

Article

Energy Security and AI in India: Transforming Technology and Policy for Energy Sovereignty

V.K. Saraswat and Tarak Nath Chell

Abstract

India's energy landscape is undergoing a profound transformation as it seeks to balance rapid economic growth, rising energy demand and the imperative of sustainability. Despite significant progress in expanding electricity capacity and deploying renewable energy, the country remains heavily dependent on imported fossil fuels, exposing it to geopolitical risks and fiscal pressures. India's evolving energy security framework highlights the strategic role of Artificial Intelligence in addressing systemic challenges across generation, distribution and consumption — enabling accurate demand forecasting, efficient grid management, predictive maintenance and improved integration of renewable energy sources. Simultaneously, India is diversifying its energy mix through renewables, nuclear power, biofuels and green hydrogen. Clean coal technologies and Carbon Capture, Utilisation and Storage further support this transition. However, critical mineral dependencies, rising data centre energy demand and cybersecurity risks complicate progress. The study argues that integrating AI into a diversified, self-reliant energy strategy is essential for achieving India's long-term energy security by 2047.

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Dr. Tarak Nath Chell holds a Doctorate in Energy Technology from Jadavpur University. He is currently assisting Dr. Saraswat in the Science & Technology Vertical of NITI Aayog, where his work focuses on advancing policy-driven innovation and sustainable energy solutions within India's national development framework.

The opinions expressed in this article are the authors' own and do not reflect the journal's policy.

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India stands at an extraordinary energy crossroads. As the world's most populous nation with 1.44 billion people, it is also the third-largest electricity consumer globally.¹ Energy security in the twenty-first century is a multifaceted concept that extends beyond merely securing fuel supplies. In the context of India's rapidly industrialising and digitally transforming economy, energy is a fundamental driver of geopolitical independence and social well-being. As the country works toward its long-term vision and development goal for 2047, the strength and intelligence of its energy systems will determine the sustainability of its economic growth, the resilience of industrial supply chains and the credibility of climate commitments.

Against this backdrop, Artificial Intelligence (AI) offers transformative potential. By leveraging AI-driven technologies, India can optimise energy generation, distribution and consumption, predict demand patterns, enhance grid reliability and integrate renewable energy sources more effectively. From smart grids and predictive maintenance of power plants to real-time energy trading and policy planning, AI is poised to revolutionise how India approaches energy security.

India's Energy Dilemma: Rising Power and Deepening Import Dependence

Despite impressive domestic coal and renewable capacity, India's energy security is undermined by a stark dependence on imported fossil fuels. According to Energy Statistics India 2025, crude oil import dependency stands at 89 percent, with imports totalling 234.26 million tonnes in the financial year (FY) 2023-24. India's crude oil import bill in 2025 amounted to approximately Rupees (₹) 22 lakh crore per year, a staggering fiscal and strategic liability. Natural gas imports account for 46.6 percent of total gas consumption, with 31.8 billion cubic metres (BCM) imported, a rise of nearly 21 percent year-on-year. Coal imports, despite India being a major producer, reached 262.99 million tonnes in FY 2023-24, up 11.2 percent over the previous year, representing 25.86 percent import dependency. Non-coking coal alone comprises 93.3 percent of domestic coal output.^{2,3}

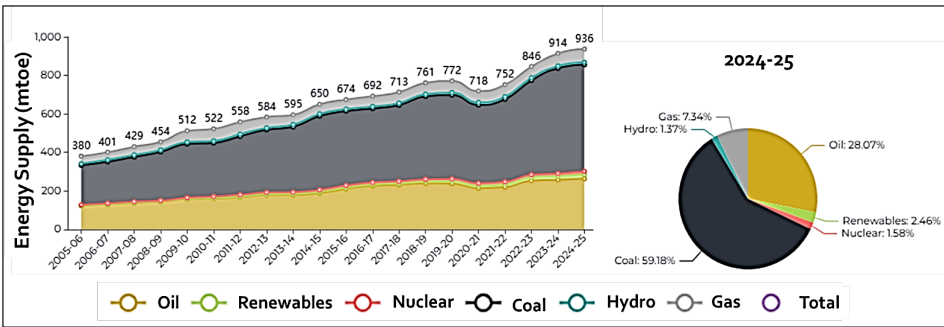
Despite diversification efforts and rising domestic production, India's energy vulnerability persists due to heavy reliance on imports.

