InSight Bulletin: A Multidisciplinary Interlink International Research Journal
Peer Reviewed International, Open Access Journal.
ISSN : 3065-7857 / Website: https://ibrj.us / Volume-3, Issue-5 / May - 2026

Original Article

The Dynamics of Electricity Consumption and Economic Growth in India: An Aggregate and Sectoral Analysis

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Manuscript ID:
IBMIIRJ -2026-030501

Submitted: 09 Apr. 2026

Revised: 15 Apr. 2026

Accepted: 05 May 2026

Published: 31 May 2026

ISSN: 3065-7857

Volume-3

Issue-5

Pp. 1-10

May 2026

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OPEN ACCESS

Quick Response Code:

Web. https://ibrj.us

DOI: 10.5281/zenodo.21636906

DOI Link:
https://doi.org/10.5281/zenodo.21636906

Abstract

India's energy sector transformation is paramount to its ambition of achieving sustained high economic growth and establishing itself as a global economic powerhouse.[1] Comprehensive statistical analysis confirms that the nation's economic output remains fundamentally linked to its energy consumption, necessitating careful policy orchestration between stimulating demand and ensuring sustainable supply. This report details the dynamics of this critical nexus, analyzing aggregate dependence, dissecting sectoral drivers, assessing efficiency trends, and synthesizing the resulting policy imperatives based on causality studies. This study critically examines the dynamic relationship between electricity consumption and economic growth in India within the broader framework of sustainable development and energy transition. The research investigates how sectoral electricity demand across industry, agriculture, and domestic consumption has evolved between 2006–07 and 2022–23, reflecting the structural transformation of the Indian economy. The analysis demonstrates that electricity remains a fundamental driver of economic productivity, industrial expansion, urbanization, and agricultural modernization. Industrial electricity demand increased significantly due to rapid industrialization and manufacturing growth, while the residential sector recorded the highest proportional rise as a consequence of urban expansion, rural electrification programs, and changing living standards. Agricultural energy demand also expanded steadily because of mechanization and irrigation requirements.

Keywords: *Electricity Consumption; Economic Growth; Energy-GDP Nexus; Sustainable Development; Renewable Energy; Energy Efficiency; Energy Intensity; Sectoral Electricity Demand; Industrialization; Demand-Side Management.*

Introduction

Energy is one of the most essential drivers of economic growth and social development in the modern world. Among all forms of energy, electricity plays a particularly significant role because it directly supports industrial production, agricultural modernization, technological advancement, transportation, communication systems, and household welfare. In developing economies such as India, the relationship between electricity consumption and economic growth has become increasingly important due to rapid industrialization, urbanization, population growth, and expanding infrastructure requirements. As India aspires to become a major global economic power while simultaneously addressing climate change and sustainability concerns, understanding the dynamics of the energy-growth nexus has become a critical area of academic and policy research.

A. Synopsis of Key Findings

Statistical analysis confirms a strong positive correlation () between Gross Domestic Product (GDP) and total energy use.[2] This relationship is quantified by regression analysis, which demonstrates that total energy consumption explains 85% of the variation in GDP, validating the high dependency of India's production function on a robust energy supply.[2]

Despite this reliance, India is exhibiting significant progress toward sustainability, showcasing progressive decoupling. The Compound Annual Growth Rate (CAGR) of per capita energy consumption has moderated substantially over the last two decades, decreasing from in the 2006–2010 period to in 2021–2023.[2] This trend confirms a structural movement toward energy-efficient growth, supported by technological adoption and targeted efficiency programs.

How to cite this article:
Kunnath, S. (2026). The Dynamics of Electricity Consumption and Economic Growth in India: An Aggregate and Sectoral Analysis. InSight Bulletin: A Multidisciplinary Interlink International Research Journal, 3(5), 1–10. https://doi.org/10.5281/zenodo.21636906

Sectoral demand dynamics between 2006–07 and 2022–23 were overwhelmingly driven by the Industrial sector (rising from GWh to GWh) and the Domestic sector (surging from GWh to GWh).[2] This concurrent growth pattern is characteristic of industrialization coupled with rapidly improving living standards and urbanization.[2]

Policy derived from causality analysis indicates the necessity for a disaggregated approach. Empirical studies show that promotional supply policies are essential for high-yield sectors like Industrial (High Voltage) and Agriculture, where electricity consumption directly drives economic growth. Conversely, general conservation mandates can be applied to other segments without unduly hindering overall economic expansion.[3] Furthermore, India has achieved a significant energy transition milestone: as of June 2025, non-fossil fuel sources contribute (235.7 GW) of the total installed power capacity of 476 GW, aligning the nation squarely on the path toward its 500 GW target by 2030.[4]

