Page 252 - 262 ***DOI:*** *https://doij.org/10.10000/IJLMH.119678*

INTERNATIONAL JOURNAL OF LAW MANAGEMENT & HUMANITIES

[ISSN 2581-5369]

Volume 8 | Issue 3

2025

India's Energy Landscape: Challenges and Future Prospects

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ABSTRACT

India's swift economic expansion has resulted in a significant rise in energy demand, positioning it as the third-largest energy consumer worldwide. Nevertheless, a combination of financial, infrastructure, and regulatory limitations make guaranteeing a steady, reasonably priced, and sustainable energy supply an extremely difficult task. The whole country is mostly reliant on fossil resources, and integration problems still exist despite efforts to switch to renewable energy.

India's energy landscape is examined in this study through an analysis of its energy mix composition, trends in consumption across important industries, and patterns of energy supply and demand. It also looks at government programs and policies meant to address issues of energy security and advance sustainability. Important issues like energy poverty, inefficient infrastructure, environmental issues, and power distribution companies' (DISCOMs') financial difficulties are also highlighted in the study. It also looks at how strategic energy collaborations, private sector participation, and foreign investments have shaped India's energy future.

Finally, this study discusses the future outlook for India's energy sector, emphasizing policy reforms, technological advancements, and international collaborations as crucial drivers of transformation. Addressing these challenges through a holistic and integrated approach, which includes expanding green hydrogen initiatives, improving grid connectivity, and leveraging AI-driven energy solutions, will be pivotal in safeguarding India's energy security and sustainability in coming decades.

Keywords: *India energy security, renewable energy, fossil fuels, energy policy, grid modernization, energy access, sustainable development*

I. INTRODUCTION

The energy landscape of India is influenced by its expanding economic ambitions, swift urbanization, and a rising population. India, the world's third-largest energy user, has seen a significant increase in energy demand due to industrialization and a rising middle class. Despite

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 [ISSN 2581-5369]

rising demand, India's per capita energy consumption is still lower than the global average, pointing to substantial latent demand[3].

This discrepancy indicates that millions of households, particularly in rural and semi-urban areas, still lack consistent access to energy. The divergence in energy consumption patterns between urban and rural areas underscores the necessity for focused measures to enhance electrification and distribution. Moreover, industrial growth continues to be energy-intensive, necessitating advanced solutions for improving energy efficiency and optimizing grid performance. India is investing in distributed renewable energy systems, including rooftop solar panels, microgrids, and advanced energy management systems, to overcome these deficiencies. These technologies aim to enhance energy security and support long-term economic development.

Ensuring an equitable and sustainable supply of energy is crucial for India's socio-economic development. The country encounters a paradox wherein, despite its abundance of energy resources, a substantial portion of the population continues to struggle with inconsistent power access. This predicament is further intensified by India's reliance on fossil fuels, which still constitute over 75% of the energy portfolio, coupled with pressing environmental implications arising from their usage.

India's energy demand is growing at an unprecedented rate, necessitating a comprehensive approach to energy security, affordability, and sustainability. While the government has set ambitious renewable energy targets, challenges related to grid integration, energy storage, and financing persist.

In response, India has undertaken ambitious initiatives to transition towards clean energy sources and enhance energy conservation efforts. Government has launched schemes such as the National Solar Mission, the Green Energy Corridor Project, and the push for offshore wind energy to diversify the energy mix. Additionally, efforts to enhance energy efficiency through smart grids, demand-side management, and digital monitoring of power distribution have gained momentum.

Despite these initiatives, issues such as regulatory bottlenecks, land acquisition challenges, and inadequate private sector participation continue to hinder progress. This paper provides an in-depth analysis of India's energy landscape, incorporating recent developments in fossil fuel exploration, nuclear energy expansion, and the challenges in the electricity sector, while also

[3] Karthik Ganesan and Rajeev Vishnu, 'Energy Access in India: Today and Tomorrow' (2014) 16 CEEW Working Paper.

 [ISSN 2581-5369]

assessing the effectiveness of existing policies and suggesting pathways for future development[4].

II. INDIA'S ENERGY DEMAND AND SUPPLY

With the rapid pace of urbanization, industrial expansion, and a growing population, India's energy needs are projected to escalate substantially. The nation's energy usage is projected to double by 2040, driven by increasing household incomes, higher industrial output, and growing demand for transportation fuels. The government is striving to meet this demand while balancing energy security, affordability, and environmental sustainability.