India receives crude oil from over 40 countries, mainly Russia, Iraq, Saudi Arabia and the UAE. The 2022 Ukraine war showed that imports can quickly shift, as India increased its import of Russian oil to cut costs, demonstrating that price and energy security often outweigh politics. Disruptions in Persian Gulf shipping or stricter Western sanctions may trigger a serious crisis because India lacks sufficient oil reserves. Despite diversification efforts and rising domestic production, India's energy vulnerability persists due to heavy reliance on imports.

India’s Energy Landscape

India’s energy metabolism is enormous and accelerating. In FY 2025–26, the country’s total installed electricity generation capacity reached 5,20,511 megawatts (MW) — an 11.22 percent year-on-year increase. The country has achieved a balanced energy mix (Figure1), with non-fossil fuel sources contributing 2,71,969 MW (52.3 percent) of total capacity, including a rapid expansion in solar and wind energy. In comparison, thermal power continues to dominate with around 2,48,542 MW (47.7 percent).⁴ Electricity generation has increased substantially from 1,168 billion units (BU) in 2015–16 to an estimated 1,824 BU in 2024–25, reflecting rising demand and improved capacity utilisation. Renewable energy generation has also grown significantly, from about 190.96 BU in 2014–15 to over 370 BU in 2024–25, increasing its share in total generation to over 22 percent.

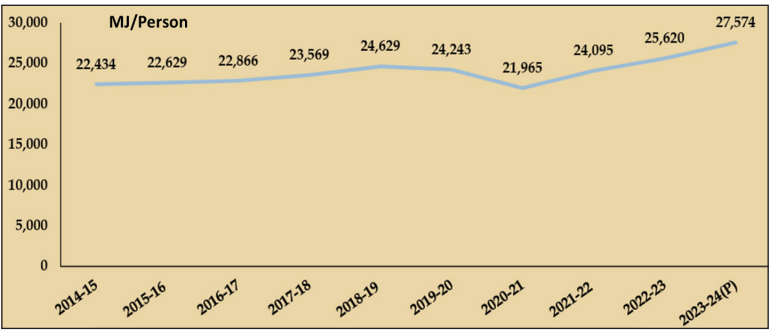
Figure 1: Source-wise Primary Energy Supply in India⁵



Source: NITI Aayog

Power shortages have drastically reduced from 4.2 percent in 2013–14 to just 0.1 percent in 2024–25, while more than 2.8 crore households have been electrified, contributing to a 45.8 percent rise in per capita electricity consumption.⁶ Despite this progress, coal remains the backbone of energy production, contributing the majority share of electricity generation due to its reliability and availability. Annual coal production crossed 1,047 million tonnes, making India the second-largest coal producer globally, behind only China.⁷ Yet despite this scale, per-capita electricity consumption sits at just 1,460 kilowatt-hours (kWh) per year,⁸ barely one-seventh of the Organisation for Economic Co-operation and Development (OECD) countries average, illustrating the vast headroom and obligation for continued growth; this is further underscored by the steady rise in overall energy use per person, as shown in Figure 2, where consumption increases from about 22,434 megajoules (MJ)/person in 2014–15 to an estimated 27,574 megajoules (MJ)/person in 2023–24, reflecting sustained demand growth and expanding energy access.⁹

Figure 2: Per Capita Primary Energy Consumption in India



Source: Authors

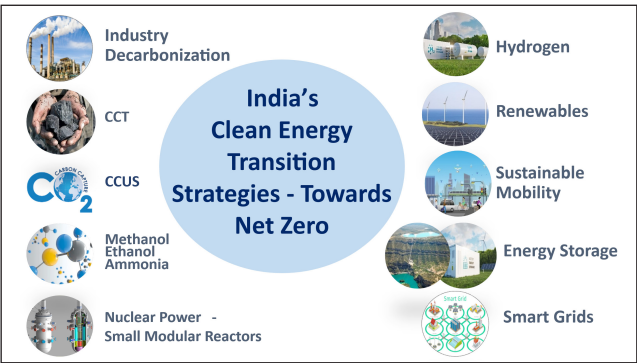
The country’s energy demand is projected to double by 2030, driven by urbanisation, industrialisation and a rising middle class. According to the International Energy Agency (IEA), India is expected to account for 18 percent of the rise in global energy consumption through 2035, positioning it as the most consequential emerging energy market in the world.

