. India ranks third in electricity generation and fourth in consumption (Anantha and Malik, 2017). The total installed capacity

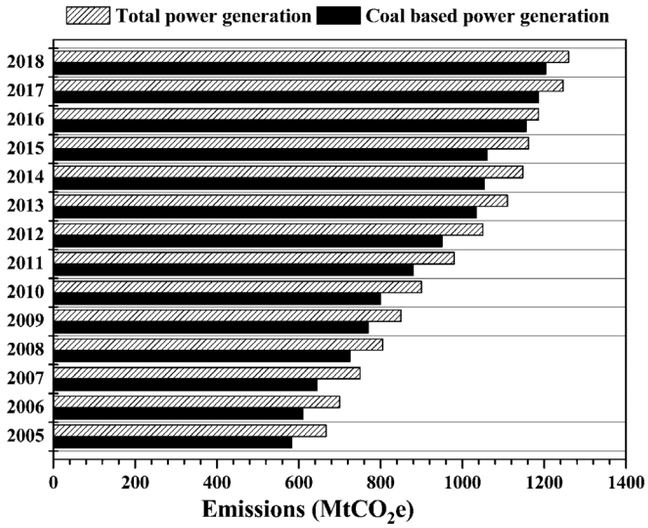

Figure 2: Share of emissions from coal-based power generations in million tonnes of carbon dioxide equivalent (2005–2018).

was 349.2 GW in March 2016, rising to 387.45 GW in May 2022 (CEA, 2016; 2022). Industries consume the most electricity, followed by residential and agricultural sectors. Per capita electricity consumption has been increasing at 5.3% annually since 2005, exceeding 1,000 kWh in 2014-15 due to population growth, urbanisation, and improved energy access.

Hydropower is a significant renewable energy source in India, contributing to total electricity output. However, thermal sources, especially coal, dominate, comprising 204 GW of the total installed capacity. Increased hydropower development is crucial for enhancing India's energy delivery systems. States like Karnataka, Uttarakhand, Bihar, and others house most of India's hydroelectric power plants (Purvaja and Ramesh, 2001), contributing to GHGs-emissions due to microbial degradation of organic matter in reservoirs (Fearnside, 2013). Odisha and Maharashtra were listed as top-emitting states. Although Chhattisgarh, Gujarat,

Table 2: An overview of major GHGs-emission estimates measured in million tonnes (Mt) from the energy sector

IPCC Id	*Source category*	*Emissions from 2018*			
		$MtCO_2$	*MtN_2O*	*$MtCH_4$*	*$MtCO_2e$*
1A	Fuel combustion	1538	0.05	2.9	1613
1A1ai	Electricity production	1093	0.01	0.01	1098
1A3	Transportation	292	0.02	0.05	299
1A4	Other sectors	152	0.01	0.99	177
1B	Fugitive emissions	0.0	0.00	1.73	39
Total		3075	0.09	5.68	3226

Source: Nazar et al., 2022

and Haryana are among the highest per capita emitting states, mainly due to coal-based electricity generation and increased automobile registrations (Mohan et al., 2019). In 2018, the public power generation sector accounted for 45% of energy sector emissions, followed by industries (26%), transportation (12%), fugitive emissions (2%), and other sectors (15%). Road emissions are the highest within the transportation industry, while diesel generator sets are major contributors in the residential and commercial sectors.

Top Per Capita Emissions States vs. Their Total Emissions

Per capita emissions of states are calculated by dividing the total amount of GHGs emitted by the individual state as a result of all relevant human (production and consumption) activities by the state population. Between 2005 and 2018, India's per capita energy-based emissions increased significantly, rising from 1.45 tCO_2e/capita in 2005 to 2.24 tCO_2e/capita in 2018 (GHG Platform-India, 2022). This represents a 1.49-fold increase, despite the population growing at a CAGR of 1.64% during the same period. The growth in per capita emissions was much higher, at a CAGR of 4.07% (Figure 3). This trend was largely driven by the increasing energy sector emissions, which accounted for the largest share of total emissions, growing from 66.3% in 2005 to 68.1% in 2018. The state-level analysis revealed some notable trends. Chhattisgarh emerged as the state with the highest per capita emissions, driven by the rapid expansion of its steel and iron industries, as well as its heavy reliance on coal-fired power plants for public electricity generation (GHGPI, 2019a) (Figure 4). Odisha also experienced a significant increase in per