One of the primary challenges in India's energy supply is its heavy reliance on fossil fuel imports. Despite ranking among the world's top coal producers, India still imports a considerable volume to satisfy its energy demands. Similarly, over 80% of its crude oil is imported, making the country highly vulnerable to global price fluctuations and geopolitical risks. To lessen reliance on imports, India has expanded national petroleum and gas exploration through initiatives such as the Hydrocarbon Exploration and Licensing Policy (HELP), which provides attractive investment options for both international and private businesses.

In addition to fossil fuels, India's electricity demand is increasing at a rate of 6-7% annually. The government has taken measures to increase power generation capacity, but challenges remain in transmission and distribution. Many regions experience numerous power outages owing to aged infrastructure, high transmission losses, as well as financial instability of power distribution companies (DISCOMs). Addressing these issues requires significant investment in grid modernization, improved storage solutions, and efficient energy distribution.

Renewable energy has emerged as a crucial component of India's energy supply strategy. The country has set ambitious targets, including obtaining 500 GW of non-fossil fuel-based energy by 2030. However, integrating large-scale renewable energy into the grid presents challenges, such as intermittent supply and the need for enhanced energy storage technologies. To overcome these concerns and maintain a consistent power supply, hybrid energy solutions combining solar, wind, and battery storage are being investigated.

Additionally, India is investing in decentralized energy solutions such as microgrids and distributed renewable energy systems. These initiatives are particularly crucial for rural and remote areas, where grid connectivity remains a challenge. Off-grid solar power projects and

[4] Sairam Bhat (ed), Energy Law and Policy in India (NLSIU Book Series 2, Bengaluru 2016) 38

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small-scale hydropower plants have been successful in supplying electricity for communities in need.

Overall, while India has made tremendous progress in growing its energy supply, ongoing issues in infrastructure, funding, and regulatory frameworks must be addressed in order to maintain a stable, secure, and long-term energy future.

III. ENERGY MIX: FOSSIL FUELS, RENEWABLES, AND NUCLEAR EXPANSION

India's energy balance remains strongly reliant on fossil fuels, which account for approximately 75-80% of total energy consumption.[5] Coal continues to be the primary source of electricity generation, accounting for more than half of the country's power supply. However, rising coal production costs, inefficiency in mining, and environmental concerns are driving India toward other energy sources. The country has also been focusing on cleaner fossil fuel technologies, including the use of ultra-supercritical coal plants and carbon capture mechanisms to reduce emissions[6].

Oil and natural gas play important roles in India's energy environment, with more than 80% of crude oil imported to meet domestic demand. Global oil price volatility and geopolitical instability threaten India's energy security. To mitigate these risks, the government has implemented plans such as the Strategic Petroleum Reserves (SPR) program and has been actively encouraging domestic investigation under the Open Acreage Licensing Policy (OALP) to boost original production[7] .

A key component of India's long-term energy policy is now renewable energy. By 2030, the nation hopes to reach its lofty goal of 500 GW of non-fossil fuel capacity. Government-supported programs have fueled the explosive rise of solar and wind energy like National Solar Mission and state-level wind energy plans[8]. The growth of renewable projects is still being slowed, though, by obstacles including land acquisition, high capital costs, and problems with grid connectivity. The creation of offshore wind farms, hybrid energy parks, and massive battery storage systems to maintain grid stability are some of the initiatives aimed at overcoming these challenges.

[5] Planning Commission, Government of India, Integrated Energy Policy (2006) http://planningcommission.nic.in accessed 20 March 2025.
6 World Energy Council, India Energy Scenarios 2047 (2025) https://www.worldenergy.org accessed 20 March 2025.
[7] Ministry of Petroleum and Natural Gas, Government of India, Official Website https://mopng.gov.in accessed 20 March 2025.
[8] Ibid

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Bioenergy and hydropower are also becoming more popular as sustainable energy sources. In distant areas, small-scale hydro projects have proven very successful in offering decentralized energy solutions. Initiatives for biomass and waste-to-energy have also been pushed as ways to manage urban and agricultural trash and improve sustainability.

As part of its plan to diversify its power generation mix, India is also making substantial progress in developing its nuclear energy capabilities. The nation's goal is to boost nuclear power from 8.2 GW to 100 GW over the next twenty years[9]. In order to close the energy gap and lower carbon emissions, new initiatives are being undertaken, such as pressurized heavy-water reactors (PHWRs) and partnerships with foreign countries. But there are obstacles to public and regulatory acceptability of nuclear growth, especially when it comes to safety and land acquisition.