India’s Energy Security Strategy

India’s long-term energy security strategy is guided by its landmark commitment to achieving net-zero emissions by 2070, along with a near-term goal of reducing the emissions intensity of its GDP by 45 percent by 2030.¹⁰ As the world’s third-largest energy consumer and one of the fastest-growing economies, India faces the dual challenge of sustaining economic growth today while building a low-carbon future. Balancing these priorities requires careful planning, innovative policy and strategic investments across all energy sectors.

India is actively accelerating its shift towards cleaner and renewable energy sources (Figure 3). Key efforts include expanding solar and wind capacity, promoting biofuels and green hydrogen, advancing ethanol blending programmes and strengthening nuclear energy as a reliable long-term option. In parallel, the country is investing in sustainable mobility solutions, energy storage technologies and smart grid systems to improve efficiency and resilience. The overall strategy is built on four key pillars — diversifying energy sources, increasing domestic production, promoting alternative fuels and advancing low-carbon technologies. Initiatives such as Carbon Capture, Utilisation and Storage (CCUS), clean coal technologies and industrial decarbonisation further reinforce this transition. Together, these efforts aim to create an energy system that is secure, affordable, sustainable and increasingly self-reliant.

Figure 3: Clean Energy Transition Strategies in India



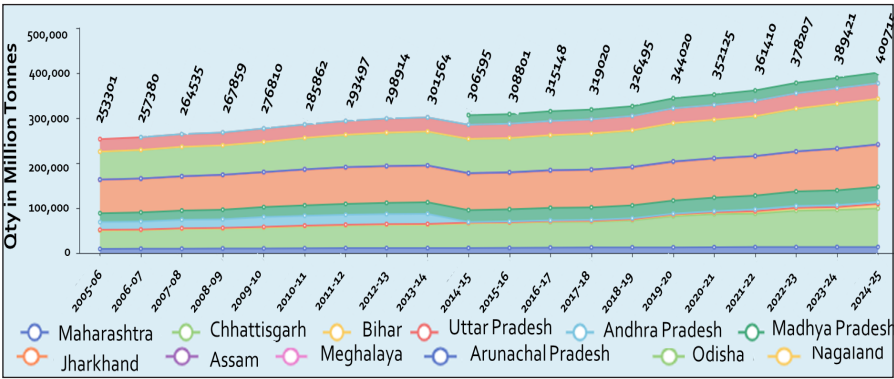
Source: Authors

The Coal Conundrum

Coal continues to dominate India’s energy mix, complicating both energy security and climate goals. It accounts for 60 percent of Total Primary Energy Supply (TPES) and approximately 70 percent of electricity generation (measured by actual generation share, not installed capacity).¹¹ The industrial sector absorbs 49 percent of total energy consumption; and coal powers much of that industrial base.

At the national level, the distribution of coal reserves (Figure 4) highlights India’s strong and well-endowed resource base. This geographic strength, when used for efficient resource utilisation, strengthens domestic energy security and provides a solid foundation for sustaining economic growth while supporting the country’s evolving energy transition.

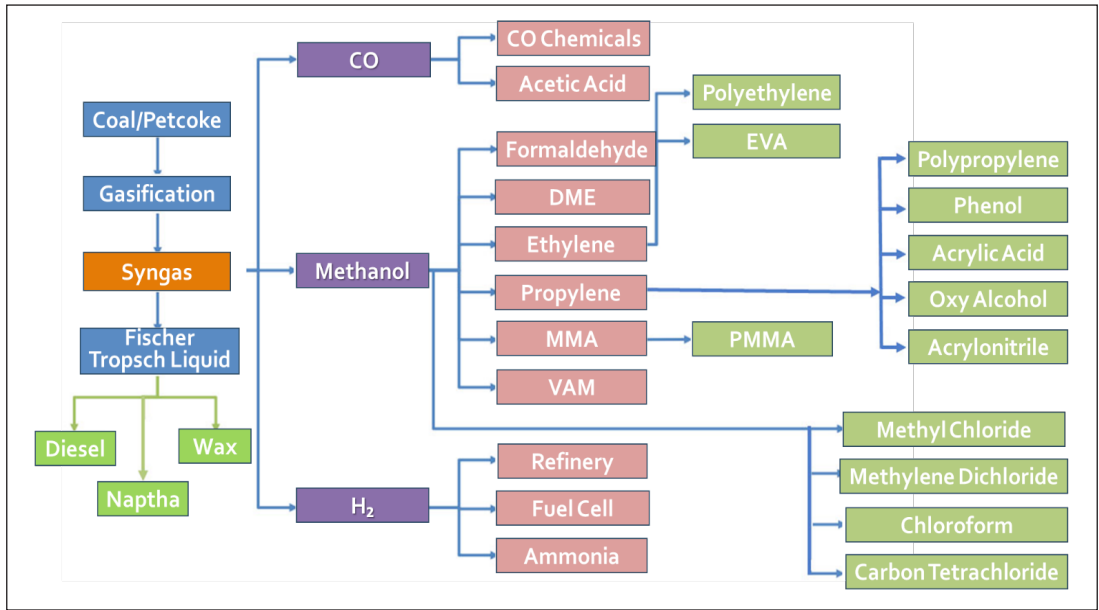
Figure 4: State-wise India Coal Reserves (ICED, NITI)¹²



