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Energy Consumption and Sustainable Development Goals (SDGs) in India: Pathways, Progress, and Challenges

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Abstract-- Energy consumption is a critical driver of sustainable development and has a direct impact on the achievement of the United Nations Sustainable Development Goals (SDGs). In the Indian context, energy plays a pivotal role not only in SDG 7 (Affordable and Clean Energy) but also influences other goals such as poverty reduction, health, education, industrial growth, sustainable cities, responsible consumption, and climate action. As the third-largest energy consumer in the world, India faces the dual challenge of meeting its rising energy demand while reducing its dependence on fossil fuels. Although coal continues to dominate the energy mix, India is making significant strides in renewable energy development through solar, wind, hydro, and bioenergy initiatives. Flagship programs such as the Saubhagya Scheme (universal electrification), Ujjwala Yojana (clean cooking fuel), the National Solar Mission, and the International Solar Alliance underscore the nation's commitment to a clean energy transition. This study examines how India's energy consumption relates to the Sustainable Development Goals, focusing on the link between per capita energy use, GDP growth, and energy intensity. It also reviews progress in renewable energy expansion and reduced fossil-fuel dependency, and highlights key challenges and policies needed to support SDG 2030 and Net Zero 2070 targets. Persistent challenges such as coal dependency, energy inequality, financial stress in power distribution, and affordability of renewable technologies remain critical barriers. Achieving energy sustainability will require robust policies, technological innovation, and inclusive strategies to ensure that India's growth trajectory remains aligned with its global climate and development commitments.

Keywords-- Energy Consumption, SDGs, Renewable Energy, Fossil Fuels, Climate Action and Net Zero Emission.

I. INTRODUCTION

India plays a crucial role in the global energy transition, with its rising population, growing energy demand, and robust economic growth making its energy pathway significant for both national development and global climate goals. Over the past decade, India has become the fourth-largest electricity consumer and the third-largest renewable energy producer, reflecting its progress in clean energy adoption (Kalia, 2024).

Despite its reliance on coal, India is expanding renewables through initiatives such as the National Solar Mission, Saubhagya, and the Ujjwala Yojana, while aligning its strategies with the Sustainable Development Goals (SDGs) and its Net Zero 2070 commitment. Key challenges remain, including energy inequality, financial pressures in the power sector, and technological affordability. India's G20 presidency emphasized the need for a just and equitable transition not only scaling up renewable capacity but also ensuring affordable, reliable power for all citizens. Rapid electrification, driven by appliance use and electric vehicles, has increased demand, prompting government measures to expand renewable capacity, promote green hydrogen, and enhance energy efficiency through building codes, LED adoption, and agricultural initiatives. The 2022 G20 Bali Leaders' Declaration further reinforced India's role in advancing clean, inclusive, and sustainable energy systems, closely tied to SDG 7 (Clean Energy), SDG 9 (Innovation and Infrastructure), and SDG 13 (Climate Action). In this context, India's energy transition stands as both a national necessity and a global imperative.

II. STATEMENT OF THE PROBLEMS

India, as the third-largest energy consumer in the world, faces a critical dilemma in aligning its growing energy demand with the achievement of the Sustainable Development Goals (SDGs). Rapid economic growth, urbanization, and industrialization have significantly increased energy consumption, yet a large section of the population still lacks access to reliable and affordable energy. Heavy dependence on fossil fuels, particularly coal, has resulted in high carbon emissions, environmental degradation, and health risks, posing a major obstacle to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). At the same time, financial and operational inefficiencies in power distribution companies, inadequate infrastructure, and affordability issues hinder the widespread adoption of renewable technologies.

Furthermore, regional and socio-economic disparities in energy access aggravate inequality, thereby affecting SDG 1 (No Poverty), SDG 3 (Good Health and Well-being), and SDG 10 (Reduced Inequalities). The challenge for India lies in balancing its development needs with the transition to cleaner, more efficient energy systems while ensuring inclusivity, affordability, and sustainability.

III. OBJECTIVE OF THE STUDY

The study sets three key objectives:

- To examine the inter-linkages between energy consumption and the Sustainable Development Goals (SDGs) in India.
- To analyze the relationship among per capita energy consumption, GDP growth rate, and energy intensity.
- To evaluate India's progress in expanding renewable energy and reducing dependence on fossil fuels.

- To identify key challenges and policy measures needed to align national energy consumption patterns with the SDG 2030 agenda and India's Net Zero 2070 commitments.

IV. METHODOLOGY

This study adopts a mixed quantitative approach to examine the relationship between energy consumption and progress on Sustainable Development Goals (SDGs) in India, combining descriptive analysis with time-series econometric techniques to identify trends, causal links, and policy-relevant implications. The analysis covers the period 2011–12 to 2023–24 (annual frequency) using national-level secondary data. Key variables include per-capita primary energy consumption, energy intensity, GDP at constant prices, population, and shares of renewables and fossil fuels. Data sources are IEA, OPEC, OPEC Bulletin, CEA, MoC, MoPNG, MNRE and Ministry of Statistics and Programme Implementation

Table – 1
Primary Energy Supply/Production

Primary Energy Supply							
Year	Non Renewable Energy					Renewable energy	
	Coal (MT)			Crude oil (MT)		Hydro (MTOE)	Solar , Wind and others (MTOE)
	Domestic Production	Import	Export	Domestic Production	Import		
2016 -2017	703	195	1.8	36	2214	10.5	7.2
2017 -2018	722	213	1.5	36	220	10.1	9
2018 -2019	773	240	1.3	34	226	11.6	11.2
2019 -2020	753	251	1	32	227	13.4	12.4
2020 -2021	754	218	2.9	30	196	13	13.3
2021 -2022	826	211	1.3	30	212	13.1	15.3
2022 -2023	937	241	1.2	29	233	14	18.3
2023 -2024	1041	265	1.4	29	234	11.3	19.8

Source: PPAC, MoC, 2025

India's primary energy supply remained heavily dependent on non-renewables, with coal production rising sharply from 703 MT to 1041 MT, underscoring its dominant role despite renewable expansion efforts. Crude oil showed stagnant domestic production (29–36 MT) and growing imports (214–234 MT), deepening vulnerability to global markets, while exports stayed marginal.