B. India's Growth Trajectory and Stable Momentum (2011–2025)

India's recent macroeconomic performance provides the foundation for energy infrastructure planning. Between the fiscal years 2011–12 and 2024–25, the economy maintained a resilient trajectory, achieving a Compound Annual Growth Rate (CAGR) of .[2] This performance is characterized by stable macroeconomic momentum, evidenced by a strong correlation () between GDP and overall growth rates.[2] The low volatility in growth rates, measured by a standard deviation of just , implies a steady and resilient growth pattern that is vital for sustaining large-scale, long-term infrastructure investments necessary for energy transition.[2]

The rise in energy consumption serves as a key metric of this broad-based development. Over the period 2006–2023, per capita energy consumption nearly doubled, rising from 672 kWh to 1331 kWh, reflecting a CAGR.[2] This increase is a tangible outcome of successful electrification efforts and widespread improvements in living standards.[2] Furthermore, policy successes, such as the reduction of power shortages from in 2013–14 to in 2024–25, underpin the stability of this growth trajectory.[4]

Table 1: India's Macroeconomic and Energy Growth Metrics (2006–2025)

Variables	Metric	Value	Interpretation
GDP (2011–25)	CAGR	6.07%	Sustainable, resilient economic growth.
Per Capita Energy (2006–23)	CAGR	4.4%	Reflects broad-based electrification and development.
GDP – Growth Rate	Correlation (r)	0.84	Strong positive correlation (stable momentum).

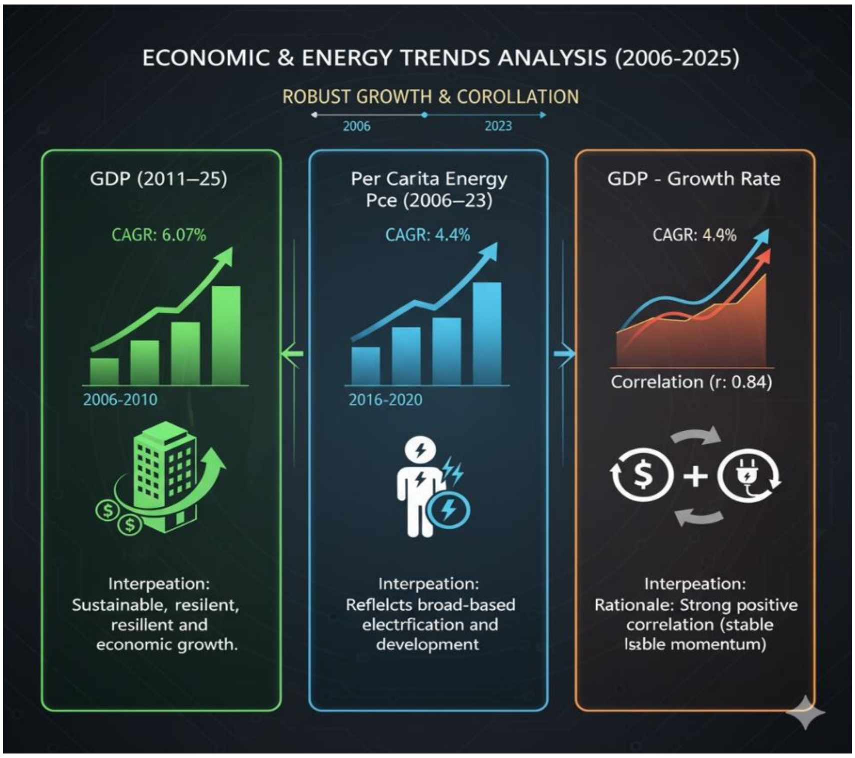


Fig:1

II. Quantitative Analysis of the Energy-Growth Nexus: Statistical Proof of Dependence

The relationship between economic activity and energy use in India is structurally reinforced by strong statistical evidence, indicating that energy is a primary input to the production function rather than a secondary commodity.

A. The Aggregate Relationship: Correlation and Significance

The aggregate statistical linkage between economic output and energy demand is striking. The calculated Pearson's correlation coefficient () between GDP and Total Energy Use is , establishing a very high positive correlation.[2] This level of linkage confirms that economic growth in India is inherently dependent on rising energy demand.