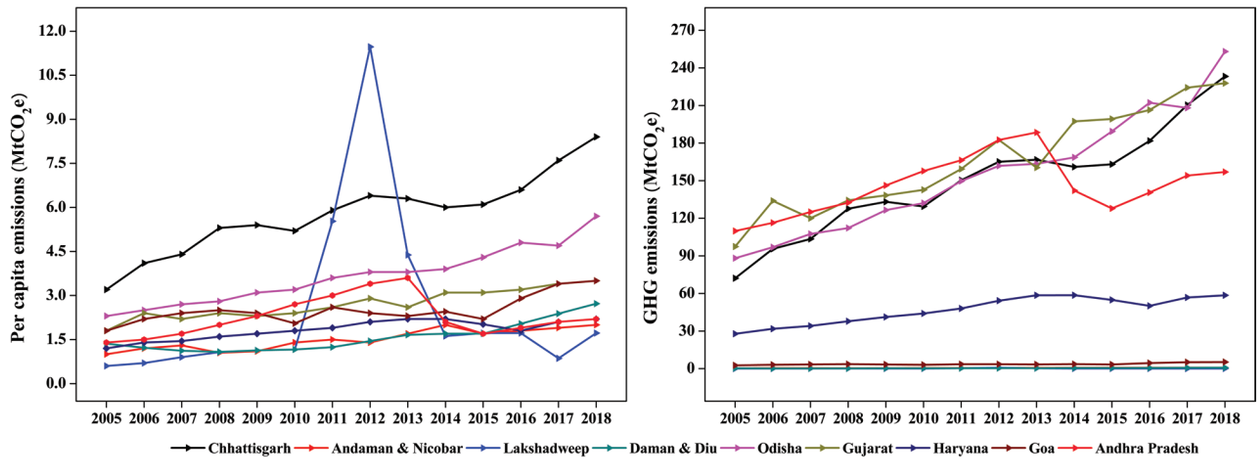

Figure 3: Top GHGs per capita emitting states vs. their total emissions measured in million tonnes of CO_2 equivalent for the year 2005 to 2018.

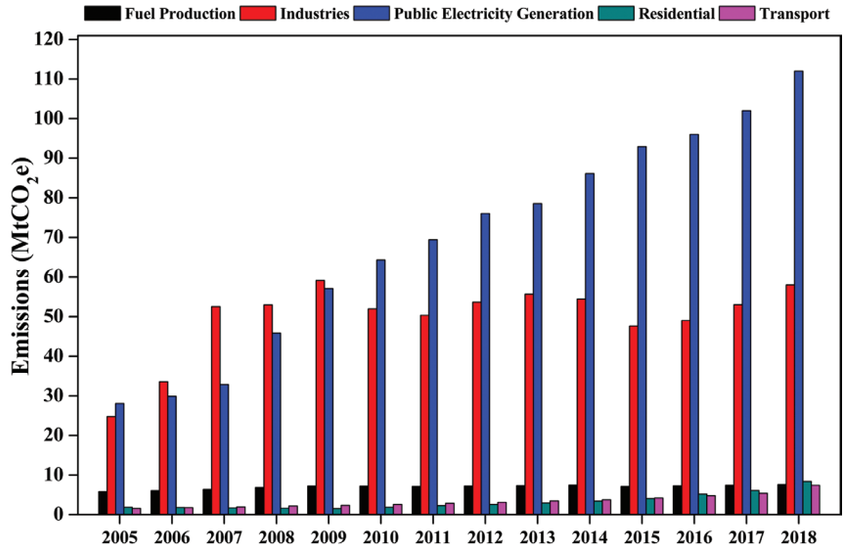

Figure 4: Chhattisgarh emissions trend from the energy sub-sectors for the year 2005 to 2018.