Among renewables, hydropower remained almost flat at 10–14 MTOE, but solar, wind, and others grew rapidly from 7.2 to 19.8 MTOE, driven by policy support. Overall, coal continues as the main growth driver, oil dependence threatens energy security, hydropower offers little future scope, and solar and wind present the most promising transition path. This dual trend highlights India's challenge of meeting rising demand with fossil fuels while working toward a cleaner, SDG-aligned energy mix.

V. STRUCTURAL BREAK ANALYSIS

The structural break model is applied to examine whether a significant shift occurred in India's primary energy supply during the years 2016–2024. Since the COVID-19 pandemic caused disruptions in energy production, imports, industrial activity, and renewable energy expansion, the period 2020–2021 is treated as a potential break point. The analysis evaluates whether the trends in non-renewable energy (coal production, coal import, crude oil production, crude oil import) and renewable energy (hydro, solar, wind, and others) changed significantly after the shock. By testing for breaks in mean levels and growth patterns, the model identifies whether the pandemic caused temporary disturbances or permanent structural shifts in India's energy composition.

Dummy Variable for Structural Break

$D_t = 0$ for years 2016–2017 to 2019–2020

$D_t = 1$ for year 2020–21 onwards

This indicates whether the observation lies before or after the pandemic break.

Specify the Structural Break Model

$$Y_t = \alpha + \beta_t + \gamma D_t + u$$

Where:

Y_t = Energy variable (coal, crude oil, hydro, solar/wind)

t = time trend (1 to 8 for 2016–2024)

D_t = structural break dummy (0 for 2016–2020 and 1 for 2020–2024)

γ = magnitude of structural break

U_t = error term

Coefficients

α = base level of supply

β = normal yearly trend

γ = sudden change due to structural break (pandemic impact)

The structural break analysis reveals distinct shifts across the energy variables during the break year 2020–21, with each series responding differently to the pandemic shock. Coal imports, which were steadily increasing from 195 MT in 2016–17 to 251 MT in 2019–20, suddenly dropped to 218 MT in 2020–21.

This sharp decline reflects reduced industrial and power-sector demand during nationwide lockdowns. However, imports rose again to 241 MT in 2022–23 and 265 MT in 2023–24, indicating that the break represented a temporary negative shock followed by full recovery and normalisation.

In contrast, crude oil domestic production shows a clear and more concerning negative structural break. Output declined from 36 MT (2016–17 and 2017–18) to 32 MT in 2019–20, then fell further to 30 MT in 2020–21, continuing downward to 29 MT in both 2022–23 and 2023–24. This pattern suggests a long-term structural decline, not merely a pandemic-related shock, indicating falling reserves, reduced extraction, or limited investment in domestic oil fields.

Crude oil imports, which were rising gradually from 221 MT in 2016–17 to 227 MT in 2019–20, also experienced a major negative break during the pandemic, dropping significantly to 196 MT in 2020–21 due to decreased mobility, grounding of flights, and reduced transport demand. As economic activity revived, imports increased again to 212 MT (2021–22) and 234 MT (2023–24), showing a gradual recovery toward pre-pandemic levels.

Hydro energy supply shows only a mild decline at the break. It increased from 10.5 MTOE (2016–17) to 13.4 MTOE (2019–20) but slightly decreased to 13.0 MTOE in 2020–21, and then remained broadly stable around 13–14 MTOE before dipping to 11.3 MTOE in 2023–24. These small fluctuations indicate that hydro energy was minimally affected by the structural shock and remained relatively stable due to its dependence on natural water availability rather than industrial cycles.

Meanwhile, solar, wind, and other renewable energy sources show a positive structural break. Their supply increased consistently from 7.2 MTOE in 2016–17 to 12.4 MTOE in 2019–20, and continued rising to 13.3 MTOE despite the pandemic in 2020–21. Post-break, renewable energy expanded even more rapidly, reaching 15.3 MTOE in 2021–22, 18.3 MTOE in 2022–23 and 19.8 MTOE in 2023–24. This demonstrates strong resilience and accelerated growth, reflecting rising investment, policy support, and technological improvements.

The structural break results highlight contrasting impacts across energy categories. Coal production and renewable energy show positive post-break shifts, indicating strong expansion after the pandemic and reinforcement of domestic supply and clean energy investments. In contrast, coal imports, crude oil production, and crude oil imports experienced negative structural breaks, showing significant declines during 2020–21.

Among these, crude oil production displays evidence of a permanent structural downturn, as output continues to decrease even after economic recovery. Hydro energy shows only a minor negative break, revealing its overall stability and limited sensitivity to short-term shocks. These patterns suggest that non-renewable energy was more vulnerable to the pandemic shock, while renewable energy demonstrated resilience and faster growth in the post-break period. The structural break model clearly identifies 2020–21 as a turning point in India’s energy landscape. Non-renewable energy sources especially crude oil imports and domestic crude oil production experienced strong negative breaks due to the collapse in transportation and industrial activity.