Furthermore, this relationship is observed consistently across different consumption variables. GDP exhibits a strong positive correlation () with Per Capita Energy Consumption, underscoring the tight coupling between national economic expansion and rising individual affluence and access to amenities.[2]

B. Econometric Validation: Regression Analysis

To quantify this dependency, a linear regression model relating GDP to Total Energy Consumption was employed, expressed as .[2] The model fit is exceptionally strong, with an value of . This implies that of the total variation observed in India's GDP is explained by its total energy consumption, validating energy use as a statistically potent explanatory variable for economic output.[2]

The coefficient () for Total Energy Consumption is and is highly significant (). This highly significant coefficient confirms the strong predictive power of the **Growth Hypothesis** in the aggregate context. The interpretation of this coefficient is critical: a increase in total energy consumption is associated with an approximate increase in GDP.[2]

The magnitude of the regression coefficient () indicates a high sensitivity of economic output to energy supply. Since this coefficient is close to unity, any policy or operational action that leads to short-term energy rationing or supply constraints—such as grid instability or fuel shortages—will translate almost directly into economic loss. Maintaining the low volatility in GDP growth () hinges critically on policy success in stabilizing and securing the energy supply chain. Therefore, policymakers must recognize energy system resilience, including fuel stocking, transmission hardening, and dispatch stability, as a primary function of macroeconomic stabilization.

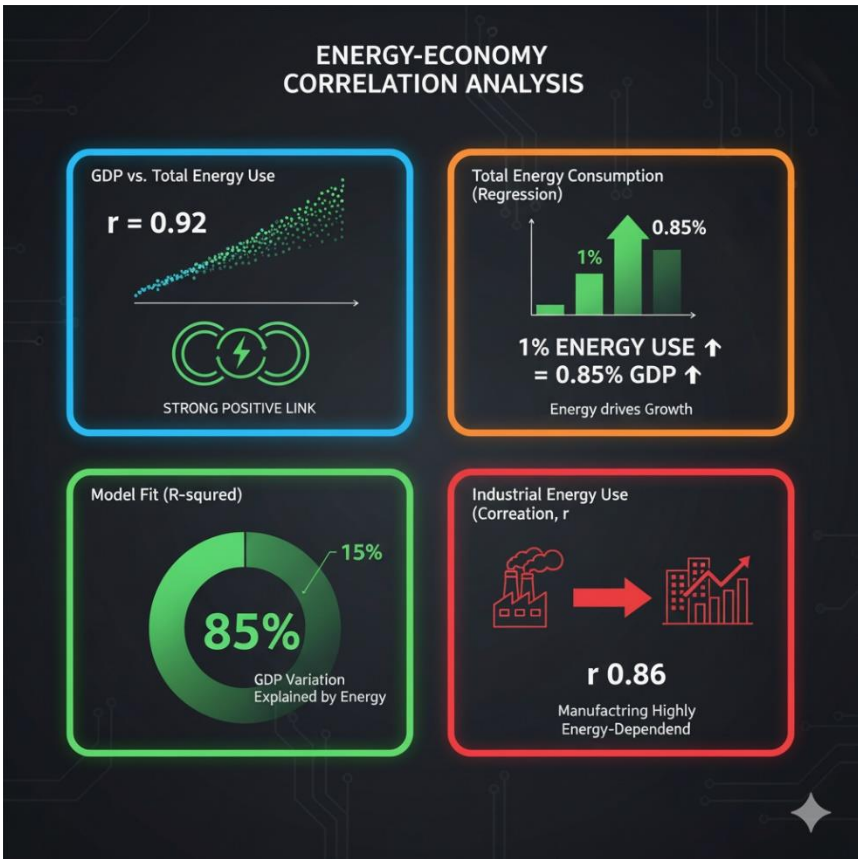
C. The Sectoral Dimension of GDP Correlation

The sectoral correlations with GDP reinforce where the energy input is most productive. Industrial energy use maintains a high correlation of with GDP.[2] This figure highlights that the manufacturing sector, which drives significant job creation and export earnings, remains structurally energy-intensive and highly dependent on reliable power.[2]

Furthermore, the Household energy use correlation () is substantial.[2] This confirms that economic growth translates into increased urbanization and fundamental shifts in residential energy demands, driven by appliance penetration and improved access to electricity. The strength of this correlation validates the effectiveness of policies aimed at universal household electrification (such as the PM JANMAN scheme) as they function not merely as social welfare measures but as robust economic multipliers, sustaining critical demand-side economic activity, digital commerce, and overall productivity.[4]

Table 2: Econometric Validation of GDP–Energy Nexus

Metric	Value	Interpretation
GDP vs. Total Energy Use (Correlation, *r*)	0.92	Strongest aggregate positive link.
Total Energy Consumption (Regression)	0.845	1% energy use increase 0.85% GDP increase.
Model Fit ()	0.85	85% of GDP variation explained by energy use.
Industrial Energy Use (Correlation, *r*)	0.86	Manufacturing sector remains highly energy-dependent.



III. Aggregate Sectoral Electricity Consumption Dynamics

An analysis of consumption trends across the primary, secondary, and tertiary sectors reveals the structural transformation occurring in the Indian economy between 2006–07 and 2022–23.