In FY 2024–25, coal-fired thermal power stations, with a combined installed capacity of nearly 271 gigawatts (GW), operated at a Plant Load Factor (PLF) of 69.45 percent, implying that they were running at only two-thirds capacity. This inefficiency represents not just wasted potential output, but also underperforming sunk capital.¹³ Crucially, these plants can theoretically ramp up to 85 percent plus PLF if demand materialises, providing a crucial buffer for grid stability as variable renewables scale up.

The underutilisation of coal-based assets, as reflected in the relatively low PLF, also highlights an opportunity beyond power generation; namely, the strategic redirection of coal towards higher-value industrial applications. Instead of viewing coal solely as a fuel for electricity, it can be repositioned as a feedstock for a diversified chemicals and materials economy, improving overall asset productivity while supporting energy transition goals. A single raw material, such as coal (or petcoke), can be transformed into a wide spectrum of products through an integrated processing route (Figure 5). It begins with gasification to produce syngas, which then acts as a versatile intermediate. From this point, multiple conversion pathways emerge, leading to fuels, basic chemicals, polymers and specialty materials.

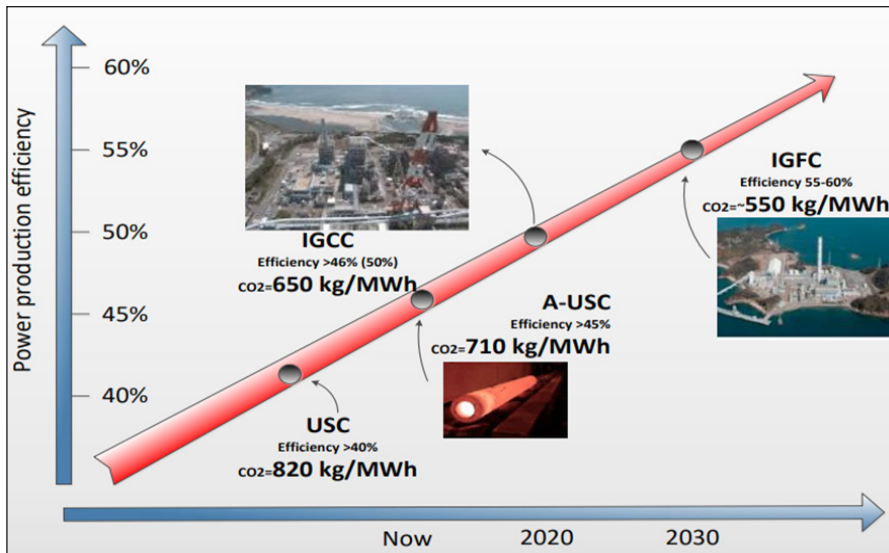
Figure 5: Coal Gasification Products



Source: Authors

Advanced coal power technologies shown in Figure 6 improve efficiency and reduce carbon dioxide (CO₂) emissions by increasing operating temperature and pressure, and by changing the energy conversion process. The present technology, Ultra Supercritical (USC) coal power technology, operates above the critical point of water (around 22.1 megapascals-MPa and 374 °C), achieving about 40 percent efficiency but still producing high emissions (~820 kilograms of CO₂/MWh). The next improvement is Advanced Ultra Supercritical Coal Power (A-USC), which uses steam conditions above 700°C with advanced nickel-based alloys to increase efficiency beyond 45 percent and reduce emissions to ~710 kg CO₂/MWh. Further advancement comes from Integrated Gasification Combined Cycle (IGCC), where coal is converted into syngas (CO and H₂) before power generation, improving thermodynamic performance through combined gas and steam cycles to reach ~50 percent efficiency and enabling easier carbon capture. The most advanced system is Integrated Gasification Fuel Cell (IGFC), which uses high-temperature fuel cells (solid oxide type) to convert chemical energy directly into electricity, reducing energy losses from combustion and achieving 55–60 percent efficiency with the lowest emissions (~550 kg CO₂/MWh). Overall, these technologies move from conventional combustion towards gasification and electrochemical conversion, significantly improving energy efficiency while minimising environmental impact.