Coal production, however, demonstrates a positive post-break adjustment, reflecting increased reliance on domestic output during the recovery phase. Renewable energy, particularly solar and wind, shows an unmistakable positive structural break, indicating that clean energy expansion continued uninterrupted through the pandemic and accelerated afterward. Hydro energy remains stable before and after the break, showing minimal disruption. Overall, the structural break model reveals a diverging trajectory between energy categories: while non-renewables faced temporary or permanent setbacks, renewable energy grew rapidly, highlighting ongoing structural changes, policy-driven transitions, and technological advancements in India’s energy sector.

Table – 2
Final Energy Consumption/Demand

Year	Industry				Electricity consumption all Sectors (TWh)
	Coal (MTOE)	Oil (MTOE)	Gas (MTOE)	Electricity (MTOE)	
2016 -2017	160	46	1	38	1061
2017 -2018	166	49	1	40	1123
2018 -2019	187	51	1	45	1210
2019 -2020	179	51	1	46	1248
2020 -2021	173	47	1	44	1230
2021 -2022	162	45	1	48	1317
2022 -2023	169	50	1	51	1440
2023 -2024	186	52	1	55	1543

Source: MoSPI, 2025

India’s final energy consumption shows coal as the dominant industrial fuel, rising overall but with fluctuations linked to cyclical activity. Oil use grew modestly, while gas remained stagnant at just 1 MTOE, reflecting limited penetration. Industrial electricity use increased steadily from 38 to 55 MTOE, and total electricity demand across all sectors surged from 1061 TWh to 1543 TWh, driven by electrification, urbanization, and digitalization. Overall, electricity shows the strongest growth momentum and is emerging as the key driver of energy demand, though coal’s continued dominance underscores challenges for decarbonization despite progress toward sustainable development goals.

PRIMARY ENERGY SUPPLY

Coal

Coal, including lignite, remains the backbone of India’s primary energy supply, accounting for 61 percent of the total share in 2023–24. It continues to be the dominant source of electricity generation, contributing nearly 75 percent of total electricity output during the last decade. This heavy dependence arises from the availability of cheaper and abundant domestic reserves. India ranks fifth globally in coal reserves, with an estimated 437 billion tonnes (MoC, 2024).



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In 2023–24, coal consumption (including lignite) reached 1,277 million tonnes (MT), of which 80 percent was domestically produced and the remaining 20 percent imported from Australia, Indonesia, and Russia (MoC, 2024). Imported coal, particularly non-coking coal, is preferred in several sectors due to its higher calorific value and lower ash content compared to domestic coal. Of the imported quantity, 58 MT was consumed by the steel industry and 203 MT by other sectors. Domestic Coal Production: India's coal production reached 998 MT (excluding lignite) in 2023–24, nearly meeting the Ministry of Coal's target of 1,000 MT (MoC, 2022). Including lignite, total output stood at 1,041 MT, reflecting a 6 percent CAGR over the last decade and an 11 percent increase compared to 937 MT in 2022–23 (MoC, 2024). Import and Export of Coal: Despite vast reserves, domestic production has not been sufficient to meet rising demand. India is the second-largest coal importer after China, importing 265 MT in 2023–24, up from 241 MT in 2022–23 (MoC, 2024). Most imports originated from Indonesia and Australia, with coking coal primarily used in the steel sector.

Crude Oil

Crude Oil remains central to India's energy supply and economic stability. The country is the third-largest importer of crude oil globally, having imported 234 MT in 2023–24. The Middle East contributed 46 percent of these imports, though India has increasingly diversified towards Eurasia, whose share rose from 3 percent in 2017–18 to 39 percent in 2023–24 (PPAC, 2024). Domestic crude oil production has steadily declined, falling from 36 MT in 2016–17 to 29 MT in 2023–24, at an annual decline of about 3 percent (MoPNG, 2023). India's recoverable crude oil reserves stood at 671.4 MT as of April 2024, marking only a marginal increase from the previous year (MoPNG, 2024). Refining and Petroleum Exports: India is the third-largest refiner in Asia and the fourth-largest globally, with a refining capacity of 256.8 MTPA as of April 2024. Strong growth in refining has enabled India to not only meet its domestic petroleum needs but also emerge as a major exporter of high-quality petroleum products. Oil Consumption and Imports: India consumed 233 MT of oil in 2023–24, making it the third-largest consumer after the United States and China. The country's dependence on imports is significant: crude oil accounted for 89 percent of total supply in 2023–24, compared to 86 percent in 2016–17. Petroleum imports contributed to 25.1 percent of India's total imports by value in 2023–24, directly impacting inflation, trade balances, and macroeconomic stability.

Crude oil is vital for producing fuels such as petrol, diesel, LPG, naphtha, jet fuel, and lubricants, making it a critical determinant of India's industrial growth, transport sector functioning, and household consumption patterns.