A. Deep Dive into Sectoral Demand Growth (2006–2023)

Over the 17-year period analyzed, total sectoral energy demand increased sharply, reflecting concurrent expansion in all major economic segments.[2]

Industrial Consumption

The Industry sector, the backbone of the secondary economy, saw its energy demand increase from GWh to GWh.[2] This significant rise reflects deep industrialization, expansion of manufacturing capacity, and continuous economic liberalization, reinforcing the sector's high correlation with GDP growth ().[2]

Domestic (Residential) Consumption Surge

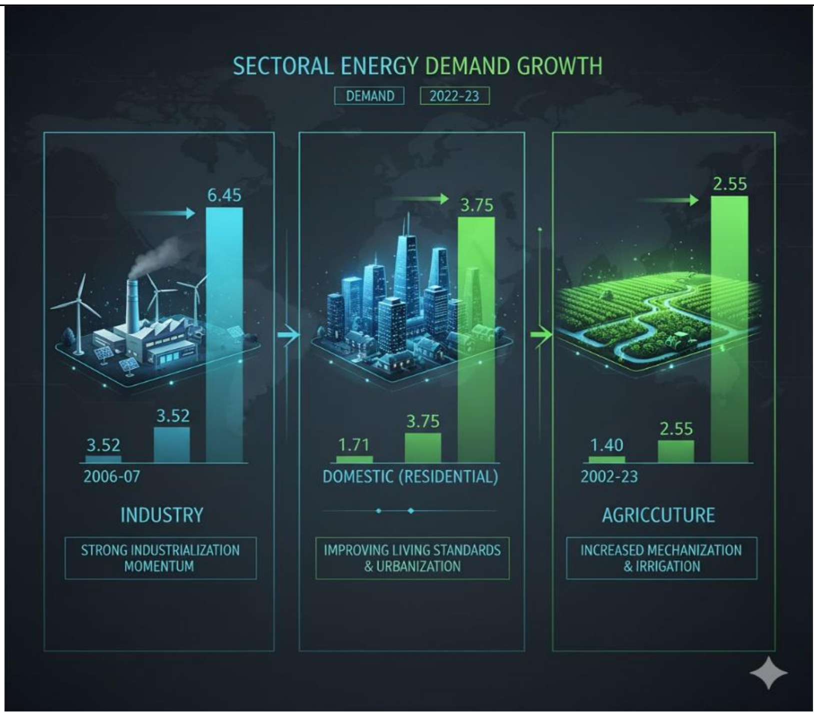
The Domestic or Residential sector experienced the highest proportional growth. Demand escalated from GWh to GWh.[2] This surge is a direct consequence of rapid urbanization, successful household electrification initiatives (such as SAUBHAGYA), and fundamental shifts in lifestyle, leading to increased utilization of electrical appliances and cooling solutions.[2]

Agricultural Mechanization

Energy demand in the Agriculture sector rose from GWh to GWh.[2] This continuous expansion is driven by the growing need for enhanced water security through electric pumping and increased agricultural mechanization, which are critical components for stabilizing the primary sector's contribution to GDP.[3]

Table 3: Aggregate Sectoral Demand Growth (2006–07 vs. 2022–23)

Sector	Demand 2006–07 ()	Demand 2022–23 ()	Interpretation
Industry	3.52	6.45	Strong industrialization momentum.
Domestic (Residential)	1.71	3.75	Reflects improving living standards and urbanization.
Agriculture	1.40	2.55	Driven by increased mechanization and irrigation.



B. Sectoral Elasticity and Productivity Prioritization

Analysis of sectoral elasticity confirms that providing reliable power to the high-elasticity secondary (industrial) and tertiary (commercial/services) sectors is an optimized allocation strategy for maximizing GDP growth.[6] These sectors often exhibit elasticity greater than unity, meaning that investments in quality power supply yield disproportionately higher economic returns.[6]

The reliability and quality of power supply are paramount. Policies must focus on infrastructural improvements such as universal metering, reducing financial losses, and ensuring reliable, high-quality power delivery across all essential sectors.[7]

While historical demand data focuses on traditional sectors, the nature of economic growth is necessitating a refinement of demand forecasting. Globally, specialized, high-density computing loads, notably from Data Centers and Artificial Intelligence (AI), are projected to double their electricity consumption by 2026.[9] In the Indian context, where the tertiary sector demonstrates high elasticity, this future demand is significant, highly concentrated, and requires ultra-reliability (e.g., constant cooling and continuous supply) that is not fully captured by the conventional "Industrial" category. Therefore, future energy planning requires the establishment of a new, distinct category for high-density computing and commercial demands to accurately forecast this specialized load and ensure the necessary grid infrastructure and power quality are provisioned to sustain India's rapidly expanding digital economy.[9]