Going forward, stronger technology advancements, better financial incentives, and ongoing policy improvement will be needed to achieve a balanced energy mix. To ensure a seamless transition to a more sustainable and energy-secure future for India, it will be essential to integrate renewables with the country's current fossil fuel infrastructure, grow smart grid networks, and improve energy storage capacity.

IV. THE ROLE OF ENERGY POLICY AND REGULATIONS

Facilitating India's energy transition requires a well-organized regulatory and policy framework. India has established a thorough legislative and policy framework to support energy efficiency, sustainability, and security over the years. The energy sector is governed by a number of important laws and regulatory agencies that influence its development toward a more sustainable future.

India's long-term energy planning is based on the Integrated Energy Policy (IEP), which was established in 2006 and places a strong emphasis on energy diversification and sustainability[10]. A historic law known as the Electricity Act of 2003 reorganized the power industry by guaranteeing consumer protection, permitting private sector involvement, and bringing competition. Additionally, it required state electrical boards to be separated into independent organizations for distribution, transmission, and generation to improve efficiency[11].

[9] Department of Atomic Energy, Government of India, Official Website https://dae.gov.in accessed 20 March 2025.
[10] Planning Commission, Government of India, Integrated Energy Policy (2006) http://planningcommission.nic.in accessed 20 March 2025.
11 Electricity Act 2003 (India) s 42.

In order to encourage the use of renewable energy, the government passed the Energy Conservation Act of 2001, creating the Bureau of Energy Efficiency (BEE) to encourage energy-saving practices in homes and businesses. Additionally, the National Tariff Policy of 2016 offers recommendations for guaranteeing reasonably priced power while encouraging the production of renewable energy through obligatory renewable purchase obligations (RPOs)[12].

Numerous initiatives have been introduced to promote the use of clean energy and increase energy efficiency. By offering marketable energy-saving certificates, the Perform, Achieve, and Trade (PAT) program of the National Mission for Enhanced Energy Efficiency (NMEEE) encourages enterprises to lower particular energy use. Likewise, required firms can fulfill their renewable purchase duties through the Renewable Energy Certificates (REC) method, via market-based trading[13].

Additionally, India has strengthened its power distribution sector through policy and financial initiatives. By restructuring their debts and increasing operational efficiency, the Ujwal DISCOM Assurance Yojana (UDAY) was created to alleviate the financial difficulties faced by power distribution firms (DISCOMs). Launched in 2021, the Revamped Distribution Sector Scheme (RDSS) aims to save aggregate technical and commercial (AT&C) losses, modernize distribution networks, and promoting smart metering to augment income collection.[14]

The National Action Plan on Climate Change (NAPCC)'s National Solar Mission seeks to position India as a world leader in solar power generation in the field of renewable energy. Offshore Wind Energy Policy, 2015, facilitates project approvals and offers financial incentives to further encourage the development of wind energy for offshore wind farms.[15]

Regulatory agencies like the Central Electricity Regulatory Commission (CERC) and State Electricity Regulatory Commissions (SERCs) are essential to the power sector's tariff setting, market control, and dispute settlement as it moves toward a low-carbon economy. Furthermore, NITI Aayog's Draft National Energy Policy describes future policy paths for attaining energy self-sufficiency through the development of energy storage and the spread of renewable energy, and electric mobility advancement.[16]

In the future, further policy improvements, improved enforcement measures, and increased private sector participation will be critical to guaranteeing India's energy security and

12 Energy Conservation Act 2001 (India) s 14.
[13]Ministry of Power, Government of India, Official Website https://powermin.gov.in accessed 20 March 2025.
[14] Ibid.
[15]Ministry of New and Renewable Energy, Government of India, Official Website https://mnre.gov.in accessed 20 March 2025.
[16] NITI Aayog, Draft National Energy Policy (2017) https://niti.gov.in accessed 20 March 2025.

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sustainability. Strengthening legislative frameworks to encourage foreign investment, streamlining project approval processes, and incorporating emerging technologies like green hydrogen and battery storage into the regulatory framework will all be critical to India's energy transition success. The Integrated Energy Policy (IEP), implemented in 2006, prioritizes energy security, diversity, and sustainability. Similarly, the Electricity Act of 2003 has helped to restructure the energy sector by increasing private sector participation and establishing a competitive market environment.

The government has launched programs including the Perform, Achieve, and Trade (PAT) scheme to improve industrial energy efficiency, as well as the Faster Adoption and Manufacturing of Electric Vehicles (FAME) project to promote electric transportation. Furthermore, the Ujwal DISCOM Assurance Yojana (UDAY) was implemented to improve the financial situation of power distribution firms by reducing losses and permitting required infrastructure expenditures.