Natural Gas

Natural gas plays a vital role in India's energy mix, although its share remains relatively modest compared to coal and oil. In 2023–24, natural gas contributed around 6 percent to the total primary energy supply (MoPNG, 2024). Natural gas is valued for being a cleaner-burning fuel, producing lower carbon emissions compared to coal and oil, and is widely used in power generation, fertilizer production, petrochemicals, city gas distribution (CGD), and transport (CNG and LNG). Domestic Production: India's domestic natural gas production stood at 36.6 billion cubic metres (BCM) in 2023–24, reflecting a marginal increase from 34.5 BCM in 2022–23 (MoPNG, 2024). The production largely comes from the Krishna-Godavari (KG) Basin, Mumbai Offshore fields, and Assam-Arakan Basin. However, domestic output has been insufficient to meet demand, covering only about 50 percent of total consumption. Imports and LNG Infrastructure: To bridge the supply gap, India has become a significant importer of liquefied natural gas (LNG). In 2023–24, LNG imports reached 26.6 BCM, accounting for about 45 percent of the country's gas consumption (PPAC, 2024). Imports primarily come from Qatar, the United States, Nigeria, and Australia. India currently operates six LNG regasification terminals with a combined capacity of 42.5 million tonnes per annum (MTPA). Additional terminals under development are expected to increase this capacity beyond 60 MTPA by 2030 (MoPNG, 2024).

Policy and Transition Role: The Government of India has set an ambitious target to increase the share of natural gas in the primary energy mix from 6 percent in 2023–24 to 15 percent by 2030 (NITI Aayog, 2023). Initiatives such as the National Gas Grid, expansion of city gas distribution (CGD) networks, and promotion of LNG as a transport fuel are central to this strategy. Natural gas is viewed as a "transition fuel" that can support India's shift towards a low-carbon economy by complementing renewable energy expansion while reducing reliance on coal.

Renewable Energy in the Primary Energy Supply Mix:

Renewable energy is assuming an increasingly vital role in India's energy supply, signifying a clear transition toward cleaner and more sustainable energy sources.



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Between 2013–14 and 2023–24, primary energy supply from renewables grew from 17.4 Mtoe to 31.1 Mtoe, raising their share in the overall primary energy supply mix to 3.4 percent (MoSPI, 2024). This growth is driven by ambitious government policies, technological advancements, and substantial investments. Key initiatives include ultra-mega solar parks, rooftop solar schemes, PM Surya Ghar Muft Bijli Yojana, Renewable Purchase Obligations (RPOs), Renewable Generation Obligations (RGOs), Production-Linked Incentive (PLI) schemes, and the Green Energy Corridor. India possesses significant renewable potential. The National Institute of Solar Energy (NISE) estimates solar potential at 748 GW, assuming only 3 percent of wasteland is utilized for solar PV deployment. Similarly, the National Institute of Wind Energy (NIWE) estimates wind potential at 1,164 GW at 150 meters hub height. Additional potential includes 133 GW from large hydro, 42 GW from biomass, and 21 GW from small hydro. To strengthen integration, the government is emphasizing Energy Storage Systems (ESS), particularly pumped storage projects. India's estimated pumped storage potential is 176 GW, which can provide reliable base/peak load power by complementing variable sources such as solar and wind (ICED, 2024).

Secondary Energy Supply: Electricity

Electricity serves as a cornerstone of India's infrastructure and economy, powering industrial growth, household consumption, and overall welfare. In recent years, India's electricity sector has undergone transformational changes, including achieving a power-surplus status, the creation of a unified national grid, universal household electrification, distribution network strengthening, and efficiency-driven reforms. India is now the third-largest electricity producer globally, with an installed capacity of 454 GW as of October 2024 (CEA, 2024). While coal-based power plants continue to dominate with 48 percent of the installed capacity, this represents a decline from 59 percent in 2016–17, highlighting progress toward reducing dependence on fossil fuels. Non-fossil fuel-based capacity (nuclear, hydro, and renewables) has grown at an annual rate of 9 percent since 2016–17, reaching 211 GW in October 2024, or 46.5 percent of the total capacity, positioning India firmly on track to meet its 2030 target of 50 percent non-fossil fuel capacity under its Nationally Determined Contributions (NDCs).

Renewable Energy Capacity in Electricity Generation

India has emerged as a global leader in renewable energy, ranking fourth worldwide in installed renewable capacity (Manohar, 2024).

As of October 2024, the total installed renewable capacity stood at 203 GW, representing 45 percent of India's total electricity capacity. Among renewable sources: Solar power contributes 45 percent of renewable capacity. Solar installations have expanded rapidly, growing more than sevenfold in the last seven years, reaching 82 GW by March 2024. Of this, 64 GW (79 percent) comes from ground-mounted projects, 12 GW (15 percent) from rooftop solar, and 3 GW (3 percent) from hybrid/off-grid projects. Additionally, 87 GW of solar projects are in the pipeline. Rooftop solar capacity has grown remarkably, from just 1 GW in 2017–18 to 14.45 GW by October 2024, supported by initiatives like the PM Surya Ghar Muft Bijli Yojana, which targets rooftop solar for one crore households with an outlay of ₹75,021 crores (MNRE, 2024).

- Wind power accounts for 23 percent of renewable capacity, supported by India's vast potential along coastal regions and inland wind corridors.
- Hydropower (large, small, and run-of-river projects combined) contributes another 23 percent of renewable capacity, ensuring flexible and dispatchable power.
- Biopower and waste-to-energy together provide around 6 percent, playing a crucial role in circular economy strategies and sustainable rural development.

The rapid increase in renewable capacity illustrates India's commitment to tripling global renewable energy capacity by 2030, in alignment with international climate goals and SDG 7 (Affordable and Clean Energy).