Concurrently, the rapid, proportional growth in the domestic sector poses a unique challenge to peak load management. The surging domestic use, particularly during weather extremes, drives unpredictable peak demand, which is inherently more difficult to manage than the more predictable industrial loads.[10] If this domestic surge is not actively managed, it risks undermining the efficiency gains achieved elsewhere in the economy. The policy response must therefore pivot toward robust **Demand-Side Management (DSM)** and active peak load reduction. Schemes such as the PM-Surya Ghar program, which targets the addition of 30 GW of rooftop solar across 1 crore households, are critical because they simultaneously meet immediate domestic energy needs while reducing the peak load pressure on the centralized utility grid, particularly during high-sunlight hours.[4]

IV. Sustainability and the Decoupling Trajectory

While India's economic growth remains energy-dependent, substantial evidence suggests that the nation is progressing toward structural decoupling, defined as the ability to increase GDP without a proportionate increase in energy consumption.

A. Efficiency Improvement Trends and Declining Energy Intensity

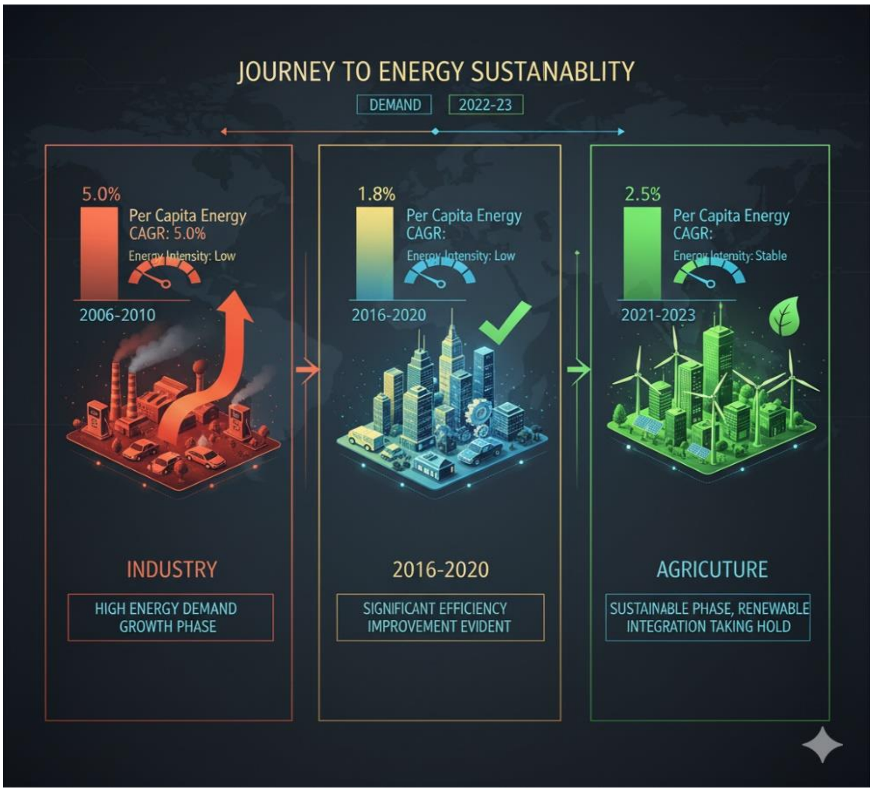
The trend analysis over the past two decades provides concrete evidence of increasing energy efficiency and declining energy intensity (GDP per GWh).

The initial period, 2006–2010, was a high-growth phase characterized by the highest Per Capita Energy CAGR () and "Low" energy intensity, indicative of rapid, energy-hungry expansion.[2] Policy initiatives and structural shifts began taking effect in the 2011–2015 period, where the CAGR moderated to and energy intensity was "Improving".[2]

A significant success period was 2016–2020, during which the CAGR for per capita energy consumption dropped to its lowest point, , and energy intensity was categorized as "Strong," confirming evident efficiency improvements.[2] In the most recent period, 2021–2023, the CAGR stabilized at , interpreted as a "Sustainable phase, renewable integration".[2] This stability indicates that the structural trend toward efficiency is holding, and new energy demands are increasingly being met by cleaner, more efficient sources.

Table 4: Trend Analysis of Energy Efficiency and Decoupling (2006–2023)

Year Range	Per Capita Energy CAGR (%)	Energy Intensity (GDP per GWh)	Sustainability Interpretation
2006–2010	5.0%	Low	High energy demand growth phase.
2016–2020	1.8%	Strong	Significant efficiency improvement evident.
2021–2023	2.5%	Stable	Sustainable phase, renewable integration taking hold.