capita emissions, becoming the second-highest emitting state. The energy sector in Odisha was responsible for 253 $MtCO_2e$ of GHGs-emission, with industrial energy use (54%), captive power plants (22%), and public electricity generation (20%) being the primary contributors (GHG Platform-India, 2022) (Figure 5). In contrast, Andaman and Nicobar showed minimal overall emissions, but their per capita emissions were comparatively much higher (GHGPI, 2019b). Gujarat, on the other hand, saw a substantial rise in emissions, with a CAGR of 6.8% from 2005 to 2018. The key sources of emissions in Gujarat's energy sector were industrial fuel combustion (58%) and public power generation (35%), predominantly from coal-fired power plants (GHGPI, 2019d) (Figure 6). The case of Lakshadweep was particularly noteworthy, as the island territory experienced a dramatic increase in per capita emissions. While per capita emissions in India and Lakshadweep were similar from 2005 to 2010, Lakshadweep's per capita emissions grew rapidly from 2011 to 2013, reaching around three times higher than the national average (GHGPI, 2019c). This sharp rise was attributed to the expansion of electricity generation from diesel-powered plants, which increased from a capacity of 51.6 kW in 1962 to 18,575 kW in 2012, making Lakshadweep one of the largest power producers in the world (Jaganmohan, 2020). However, the trend reversed after 2012, as Lakshadweep began to adopt solar energy to reduce emissions and protect the environment (U.T. Administration of Lakshadweep, 2021).

The abrupt increase in emissions observed in Andhra Pradesh and other states after 2015 was linked to the implementation of the "24×7 POWER FOR ALL" program, a joint initiative of the Government of India with all states and Union Territories to provide 24×7 reliable and affordable power to all by 2019 (Ministry

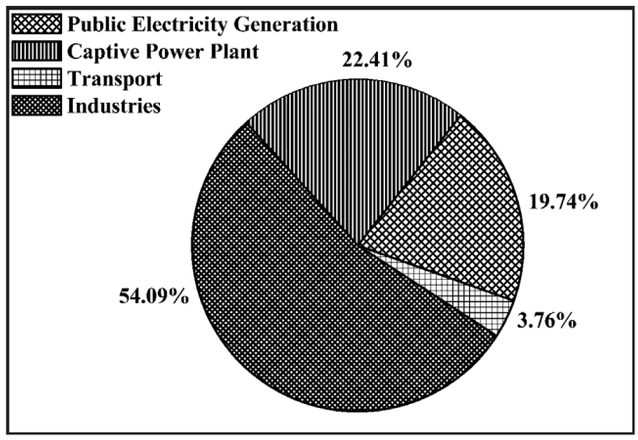

Figure 5: Odisha's share of emissions from the energy sub-sectors (2005-2018).

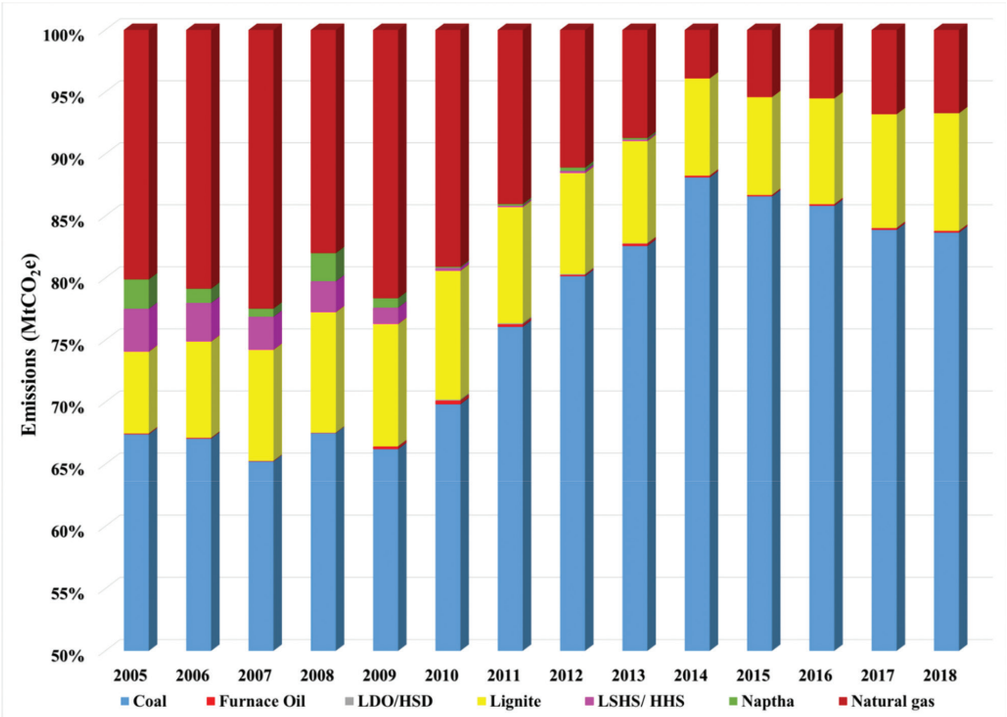

Figure 6: GHGs-emission estimates for Gujarat public electricity generation (2005-2018).