Non-Utility Plants: Capacity and Generation

Non-utility, or captive, power plants are primarily established by energy-intensive industries such as aluminum, cement, chemicals, fertilizers, iron & steel, paper, and sugar. These plants supplement electricity purchased from utilities or serve as backup power in case of grid unreliability. As of 2023–24, India's non-utility generating capacity reached 79 GW, reflecting a 6.4 percent annual growth since 2016–17. Coal contributes the largest share at 59.1 percent, followed by diesel (23.1 percent), renewables (9.6 percent), gas (8.2 percent), and hydro (0.2 percent). These plants generated a total of 215 BU in 2023–24, showing a 3.2 percent annual growth since 2016–17. Generation, however, dipped by 6 percent in 2020–21 due to COVID-19 restrictions and by 7 percent in 2021–22 because some non-utility plants were converted to utility plants.



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According to the Central Electricity Authority (CEA), 8,408 industrial units with a demand of 0.5 MW or above operate captive power plants in India. Among these, the iron & steel sector holds the largest share at 20 percent (15 GW), followed by aluminum at 13 percent, and cement and sugar industries each at 9 percent.

Demand-Side Management

India has witnessed a substantial rise in electricity consumption across all sectors. In 2023–24, total electricity consumption reached 1,543 TWh, representing a 7 percent increase from the previous year, with per capita consumption rising to 1,395 kWh—nearly double the level from a decade ago. The industrial sector, which accounts for 42 percent of total consumption, drives the nation’s manufacturing and production activities. The residential sector is the second-largest consumer at 24 percent, growing at 6 percent annually due to increased appliance usage and improved electricity access in rural and underserved areas, supported by government initiatives such as the Saubhagya Scheme. The agriculture sector accounts for 17 percent of consumption, driven by increased reliance on electric pumps for groundwater irrigation, following the government’s phasing out of diesel pumps.

Energy Demand and Supply

India’s primary energy supply is shaped by rapid population growth, urbanization, and industrial expansion. In 2023–24, coal and oil together met 88 percent of total primary energy needs, with coal remaining predominant in the power and industrial sectors. Oil is critical for transportation and industrial use, with import dependency rising to 89 percent in 2023–24 due to increasing demand.

Renewable energy, including large hydro, expanded from 76 GW in 2013–14 to 191 GW in 2023–24, contributing 3.4 percent to the primary energy supply. Natural gas, a cleaner alternative to coal and oil, accounted for 6.9 percent of primary energy supply, with 46 percent of its supply imported as LNG, making India the fourth-largest LNG importer globally. India is the third-largest energy consumer worldwide. In 2023–24, energy consumption by type was 39.9 percent oil, 31.2 percent coal, 22.2 percent electricity, and 6.7 percent natural gas. Over the past decade, electricity’s share increased by 4 percent while coal’s share declined by 6 percent, reflecting rising electrification and renewable energy adoption. Industry remains the largest consumer at 49.5 percent, followed by transport at 12 percent, which grew by 104 percent over the past decade due to rising vehicle usage and infrastructure expansion. Oil continues to dominate the transport sector, though EV adoption increased from 0.3 percent in 2016–17 to 7 percent in 2023–24. Residential energy consumption accounted for 10.4 percent, with electricity usage nearly doubling from 200 BU in 2013–14 to 375 BU in 2023–24, driven by higher living standards and extreme weather events. Per capita energy consumption also increased, with primary energy supply per person rising from 0.47 toe in 2013–14 to 0.65 toe in 2023–24, and final energy consumption per capita increasing from 0.33 toe to 0.43 toe. Per capita electricity consumption grew from 698 kWh to 1,106 kWh. Energy intensity, measured as total energy use per unit of GDP, improved over the decade, declining from 0.006 toe per ₹1,000 GDP in 2013–14 to 0.005 toe per ₹1,000 GDP in 2023–24, indicating enhanced energy efficiency.

Table -3
Per-Capita Primary Energy Consumption and Energy Intensity in India

Year	Energy Consumption in petajoules	Mid year population (in Thousands)	GDP at 2011-12 prices (Rs. Cr)	Per Capita Energy Consumption (in Megajoules)	Energy Intensity (Megajoules per rupee)
2011-12	21,869	12,20,171	87,36,329	17,923	0.2503
2012-13	26,249	12,36,220	92,13,017	21,233	0.2849
2013-14	26,822	12,52,267	98,01,370	21,419	0.2737
2014-15	28,453	12,68,310	1,05,27,674	22,434	0.2703
2015-16	29,063	12,84,350	1,13,69,493	22,629	0.2556
2016-17	29,713	12,99,434	1,23,08,193	22,866	0.2414
2017-18	30,966	13,13,815	1,31,44,582	23,569	0.2356
2018-19	32,712	13,28,206	1,39,92,914	24,629	0.2338
2019-20	32,548	13,42,586	1,45,34,641	24,243	0.2239
2020-21	29,807	13,56,980	1,36,94,869	21,965	0.2176
2021-22	33,018	13,70,311	1,50,21,846	24,095	0.2198
2022-23	35,430	13,82,894	1,61,64,913	25,620	0.2192
2023-24(P)	38,479	13,95,478	1,76,50,591	27,574	0.2180
Growth rate of 2023-24 over 2022-23 (percent)	8.60	0.91	9.19	7.62	-0.54
CAGR 2014-15 to 2023-24(P) (percent)	3.41	1.07	5.91	2.32	-2.36

Source: Energy statistics, 2025

Simple linear Regression Model

$$Y_t = \alpha + \beta t + \epsilon_t$$

where:

Y_t = Per Capita Energy Consumption / Energy Intensity

- t = time (2011–12 = 1, ... , 2023–24 = 13)
- β = average annual change

The per-capita energy consumption or energy intensity and t denotes time, highlights two important trends in India’s energy sector. Per-capita energy consumption shows a clear upward trajectory, increasing from 17,923 megajoules in 2011–12 to 27,574 megajoules in 2023–24, with a compound annual growth rate of 2.32 percent.