B. The Decoupling Phenomenon and Policy Enablement

The overall trajectory confirms structural decoupling: the rate of energy use growth is consistently slower than the rate of GDP growth.[2] This is fundamentally necessary for long-term sustainability, as it allows economic progress to continue without proportional increases in resource depletion or carbon emissions.[2] This shift is supported by deliberate policy mandates focused on leveraging cleaner technologies, investing in efficient infrastructure, and pushing for digital transformation across the energy value chain.[2]

India's success in achieving efficiency gains positions it favorably in the global context. Given its historically low per capita electricity use, which results in per capita emissions well below the global average [5], the observed reduction in energy CAGR demonstrates that rapid economic development and decarbonization efforts can be pursued concurrently, strengthening India's commitment to Sustainable Development Goals 7 and 13.[2]

C. Renewable Integration and the Marginal Supply Challenge

Renewable energy adoption, particularly through solar and wind capacity additions, is central to stabilizing total energy consumption growth while sustaining economic output.[2] India has demonstrated remarkable scale-up, increasing its solar capacity by more than 39 times since 2014.[4] The existing policies, such as the National Solar Mission and the PAT scheme, are crucial components in this clean energy transition.[2]

However, the efficacy of this transition is constrained by the challenge of meeting marginal demand growth. While renewables provide substantial aggregate capacity, thermal power remains the critical marginal supplier necessary to meet instantaneous demand spikes and grid volatility. In 2024, coal generation met of India's *new* electricity demand growth, albeit a sharp drop from in 2023.[12] This reliance underscores that meeting the ambitious non-fossil fuel capacity target (49% as of 2025) is only the first step (energy *quantity*). To fully displace thermal power, investment priority must shift to energy *quality*—specifically, grid flexibility, energy storage, and transmission hardening.[1] Strategically allocating capital towards these flexibility mechanisms is essential to ensuring that the committed 500 GW of renewable capacity by 2030 can be effectively utilized and integrated, maximizing its potential to displace fossil fuels at the margin.

V. Synthesizing the Causality Debate and Policy Implications

Understanding the causal relationship between electricity consumption and economic growth is critical for formulating effective policy. Since energy is a limited resource, misinterpreting the direction of causality can lead to policies that either unnecessarily restrict economic growth (if consumption drives GDP) or fail to achieve conservation targets (if GDP drives consumption).

A. Overview of Causality Hypotheses and Empirical Ambiguity

Aggregate research on the energy-GDP nexus in India yields complex and often inconclusive results. Empirical studies frequently show fluctuations among the Neutrality Hypothesis (implying conservation policies have no effect on growth), the Conservation Hypothesis (GDP drives energy consumption), and short-run Bi-directional Causality (where both influence each other).[7]

This ambiguity confirms a key methodological insight: a unified, single national energy policy (e.g., blanket conservation mandates) will be suboptimal and potentially damaging. The mixed results underscore the necessity of moving beyond aggregate analysis toward a disaggregated, sector-specific policy framework informed by localized causality findings.[3]

B. Sector-Specific Causality: The Basis for Targeted Policy

Sectoral analyses using advanced methods, such as frequency domain approaches, reveal distinct causal patterns that mandate differential policy responses:

Sectors Requiring Promotional Policy (Growth Hypothesis Support)

For the Industrial (High Voltage) sector and the Agricultural sector, evidence strongly suggests a **unidirectional causality running from electricity consumption to economic growth** in both the short and long term.[3] This confirms that electricity is a limiting factor in production for these segments.

- **Industrial (HV) Policy:** For the HV industrial sector, a power consumption *promotional* policy ensuring adequate and reliable supply is necessary to maximize manufacturing output and overall economic expansion.[3] Implementing conservation policies here would directly impede GDP growth.
- **Agricultural Policy:** Similarly, promotional policies are vital for agriculture to support mechanization, irrigation, and water security.[3] The failure to provide quality power directly limits the primary sector's ability to mechanize and add value.[6]

Sectors Allowing Conservation Policy

In sectors where the causality link is weak, non-existent, or bi-directional (e.g., general consumption, parts of the commercial sector), conservation strategies may be implemented without directly sacrificing long-term economic expansion.[3]