Furthermore, measures like the Renewable Energy Certificates (REC) mechanism and Viability Gap Funding (VGF) for solar and wind projects have helped to drive private investment in the renewable sector. The regulatory landscape is also changing to accommodate energy storage technology and hybrid power projects, resulting in improved grid stability and reliability. As India advances, ongoing policy evolution and regulatory adjustments will be crucial for accomplishing its energy transition objectives.[17]

V. CHALLENGES IN INFRASTRUCTURE AND ENERGY ACCESS

Millions of people in rural areas still do not have consistent access to electricity, despite government efforts. The problem is complex and includes administrative inefficiencies, financial limitations, and shortcomings in the physical infrastructure. Many isolated areas continue to rely on antiquated and unreliable transmission networks, which leads to frequent power outages and subpar electricity supplies. Major financial investment is needed to expand and modernize these networks, and many state-owned distribution firms (DISCOMs) find it difficult to obtain this funding.

The high rate of aggregate technical and commercial (AT&C) losses, which include transmission inefficiencies, power theft, and billing-related problems, is one of the main causes for concern. These losses put a burden on DISCOMs' financial stability, prohibiting them from expanding their infrastructure and improving service quality as needed. Electricity distribution

[17] Planning Commission, Government of India, Integrated Energy Policy (2006) http://planningcommission.nic.in accessed 20 March 2025.

inefficiencies are made worse by a lack of smart grid technology and real-time monitoring systems, which makes it challenging to efficiently balance supply and demand.

Connectivity in the last mile is another significant obstacle. Despite the expansion of grid infrastructure brought about by rural electrification projects, bureaucratic obstacles, land acquisition issues, and budgetary limitations continue to keep many people and businesses unplugged. Many places are forced to rely on costly and unreliable diesel generators or biomass-based energy sources since the high cost of installing electricity lines to isolated communities deters investment.

Additionally, a significant problem for lower-income groups continues to be access to reliable and reasonably priced electricity. Due to financial limitations, many rural households find it challenging to pay for regular power use. There are financial aid programs and subsidies, but their efficacy is sometimes restricted by ineffective execution and fund release delays.

Energy infrastructure is also under risk from climate-related vulnerabilities. Cyclones, floods, and heat waves are examples of extreme weather occurrences that have frequently destroyed electricity transmission lines and substations, resulting in extended outages in the impacted areas. Energy security in susceptible areas can be improved by integrating decentralized renewable energy sources like microgrids and standalone solar systems and fortifying energy infrastructure to withstand the effects of climate change.

A multifaceted strategy is required to address these issues. AT&C losses can be considerably decreased by investing in smart grid technology, digital invoicing systems, and theft prevention measures. Public-private partnerships (PPPs) can also guarantee effective service delivery and assist in funding infrastructure expansion. Targeted financial incentives for rural consumers, along with better enforcement of electrification schemes, can bridge the urban-rural energy divide and promote inclusive energy access for all[18]. Progress is hampered by poor transmission networks, significant distribution losses, and power distribution companies' (DISCOMs') financial difficulties. Outdated infrastructure also adds to inefficiency, which raises consumer electricity bills.

The financial sustainability of DISCOMs is still a major issue; they are hampered by accrued debt and operational inefficiencies, which result in frequent power outages and the inability to maintain equipment. The problem is made worse by a lack of last-mile connectivity, which keeps rural residents from taking advantage of electrification initiatives.

[18] Registrar General & Census Commissioner, India, Census of India 2011 (2011) https://censusindia.gov.in accessed 25 March 2025.

 [ISSN 2581-5369]

Expanding equitable and dependable energy access requires improving grid infrastructure, integrating cutting-edge smart grid systems, and guaranteeing financial viability in the power industry. Government-backed programs like the Revamped Distribution Sector Scheme (RDSS) are examples of recent efforts that aim to increase service dependability, minimize aggregate technical and commercial (AT&C) losses, and upgrade distribution networks. In order to overcome these structural obstacles and provide universal energy access, it will also be crucial to promote private sector involvement and creative finance strategies.

VI. THE FUTURE OF INDIA'S ENERGY LANDSCAPE

The future of energy in India will be significantly shaped by technological developments, foreign partnerships, and heightened private sector participation. India must prioritize diversifying its energy portfolio by incorporating cutting-edge renewable energy technology, improving grid flexibility, and funding cutting-edge solutions like carbon capture and storage (CCS) and hydrogen energy as the country's energy demand continues to climb.