The regression line would thus display a significant positive slope ($\beta > 0$), indicating that energy use per person has been rising steadily as a result of economic expansion, higher incomes, industrial growth, and improved living standards. In contrast, energy intensity has declined consistently from 0.2503 to 0.2180 megajoules per rupee of GDP during the same period, with a negative CAGR of – 2.36 percent. This downward trend implies a negative slope ($\beta < 0$) in the regression, reflecting improved energy efficiency, greater adoption of renewable energy, technological advancements, and a gradual structural shift from energy-intensive industries to services. Together, these findings suggest a dual dynamic: while energy demand per capita continues to rise significantly, the economy is simultaneously becoming more energy-efficient.

The policy implication is that India must strengthen its focus on renewable energy investment and conservation strategies to ensure that the benefits of efficiency gains are not offset by the overall increase in consumption, thereby supporting long-term sustainability.

Chi-square test:

The Chi-square test is applied to examine whether a statistical association exists among the key indicators of India’s energy–economy relationship: Per-Capita Energy Consumption, GDP (at 2011–12 prices), and Energy Intensity. These three variables together reflect the overall pattern of economic development, energy use efficiency, and the living standard of the population. Per-capita energy consumption indicates the average energy used by an individual and is directly linked to lifestyle changes and economic growth. GDP captures the size and performance of the economy, while energy intensity measures the amount of energy required to produce one unit of output, representing the efficiency of energy use. Studying the association among these variables helps to understand whether rising income levels lead to higher or lower energy intensity, and whether improvements in efficiency are associated with changes in per-capita energy demand. By categorizing all three variables into low, medium, and high groups, the Chi-square test evaluates if these variables move independently or exhibit statistically significant interrelationships. This analysis provides meaningful insights into India’s long-term energy efficiency trends and the energy requirements of its growing economy.

Hypothesis (1)

- *Null Hypothesis (H₀):* There is no association between Per-Capita Energy Consumption and Energy Intensity in India.
- *Alternative Hypothesis (H₁):* There is an association between Per-Capita Energy Consumption and Energy Intensity.

Apply the Chi-Square Test

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where

O = Observed frequency

E = Expected frequency = (Row Total × Column Total) / Grand Total

Computed Chi-square Value

$$\chi^2 = 6.48$$

Degrees of Freedom

$$df = (r-1) (c-1) = (3-1) (3-1) = 4$$

Table Value (at 5 percent level)

$$\chi^2_{0.054} = 9.488$$

Since

$\chi^2_{cal} = 6.48 < 9.488 = \chi^2_{table}$ finally concluded that Fail to Reject the Null Hypothesis

The Chi-square test was applied to examine the association between Per-Capita Energy Consumption and Energy Intensity in India using categorized annual data from 2011–12 to 2023–24. The calculated Chi-square value (6.48) was lower than the critical table value (9.488) at the 5 percent significance level. This indicates that there is no statistically significant association between per-capita energy consumption and energy intensity during the study period. In other words, changes in individual energy use do not necessarily correspond with proportional changes in the energy intensity of the economy. This suggests that improvements in energy efficiency, technological changes, and structural shifts in the Indian economy may operate independently of per-capita consumption trends.

Hypotheses (2)

- *Null Hypothesis (H₀):* There is no association between GDP and Energy Intensity.
- *Alternative Hypothesis (H₁):* There is an association between GDP and Energy Intensity.

Chi-Square Value

$$\chi^2 = 13.78$$

Degrees of Freedom

$$df = (r-1) (c-1) = (3-1) (3-1) = 4$$

Table Value (at 5 percent level)

$$\chi^2_{0.054} = 9.488$$

Since

$\chi^2_{cal} = 13.78 > 9.488 = \chi^2_{table}$ finally concluded Reject the Null hypothesis



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The Chi-square test was applied to examine whether GDP and Energy Intensity in India are statistically associated over the period 2011–12 to 2023–24. After classifying GDP into low, medium, and high categories and grouping energy intensity into low, medium, and high ranges, a 3×3 contingency table was constructed. The calculated Chi-square statistic (13.78) exceeded the critical value (9.488) at the 5 percent significance level, leading to the rejection of the null hypothesis. This indicates that a significant association exists between GDP and Energy Intensity in India. In other words, variations in national income are systematically linked with changes in energy intensity. As GDP rises, energy intensity tends to decline, reflecting improved energy efficiency, structural economic transformation, and technological progress accompanying economic growth.

VI. ENERGY CONSUMPTION AND THE SUSTAINABLE DEVELOPMENT GOALS (SDGs)

Energy and SDG 7: Affordable and Clean Energy: Energy plays a central role in the achievement of Sustainable Development Goal 7 (SDG 7), which aims to ensure universal access to affordable, reliable, sustainable, and modern energy by 2030 (United Nations, 2015). For India, this goal is critical as it balances rapid economic growth with environmental sustainability. The Government of India set ambitious renewable energy targets, including 175 GW by 2022 and 40 percent of installed power capacity from non-fossil sources by 2030 (Ministry of Power, 2022). As of June 2023, renewable energy capacity reached 129.64 GW, accounting for about 31 percent of the country's total installed capacity (MNRE, 2023). India has also achieved near-universal electricity access, which is a milestone in its progress towards SDG 7. However, significant challenges remain. The growing energy demand from a large and diverse population raises concerns about equitable distribution of benefits. Furthermore, renewable energy projects require high capital investment, while the availability of affordable finance is limited. According to UNCTAD's World Investment Report 2023, developing countries face an annual investment deficit of nearly USD 4 trillion to achieve SDGs, highlighting the financing barrier for India's energy transition. Additional issues such as intermittency of renewables also require investments in smart grids, storage, and demand-side management solutions.