Figure 6: Future Clean Coal Technologies



Source: Authors

In India, CCUS is emerging as a key solution for decarbonising coal-fired power plants. The government has allocated ₹20,000 crore in the 2026–27 budget to advance carbon capture, utilisation and storage in the power sector.¹⁴ Pilot projects, including geological CO₂ storage wells led by the Indian Institute of Technology (IIT)-Bombay and NTPC, demonstrate India’s capability to capture CO₂ from coal-based thermal power. By integrating CCUS with existing coal infrastructure, India can continue using its coal resources efficiently while significantly reducing emissions and moving towards net-zero goals.

Key Data Point: Coal’s Grip on India’s Grid
Coal still supplies ~60 percent of India’s Total Primary Energy Supply and ~79 percent of its industrial energy input. India is the world’s second largest coal producer, yet imports 262.99 million tonnes (MT) annually. The economic cost: India pays for fossil fuel imports that constitute the single largest drain on its current account deficit.

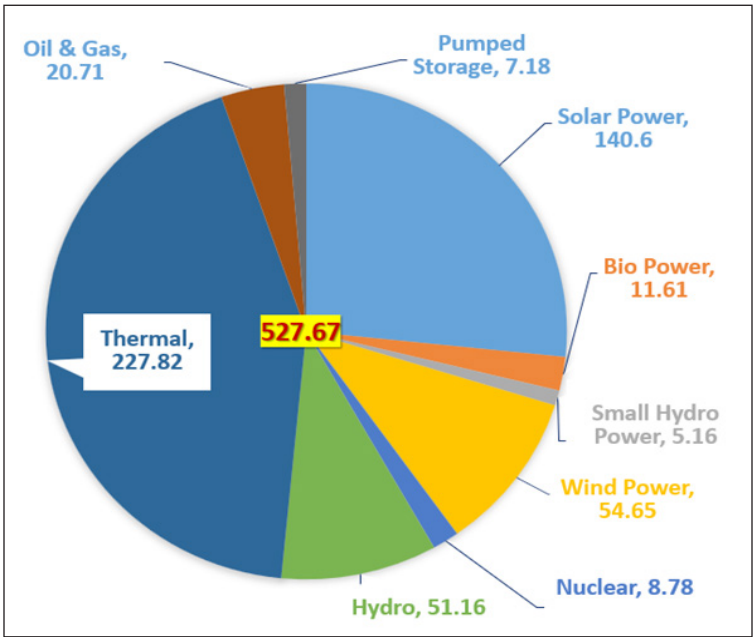
Renewable Energy Expansion and System Integration

India’s renewable energy expansion has been one of the defining economic stories of the 2020s. Between 2015 and 2026, installed renewable capacity (Figure 7) grew from 81,593 MW to 263,189 GW, a Compound Annual Growth Rate (CAGR) of 11.23 percent. Non-hydro renewables alone expanded by over 210 percent in ten years. By March 2025, the total installed renewable energy capacity reached 220.10 GW after a record addition of 29.52 GW in FY 2024–25, more than double the 15.03 GW added the previous year. Solar power led this surge, contributing 23.83 GW of the annual addition, bringing total solar capacity to 105.65 GW.¹⁵

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In a landmark achievement in June 2025, India crossed 50 percent non-fossil fuel share in installed electricity capacity, a milestone targeted for 2030 under its Paris Agreement Nationally Determined Contributions (NDCs), accomplished five years ahead of schedule. India has also become the world’s third-largest solar energy producer, generating 108,494 gigawatt-hours (GWh) of solar electricity, surpassing Japan’s 96,459 GWh.