The development of green hydrogen technology is one of the most exciting trends. To encourage the development and use of green hydrogen as a clean substitute for fossil fuels, the Indian government established the National Hydrogen Mission. Green hydrogen has the potential to drastically lower the nation's carbon footprint by decarbonizing sectors including transportation, steel, and cement. However, substantial investments in infrastructure development, governmental incentives, and electrolyzer technology will be necessary for widespread implementation.

Battery storage technology will also be crucial in maintaining grid stability and incorporating intermittent renewable sources such as solar and wind energy. India has previously made strides in creating battery storage systems, but high costs and limited domestic production capacity remain significant obstacles. Making large-scale energy storage economically viable would require strengthening battery supply chains, stimulating R&D, and fostering global alliances.

The move to smart grid systems will increase India's energy resiliency. Smart grids enable real-time monitoring, effective load management, and automated fault identification, reducing transmission losses and increasing overall power distribution efficiency. The use of smart meters and artificial intelligence-driven demand forecasting can optimize electricity use while reducing strain on existing infrastructure.

Furthermore, international energy alliances would be critical in fulfilling India's sustainable energy objectives. India is actively participating in programs such as the International Solar Alliance (ISA) and working with nations such as the United States, Germany, and Japan to

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accelerate technology transfers and attract foreign investment in renewable energy projects. Expanding such collaborations will aid in the funding of large-scale infrastructure projects and allow knowledge sharing on best practices in energy management.

Furthermore, policy reforms will continue to influence India's energy landscape. Strengthening regulatory frameworks to attract private investment, expediting land acquisition procedures for renewable projects, and establishing carbon pricing systems will all be critical to promoting sustainable energy development. Encouraging greater participation from state governments and local communities in energy planning can result in more region-specific solutions that are customized to local needs.

Heading ahead, India must take a comprehensive approach that considers economic growth, environmental sustainability, and energy security. By emphasizing cutting-edge technologies, improving regulatory systems, and extending international cooperation, India may position itself as a global leader in the clean energy transition. A well-coordinated effort between the government, private sector, and research institutions will be key to ensuring a future where energy is both accessible and sustainable for all . Recent developments including green hydrogen, better battery storage, and AI-powered energy management systems are poised to transform the sector. Furthermore, worldwide cooperation in renewable energy development and strategic energy partnerships will strengthen India's energy security. A sturdy legal and policy framework must be in place to facilitate these developments while balancing economic growth and environmental sustainability[19].

VII. CONCLUSION

India's energy sector stands at a pivotal moment, facing a complex mix of opportunities and challenges. Providing a secure, affordable, and sustainable energy supply is crucial for the country's economic progress and residents' quality of life. The efforts made by the government to promote renewable energy, improve energy efficiency, and implement regulatory reforms are important steps in this direction. However, significant obstacles remain, including financial constraints, outdated infrastructure, policy implementation gaps, and the urgent need for technological advancements.

Moving to a more sustainable power future demands a multifaceted approach. Strengthening policy frameworks to encourage private sector investments, fostering research and innovation in energy storage solutions, and improving grid management through smart technology are key

[19] World Energy Council, India Energy Scenarios 2047 (2025) https://www.worldenergy.org accessed 25 March 2025.

strategies for overcoming current barriers. Additionally, financial sustainability must be ensured in the power sector, particularly for distribution companies (DISCOMs), to create a stable and efficient energy supply chain.

Furthermore, the country's role in global power administration is becoming more important. The national government has actively participated in international collaborations, such as the International Solar Alliance (ISA), as well as partnerships with numerous worldwide organizations, to build sustainable energy projects and share technological expertise. These alliances would help India meet its aspirational renewable energy ambitions and ensure an efficient energy future.

Addressing socioeconomic concerns will also be critical to the successful completion of India's energy transformation, such as improving energy access for rural communities and ensuring affordability for low-income households. Decentralized renewable energy solutions, microgrids, and off-grid solar projects must be expanded to bridge the rural-urban energy divide. Public awareness campaigns and incentives for energy conservation can further drive sustainable consumption practices.

Ultimately, a balanced and integrated approach—incorporating policy reforms, infrastructure upgrades, investment in innovation, and global cooperation—will be essential in securing India's energy future. By tackling these challenges proactively, India may attain its energy independence and become a global leader in alternative energy technology.

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 [ISSN 2581-5369]