Energy and Employment: Advancing SDG 8: India's energy transition has become an important driver of economic opportunity under SDG 8, which promotes decent work and economic growth.

The renewable energy sector has emerged as a significant job creator, with estimates suggesting that around 700,000 new jobs will be generated by 2030 (Government of India, 2021). As of 2019–20, the sector already employed more than 100,000 full-time skilled and unskilled workers (IRENA, 2020). To meet these requirements, the Government of India established the Skill Council for Green Jobs (SCGJ) in 2015, which promotes skills for green industries and partners with the International Solar Alliance (ISA) to build capacity across member countries (SCGJ, 2019). Further, initiatives such as the Pradhan Mantri Kaushal Vikas Yojana (PMKVY) aim to align skill development with industrial needs and create employment opportunities in the green sector. The National Green Hydrogen Mission is also expected to add about 600,000 jobs in coming years (NITI Aayog, 2022). Despite these gains, challenges persist in integrating green skills into educational curricula, ensuring rural inclusion in training, and shifting from supply-driven to demand-driven skill development models.

Energy and Urban Development: Supporting SDG 11: Urban sustainability in India is closely tied to energy efficiency and renewable energy adoption, aligning with SDG 11, which emphasizes sustainable cities and communities. The Government of India has launched several initiatives, including the National Solar Mission, with a target of achieving 40 GW of rooftop solar capacity by 2026 (MNRE, 2022). Similarly, the Solar City Programme aims to reduce conventional energy use in urban areas by at least 10 percent through renewable adoption and efficiency measures. Complementing this, the Grid-Connected Rooftop Solar Scheme provides financial support to households and institutions to encourage adoption. Despite progress, challenges remain, such as high upfront installation costs, limited consumer awareness, and technical as well as regulatory hurdles (World Bank, 2021). Addressing these issues is crucial for ensuring cities evolve into hubs of sustainable energy consumption.

Energy and Responsible Consumption: Advancing SDG 12: India has undertaken multiple efforts to promote sustainable consumption and production patterns, aligned with SDG 12. The Street Lighting National Programme (SLNP) has successfully installed more than 12 million LED streetlights, leading to substantial energy savings and reduced greenhouse gas emissions (EESL, 2021). The Standards & Labeling Programme has informed consumers about the benefits of energy-efficient appliances, saving around 55 million tonnes of CO₂ annually (BEE, 2022).



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Additionally, the Energy Conservation Building Code (2017) and the Eco-Niwas Samhita (2021) have enhanced efficiency in commercial and residential buildings. On the consumer front, the Government of India launched Mission LiFE (Lifestyle for Environment), which encourages behavioral change, influences industry practices, and drives large-scale policy interventions towards sustainable production and consumption (NITI Aayog, 2022). At the grassroots level, schemes like the Ujjwala Yojana provide access to clean cooking fuel, directly contributing to poverty reduction (SDG 1) and improved health outcomes (SDG 3). Energy access also supports education (SDG 4) and fuels industrial development (SDG 9), demonstrating the cross-cutting impact of responsible energy use.

Energy, Industry and Innovation: Achieving SDG 9: SDG 9 emphasizes the need to build resilient infrastructure, promote sustainable industrialization, and foster innovation. India's renewable energy policy framework aligns strongly with this goal. Under its foreign direct investment (FDI) policy, India allows 100 percent FDI in renewable energy projects under the automatic route without prior approval (Department for Promotion of Industry and Internal Trade, 2023). This has spurred investment inflows, with renewable energy FDI reaching USD 2.5 billion in 2023, up from USD 1.6 billion in 2022 (Reserve Bank of India, 2023). In terms of energy efficiency, the Bureau of Energy Efficiency's (BEE) Perform, Achieve, and Trade (PAT) scheme has driven emission reductions across 13 industrial sectors, saving approximately 26 MTOE and avoiding 70 million tonnes of CO₂ emissions by 2023 (BEE, 2023). India is also fostering innovation through programmes such as the National Mission on Transformative Mobility and Battery Storage, the Smart Grid Mission, and the FAME scheme for electric vehicles. However, large-scale investment in infrastructure, ensuring inclusivity (particularly gender equality in energy value chains), and tailoring innovation to local needs remain persistent challenges (World Economic Forum, 2022).

Energy and Climate Action: Progress Towards SDG 13: India's energy transition is deeply interlinked with climate action under SDG 13. The country ratified the Paris Agreement in 2016 and pledged to reduce emissions intensity of GDP by 33–35 percent from 2005 levels by 2030 while achieving 40 percent of electricity generation from non-fossil sources (UNFCCC, 2016).

At the COP26 summit, India announced its Panchamrit strategy, which includes targets such as reaching 500 GW of non-fossil fuel capacity by 2030, sourcing 50 percent of energy from renewables, cutting one billion tonnes of cumulative carbon emissions by 2030, reducing carbon intensity by 45 percent compared to 2005 levels, and achieving net-zero emissions by 2070 (MoEFCC, 2021). Despite being the world's third-largest emitter, India has made significant strides in renewable energy adoption, ranking fourth globally in installed renewable capacity as of 2022 (IRENA, 2022). Initiatives like the International Solar Alliance (ISA), the Coalition for Disaster Resilient Infrastructure (CDRI), and the National Green Hydrogen Mission further reinforce India's commitment to integrating climate action with economic growth. Importantly, India is the only G20 country currently on track to meet its climate commitments (Climate Action Tracker, 2023), making it a global leader in renewable energy deployment and climate resilience.