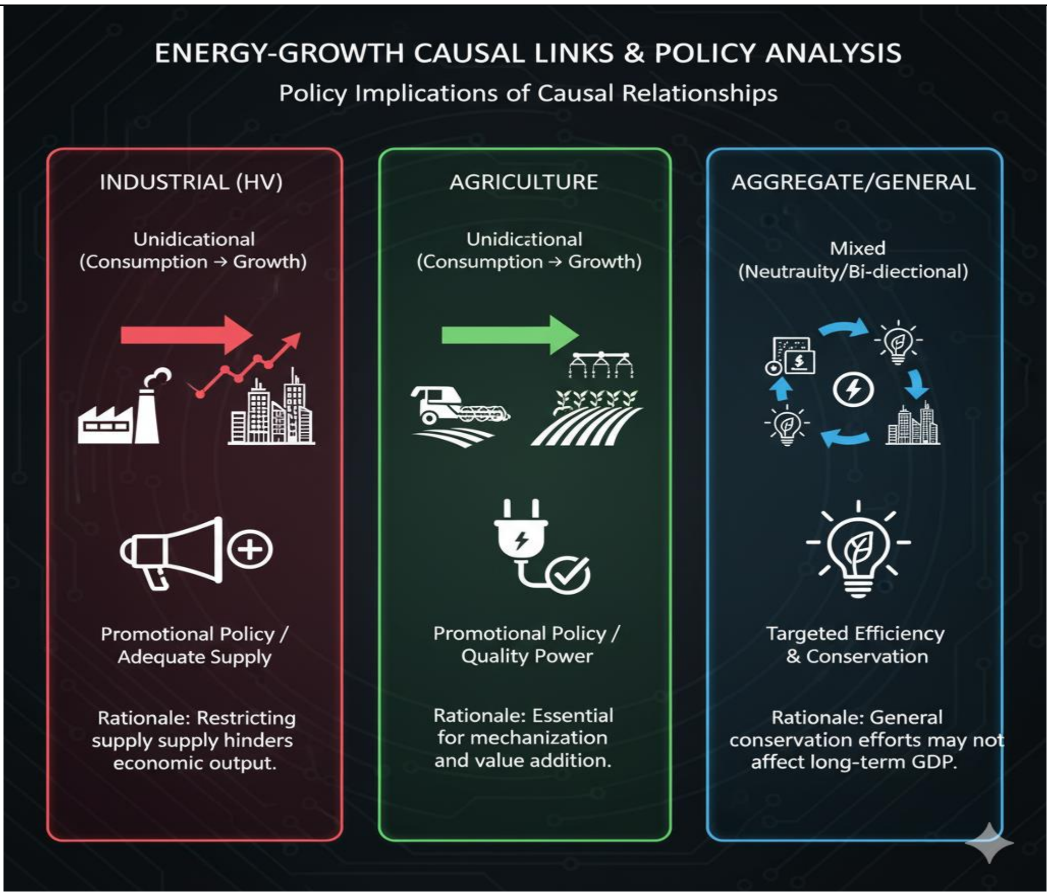
C. Policy Intervention for Efficiency and Financial Viability

While promotional policies are essential for growth-critical sectors, this approach historically risks erosion of the financial health of Distribution Companies (DISCOMs) due to high cross-subsidization and leakages.[6] To sustain the critical causal link without financially crippling the energy distribution system, policy must strategically decouple welfare support from energy pricing. Initiatives like the PM-KUSUM scheme, which promotes solar pump adoption for farmers, move toward ensuring agricultural energy security while mitigating the financial strain of subsidized grid power.[4] This structural change ensures the economic causal link remains effective and financially viable.

Furthermore, policy must leverage temporal analysis. Studies using frequency domains show that causality can differ between short-run demand responses and long-term capacity requirements. For instance, in sectors exhibiting short-term bi-directional causality, flexible pricing signals and dynamic tariff structures enabled by smart grid technology are often more effective than rigid supply mandates. This approach allows policymakers to manage short-run consumption volatility and optimize energy allocation dynamically.[3] Given the importance of electricity, intervention from regulatory commissions is essential to reduce technical and commercial losses (leakages) and ensure generation capacity is efficiently utilized, thereby directly contributing to economic productivity.[6]

Table 5: Summary of Sectoral Causality and Policy Recommendations

Sector	Causal Relationship (General Finding)	Policy Implication	Rationale (Causal Link)
Industrial (HV)	Unidirectional (Consumption Growth)	Promotional Policy / Adequate Supply	Restricting supply hinders economic output.[3]
Agriculture	Unidirectional (Consumption Growth)	Promotional Policy / Quality Power	Essential for mechanization and value addition.[3]
Aggregate/General	Mixed (Neutrality/Bi-directional)	Targeted Efficiency & Conservation	General conservation efforts may not affect long-term GDP.[7]



VI. Strategic Outlook and Future Policy Roadmap

India's energy roadmap is guided by ambitious decarbonization goals, anchored by the commitment to achieve Net Zero emissions by 2070.[16] The immediate strategic horizon focuses on achieving the 2030 targets through massive capacity scale-up and infrastructure modernization.