Figure 7: India’s Installed Power Capacity Mix, January 2026 (GW)



Source: Authors

Expanding India’s Solar Ecosystem

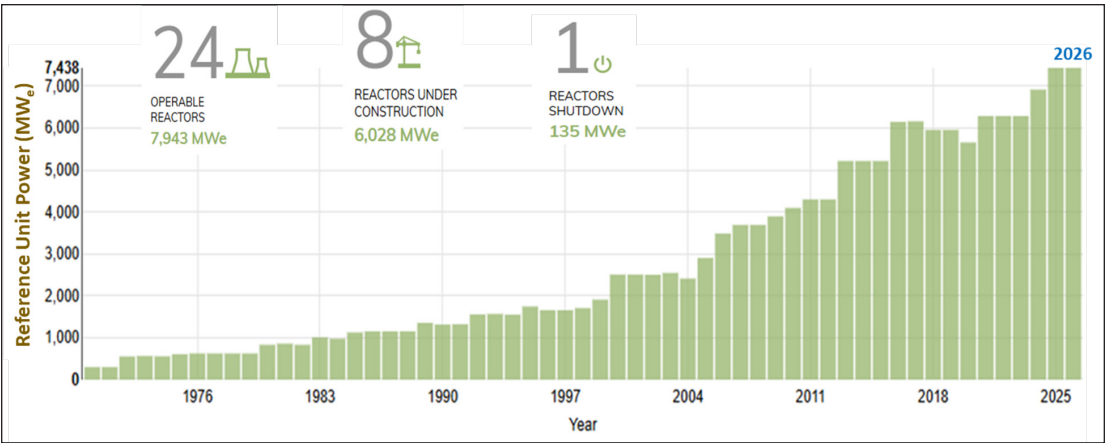
Currently, our solar energy systems depend on the import of solar cells, modules, converters and other components, which is affecting our self-reliance goal. The Government of India has initiated many schemes to promote indigenous production of these components. To accelerate solar adoption, the government launched the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) Scheme, which targets 34,800 MW of solar capacity in agriculture and the installation of over three million solar pumps, helping reduce diesel use and increase farmers’ income. The PM Surya Ghar: Muft Bijli Yojana (2024) aims to install rooftop solar systems in one crore households. Large-scale solar expansion in India is being driven by flagship initiatives such as the Solar Park Scheme, which targets around 40 GW of installed capacity by providing ready-to-use infrastructure for developers. This is complemented by emerging efforts, such as floating solar projects that use water bodies to optimise land use. On the manufacturing side, the Production Linked Incentive (PLI) scheme plays a central role in strengthening domestic capabilities, with a target of establishing nearly 65 GW of integrated solar manufacturing capacity across the value chain.¹⁶

In addition, several supporting policy measures have been introduced to boost indigenous manufacturing. These include the Basic Customs Duty (BCD) on imported solar modules and cells to encourage local production, the Approved List of Models and Manufacturers (ALMM) to promote quality and reliability in domestically produced equipment and the Domestic Content Requirement (DCR) in select government projects to prioritise Indian-made components. The National Wind-Solar Hybrid Policy encourages the integrated use of wind and solar resources to improve efficiency and grid stability. The National Bioenergy Programme supports biomass power, biogas and waste-to-energy projects, contributing to rural energy security and waste management, with a target of generating thousands of megawatts from biomass resources.

Nuclear Power: India’s Baseload Gambit

Nuclear energy has long occupied a modest but strategically pivotal position in India’s electricity mix. As of early 2026, India operates 25 reactors across seven stations, delivering approximately 8,880 MW, about 2.3 percent of total installed capacity and roughly three percent of actual generation (Figure 8). The fleet is anchored by Pressurised Heavy Water Reactors (PHWRs) of indigenous design, supplemented by Russian-designed VVER-1000 Light Water Reactors at Kudankulam, Tamil Nadu, which will ultimately deliver 6,000 MW across six units. Six additional reactors totalling approximately 4,700 MW are under construction. Capacity has grown 71 percent since 2014, from 4,780 MW, but the transformational phase has only just begun.¹⁷

Figure 8: Nuclear Power Capacity in India



Source: Authors

December 2025 marked a watershed moment when the Lok Sabha passed the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Bill, which repeals the Atomic Energy Act of 1962 and the Civil Liability for Nuclear Damage Act of 2010.¹⁸ India has also launched a Nuclear Energy Mission under the Viksit Bharat initiative, allocating ₹20,000 crore in Budget 2025–26 for at least five Small Modular Reactors (SMRs) to be commissioned by 2033.¹⁹ A Central Electricity Authority roadmap, submitted in June 2025, charts the path to 100 GW of nuclear capacity by 2047.²⁰