VII. PROGRESS IN RENEWABLE ENERGY AND ENERGY TRANSITION

India, as a climate-vulnerable nation, faces the dual challenge of meeting its rising energy demand while safeguarding natural ecosystems, agriculture, and bio-resources on which a large share of its population depends. The country has made remarkable progress in renewable energy deployment and is steadily advancing towards its 2030 climate goals under the 'Panchamrit' framework, announced as part of its Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). India's renewable energy capacity has expanded significantly, increasing nearly five-fold from 24 GW in 2014–15 to 136 GW in 2024–25. Similarly, non-fossil fuel-based installed capacity has grown from 78 GW (29 percent of total capacity) in 2014–15 to 199 GW (45 percent of total capacity) in 2023–24, placing the country on track to achieve its target of sourcing 50 percent of power generation from non-fossil sources by 2030. In line with its long-term vision, India has committed to achieving 500 GW of non-fossil-based capacity by 2030, with around 135 GW currently under construction or development. At the present pace, this target appears achievable. India has also demonstrated progress in emissions reduction. The country's emissions intensity has already declined by 40 percent relative to 2005 levels, moving closer to its NDC target of a 45 percent reduction by 2030.



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This progress reflects policy measures such as the Renewable Purchase Obligations (RPOs), which have steadily increased the mandated share of renewable energy in utilities and open-access consumption—from an initial 2–5 percent to nearly 30 percent today. In addition to renewables, India is expanding nuclear power to provide low-carbon base load energy. The government has announced plans to triple the existing 22,480 MW of nuclear capacity by 2031–32, underscoring its role in India’s energy mix for a Viksit Bharat (developed India). While the nuclear sector remains state-controlled, foreign investment is permitted in equipment manufacturing and material supply, supporting its gradual expansion. Despite these strides, coal remains a dominant component, contributing about 59 percent of India’s primary energy supply in 2023. Given the steep rise in energy demand, coal is expected to continue playing a significant role in the short-to-medium term. To meet this demand, India has set ambitious production targets, aiming for 1.31 billion tonnes of coal by FY25 and scaling output further to 1.5 billion tonnes by 2030. India’s energy transition reflects a careful balance: aggressively scaling up renewable and nuclear energy, reducing emissions intensity, and pursuing climate goals, while simultaneously relying on coal to ensure energy security during its development trajectory.

VIII. MAJOR CHALLENGES

India’s energy transition faces several key challenges that must be addressed to achieve a sustainable and inclusive energy future. Coal Dependency remains a significant issue, as coal continues to account for a substantial portion of electricity generation despite rapid growth in renewables. This dependence not only affects environmental sustainability but also exposes the energy sector to price volatility and supply disruptions. Energy Inequality is another critical challenge, with disparities in energy access and affordability between urban and rural areas, and across socio-economic groups, limiting equitable development and social inclusion. Financial Stress in the power sector further complicates the transition, as many distribution companies (DISCOMs) face liquidity constraints and high debt burdens, hindering investments in renewable infrastructure and grid modernization. Affordability and Technological Barriers pose additional constraints, as the deployment of advanced renewable energy technologies, energy storage systems, and smart grids requires substantial upfront investment and technical expertise.

Additionally, grid integration and intermittency of renewable sources present operational challenges, necessitating reliable energy storage and demand management solutions. Policy uncertainty, regulatory bottlenecks, and the need for skilled manpower also act as impediments to scaling up clean energy deployment at the pace required to meet climate targets.

IX. PATHWAYS TO ACHIEVE SUSTAINABLE ENERGY GOALS

To overcome these challenges, India must pursue a multi-pronged approach. Robust Policies and Regulatory Frameworks are essential to guide the energy transition, provide long-term investment certainty, and align national energy strategies with Sustainable Development Goals (SDGs) and climate commitments. Technological Innovation is crucial, including the development of high-efficiency solar panels, wind turbines, energy storage systems, green hydrogen, and smart grid technologies, which enhance efficiency, reliability, and affordability. Inclusive Strategies must be prioritized, ensuring that energy access and benefits of the transition reach all sections of society, particularly rural and marginalized communities. Strengthened Financial Mechanisms are needed to support investments in renewables, energy efficiency, and grid modernization, leveraging both public and private capital. Furthermore, alignment with climate goals is imperative, as India aims to achieve Net Zero by 2070 while meeting intermediate targets such as reducing emissions intensity by 45 percent by 2030. Enhancing cross-sectoral collaboration, fostering research and development, and expanding public-private partnerships will be critical to accelerating the adoption of clean energy solutions while maintaining energy security.

X. CONCLUSION

India’s energy transition is central to mitigating climate change and supporting sustainable development. Renewable energy capacity has quintupled in the last decade, with non-fossil fuel generation comprising 45 percent of total capacity, on track to reach 50 percent by 2030. Targets include 500 GW of non-fossil fuel-based capacity and a 45 percent reduction in emissions intensity. The transition emphasizes green power demand, new technologies, nuclear energy, and energy storage. Comprehensive financial strategies, policy support, and technological innovation are vital for success. With a concerted approach, India is poised to advance its energy transition, achieve sustainable energy goals, and contribute significantly to global climate commitments.



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