of Power, 2022). This program aimed to meet the growing electricity demand driven by increased urbanisation, changes in lifestyle, and rising disposable incomes among the state's residents. Furthermore, the transportation sector also played a significant role in the overall emissions landscape. As of 2013, the transportation sector accounted for 90.7% of the GHGs-emissions in the top GHG-generating states, with the road transportation sector being the largest contributor, emitting 88% of all transport-related emissions in 2015 (GHG Platform-India, 2022). Interestingly, Haryana recorded a steep fall in emissions after 2014, followed by a rise in 2016. This fluctuation was attributed to changes in the state's government policies, such as the implementation of the Haryana Solar Power Policy in 2014 and the promotion of wind energy. These initiatives aimed to shift the state's energy mix towards renewable sources, reducing its reliance on non-renewable energy, such as thermal coal and nuclear power plants.

Initiatives and Mitigation Measures to Reduce GHGs-Emission

India's growing energy demand, driven by economic growth, urbanisation, and improving living standards, has resulted in a heavy reliance on non-renewable energy sources, particularly coal-fired power plants, which currently meet 55% of the country's energy needs (CEA, 2018). This has led to a significant increase in GHGs-emission from the energy sector, which is the primary source of emissions for most states. To address this challenge, the Government of India has initiated several legislative measures and policies focused on promoting renewable energy, with a particular emphasis on solar power. As part of the Paris Agreement, India has pledged to reduce its GHGs-emission intensity by 33-35% compared to 2005 levels by 2030 (MoEFCC, 2015). To achieve this goal, the government has set ambitious targets for renewable energy capacity, aiming to reach 175 GW by 2022 and 500 GW by 2030. One of the key initiatives in this regard is the Jawaharlal Nehru National Solar Mission (JNNSM), which was launched in 2011 as part of the National Action Plan on Climate Change (NAPCC) (Pandve, 2009). The JNNSM aims to optimize and expand solar energy resources, capitalizing on India's abundant sunshine for more than 300 days a year (Bansal et al., 2019). The mission's solar installation targets have been raised from 20 GW to 100 GW by 2021-2022 (Goel, 2016). In addition to the JNNSM, the government has implemented various state-specific solar energy policies, such as the Solar Energy Policy of Tamil Nadu (2012), the Solar Energy Policy of Rajasthan (2014), and the Gujarat Solar Power Policy (2015) (Government of Gujarat, 2015; Government of India, 2015b, 2015c). These policies have further incentivised and facilitated the adoption of solar power across different states. Another key initiative under the NAPCC is the National Mission on Enhanced Energy Efficiency, which serves as the focal point for the government's efforts to improve energy efficiency (Atteridge et al., 2009). This mission has led to the implementation of policies such as the Auto Fuel Policy (2003), which sets emission standards for new vehicles, and the National Urban Transport Policy, which emphasises the development and use of public transportation and non-motorised modes over individual vehicle use (Thomalla et al., 2009). The government has also recognised the potential of hydropower as a renewable energy source to offset GHGs-emission from fossil fuel-based power generation. However, the development of hydropower projects has also been associated with significant GHGs-emission, particularly from the decomposition of organic matter in hydropower reservoirs (Owusu and Asumadu-Sarkodie, 2016). To address this, the government has emphasized the need for a rigorous approach to monitoring the development and impact of mitigation measures for GHGs inventory systems in the hydropower sector, as well as in the agricultural and forestry sectors. While these initiatives and policies have made significant progress in promoting renewable energy and improving energy efficiency, there is still a long way to go to achieve the ambitious targets set by the government. The continued reliance on coal-fired power plants, the rapid growth in energy demand, and the complex challenges associated with various sectors, such as transportation and hydropower, require a comprehensive and coordinated approach to reduce India's GHGs-emission effectively.