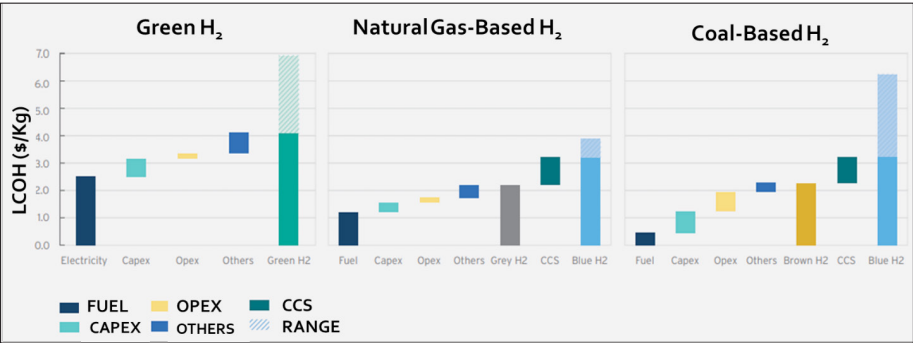
The recent achievement of criticality in India's Prototype Fast Breeder Reactor (PFBR) marks a significant milestone in the second stage of the country's three-stage nuclear programme.²¹ This development demonstrates India's growing capability in advanced nuclear technology, particularly in fast breeder reactors that generate more fissile material than they consume. By efficiently utilising Plutonium derived from earlier-stage reactors, the PFBR plays a crucial role in producing Uranium-233 from Thorium. This progress brings India closer to transitioning towards Thorium-based nuclear energy, which is abundant domestically and essential for long-term energy security and sustainability.

Green Hydrogen: India's Bold Energy Transformation

Green Hydrogen, produced by electrolysing water using renewable electricity, represents India's most ambitious bid to reduce dependence on fossil fuel imports in hard-to-electrify sectors such as fertilisers, steel, shipping, aviation and long-haul transport. As shown in Figure 9, Hydrogen Production Cost by Source in India, cost competitiveness varies significantly across production pathways, with Green Hydrogen currently positioned at a higher cost level compared to fossil-based alternatives, underscoring the importance of scaling renewable power and electrolyser manufacturing to achieve long-term parity. India's current crude oil import bill of ₹22 lakh crore annually can be reduced by ₹1 lakh crore annually through Green Hydrogen adoption, according to government projections, while reducing carbon emissions by 2.6 gigatons by 2050.

In September 2025, India launched a ₹500 crore Green Hydrogen Highways trial for hydrogen-fuelled trucks on 10 long-distance national highway routes, in partnership with Tata Motors, Ashok Leyland and Volvo for vehicles, and the Bharat Petroleum Corporation Limited (BPCL), the Indian Oil Corporation Limited (IOCL), NTPC and Reliance for hydrogen supply. The National Green Hydrogen Mission targets five million tonnes per annum of production capacity by 2030, with 125 GW of associated renewable energy capacity, a target that, if achieved, would make India one of the world's largest Green Hydrogen economies.²²

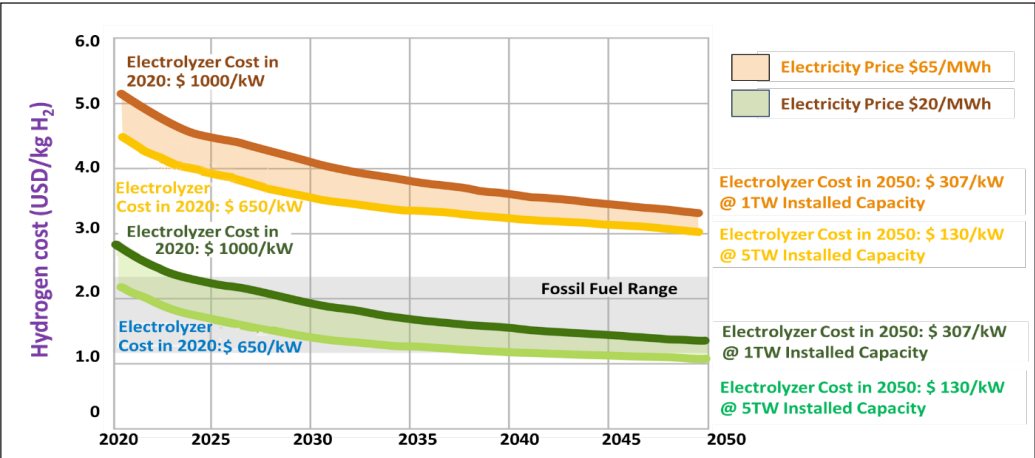
Figure 9: Hydrogen Production Cost by Source in India