A. The Current Energy Mix and Transition Challenge (June 2025)

As of June 2025, India's total installed power capacity reached 476 GW.[4] Non-fossil fuel sources now contribute GW, accounting for of this total, composed of GW of renewable energy and GW of nuclear power.[4] This milestone positions India firmly on track to meet its goal of non-fossil fuel capacity by 2030.

However, thermal power remains functionally dominant, accounting for GW, or of the installed capacity.[4] To ensure short-term energy security and meet soaring demand, India is expanding domestic coal mining.[12] This expansion creates a significant climate challenge, particularly regarding methane emissions—a potent greenhouse gas. To align short-term security with long-term climate commitments, regulatory reforms and incentives are immediately required to promote the capture and utilization of fugitive methane, a measure that could mitigate over 1.6 Mt of emissions by 2030.[12]

B. Roadmap to 2030 and Beyond (Net Zero 2070)

The GW non-fossil fuel capacity target by 2030 remains the key performance indicator for the decade.[2] Complementing this, deep decarbonization efforts are institutionalized through initiatives like the National Green Hydrogen Mission (NGHM), launched in January 2023.[4] The NGHM aims to achieve a Green Hydrogen production capacity of approximately 5 MMT per annum by 2030, specifically targeting the decarbonization of hard-to-abate sectors like heavy industry and transportation.[4]

Key policy schemes are concurrently driving decentralized power generation and energy access:

- **PM-Surya Ghar: Muft Bijli Yojana:** Launched in February 2024, this program aims to integrate 30 GW of solar capacity into the residential sector by providing free electricity to 1 crore households through rooftop solar systems.[4] This initiative enhances energy access while simultaneously reducing peak-hour grid stress.
- **PM-KUSUM Scheme:** This initiative, targeting 34.8 GW of solar capacity, is central to enhancing energy and water security for the agricultural community, directly supporting the high-yield primary sector.[4]
- **Grid Modernization:** Continued investment in the unified national power grid and technological advancements (as reflected by the drastic reduction in power shortages) is vital for ensuring resilience and facilitating the integration of intermittent renewable sources.[1]

The burgeoning digital economy introduces a new factor into future infrastructure planning. Global electricity demand from Data Centers, fueled by Artificial Intelligence, is projected to surge dramatically.[9] Given the high elasticity and concentrated nature of this commercial and tertiary sector demand [6], India must ensure that its grid expansion anticipates this specialized, massive energy requirement to maintain its competitive advantage. Strategic investment allocation is therefore required for ultrahigh reliability transmission infrastructure specifically targeting major digital and financial hubs, potentially utilizing dedicated renewable energy supply chains to moderate the overall carbon footprint of this rapidly growing consumption segment.[9]

Table 6: India's Energy Capacity and 2030 Targets (2025 Snapshot)

Metric	Value (June 2025)	2030 Target
Total Installed Capacity	476 GW	-
Non-Fossil Fuel Capacity	235.7 GW (49%)	500 GW (50%)
Thermal Power Capacity	240 GW (50.52%)	Declining Share
Green Hydrogen Production	-	5 MMT per annum

VII. Concluding Strategy: Achieving Sustainable, Energy-Driven Growth

India's economic landscape is defined by the dual challenge of sustaining a high growth rate (CAGR) while aggressively decarbonizing its energy mix to meet global climate commitments. The analysis confirms that high GDP dependence on energy consumption () necessitates continuous prioritization of energy system resilience and supply reliability as a core element of macroeconomic stabilization.

The central strategic challenge lies in maximizing the benefits of the massive renewable capacity additions. While India is successfully meeting its non-fossil fuel *quantity* targets (49% achieved by 2025), future policy must pivot toward solving the energy *quality* issue. Investment capital must be strategically allocated to grid flexibility, large-scale storage, and advanced transmission infrastructure to ensure that clean energy effectively displaces thermal generation as the marginal power source.

Furthermore, the insights derived from sectoral causality studies mandate granular, differential policy implementation. Promotional supply policies must be reinforced for critical, high-elasticity sectors (Industrial HV and Agriculture) where consumption directly drives growth. Concurrently, targeted efficiency programs and demand-side management, particularly for the surging Domestic sector (which is straining peak load management), must be rigorously pursued to maintain the trajectory of structural decoupling and ensure sustainable, energy-driven economic progress.

Acknowledgment
I would like to express my sincere gratitude to all those who contributed to the successful completion of this research work. First and foremost, I extend my heartfelt thanks to my guide and mentor, Dr. Sara Kunnath, for her valuable guidance, continuous encouragement, constructive suggestions, and constant support throughout the preparation of this study.

Financial support and sponsorship
Nil.

Conflicts of interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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