To further strengthen its mitigation efforts, India may need to consider additional measures, such as:

- Accelerating the phase-out of coal-fired power plants and deployment of renewable energy sources
- Implementing more stringent energy efficiency standards across various sectors, including buildings, industry, and transportation
- Investing in the development of smart grid infrastructure and energy storage solutions to support the integration of renewable energy
- Promoting the adoption of electric vehicles and sustainable urban planning to reduce emissions from the transportation sector

- Enhancing the monitoring and management of GHGs-emission from hydropower and other land-use sectors

By leveraging a combination of policy interventions, technological solutions, and institutional coordination, India can continue to make progress in its efforts to mitigate climate change and achieve its ambitious GHGs reduction targets.

Conclusions and Future Prospects

Conclusions

India's rapidly growing economy has led to significant development across its states, which in turn has driven a surge in energy demand, particularly in the residential sector, which accounts for nearly 36% of total energy consumption. This has resulted in a substantial increase in GHGs-emission, with the top-emitting states, such as Maharashtra, Gujarat, and Uttar Pradesh, being the primary contributors. The transition from traditional biomass fuels to modern household energy sources like natural gas and electricity has played a role in this trend. While this transition has improved energy efficiency, the overall energy consumption and associated emissions have continued to rise due to factors like urbanisation, population growth, and economic development, including in the transportation and industrial sectors.

Interestingly, some smaller states, such as Odisha, Chhattisgarh, and Lakshadweep, have also emerged as significant per capita emitters, despite their relatively smaller size and population. Lakshadweep, in particular, saw a sharp increase in per capita emissions, which eventually became three times higher than the national average by 2013. This was largely driven by the rapid expansion of energy generation capacity on the islands to meet the growing electricity demand, which increased at a rate of 5% per year. The analysis also revealed that the transportation sector, particularly road transportation, accounted for a significant portion (90.7%) of the total emissions in the top-emitting states. This highlights the need for targeted interventions in this sector to address the rising emissions. We are more concerned about the emissions from the big cities such as Maharashtra, Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, Gujarat and less concerned about the developing small states such as Chhattisgarh, Odisha, Lakshadweep, Andaman and Nicobar. However, these states per capita emissions rate drastically increased in the reference period (2005-18). This implies that rapid urbanisation, industrialisation, and economic development have led to the production of more GHGs over a small area size, which is a matter of concern.

Future Prospects

To address the growing GHGs-emission, the Government of India has implemented various policies and initiatives, such as the National Mission on Enhanced Energy Efficiency (NMEEE) under the NAPCC. The NMEEE aims to improve energy efficiency in the market by establishing new laws, policies, and regulations. Additionally, the Indian Bureau of Energy Efficiency has developed a national Building Energy Code (BEC) for commercial buildings, which sets minimum energy efficiency standards. However, the adoption of the BEC has been limited, as most states have yet to incorporate it into their regulations, and the code primarily focuses on commercial structures, leaving out a significant portion of the residential sector.

Some states, such as Haryana, Andhra Pradesh, and West Bengal, have made progress in reducing emissions from the residential sector by implementing targeted laws and supporting the establishment of renewable energy production in dwellings. These states have shifted their energy mix away from high-emission fuels (coal and oil) and towards cleaner sources like electricity and natural gas, while also strengthening their BECs and introducing better energy regulations and laws for equipment. India has also made significant strides in promoting renewable energy, with a focus on solar, wind, biogas, and hydropower. The government, state governments, local distribution companies (DISCOMs), and private households have all taken steps to encourage solar energy adoption, offering incentives such as subsidies and tax breaks.

The recently launched Sustainable Rooftop Implementation for Solar Transfiguration of India (SRISTI) initiative is a step in the right direction, as it aims to promote grid-connected rooftop solar systems by involving DISCOMs as active partners in the deployment process.

These efforts, along with the ongoing expansion of renewable energy capacity, will help India meet its international commitments to reduce GHG emissions. Furthermore, the bigger states in India should also support their smaller neighbouring states in mitigating GHG production, as a collaborative approach will be essential to achieve meaningful reductions.

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