Source: Authors

Figure 10 shows that the cost of Green Hydrogen is likely to fall from 2020 to 2050 as electrolyser deployment increases and renewable electricity becomes cheaper. In 2020, electrolyser costs were high (USD 650–1000/kW), but they declined significantly with scale, reaching about USD 307/kW in a 1 terawatt (TW) scenario and USD 130/kW in a 5 TW scenario by 2050. Electricity price is the most important factor; hydrogen is much cheaper when electricity costs USD 20/MWh compared to USD 65/MWh. Overall, the figure suggests that with large-scale deployment and low-cost renewables, green hydrogen could become competitive with fossil-fuel-based hydrogen by 2050.²³

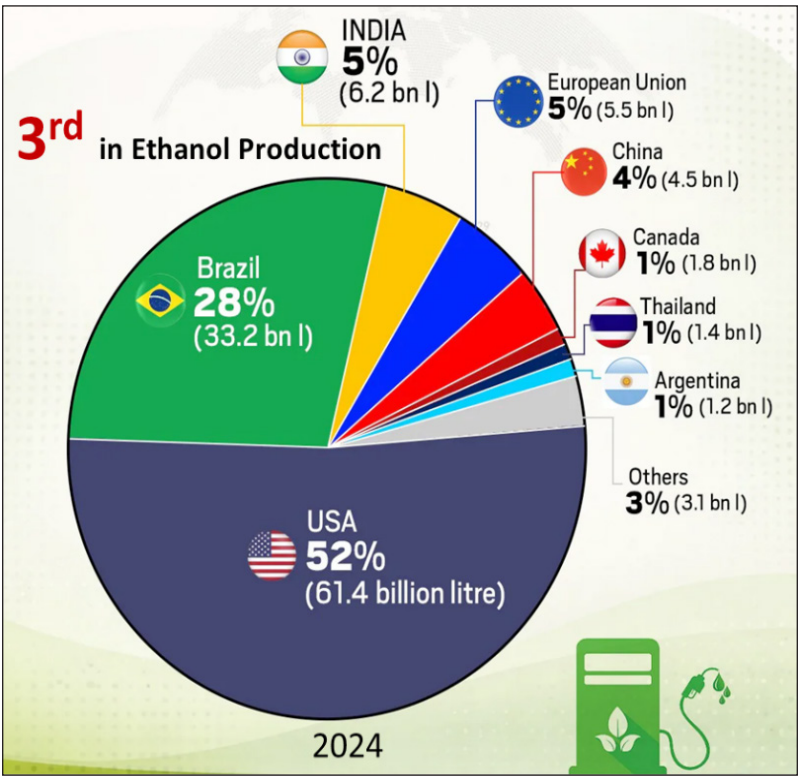
Figure 10: Cost of Green Hydrogen Production as a Function of Electrolyzers Deployment Over the Period 2020-2050 (IRENA-2020b)²⁴



Ethanol: India’s Most Successful Energy Policy Execution

India’s Ethanol Blended Petrol (EBP) Programme deserves recognition as one of the most successfully executed energy policies in Indian history. As shown in Figure 11, Ethanol global production illustrates the broader international context of expanding ethanol output, highlighting India’s rapid alignment with global biofuel growth trends. Launched in 2003 with blending rates below two percent, the programme was transformed from 2014 onwards through administered pricing, multi-feedstock eligibility, long-term Oil Marketing Company (OMC) offtake agreements and a compressed timeline, advancing the E20 (20% Ethanol blending) target from 2030 to 2025–26. Blending reached 12.06 percent in the Ethanol Supply Year (ESY) 2022–23, 14.60 percent in ESY 2023–24 and peaked at 19.93 percent in July 2025, when the E20 target was formally declared achieved—five years ahead of the original 2030 target.

Figure 11: Ethanol Global Production



Source: Authors

The programme has generated tangible economic outcomes beyond import substitution; ₹87,558 crore paid directly to farmers as ethanol feedstock income, 18+ billion litres of annual production capacity built from near zero, and 544 lakh tonnes of CO₂ emissions avoided over ten years. However, the E20 achievement was not without friction.²⁵

Compressed Biogas: Waste into Fuel

Compressed Biogas (CBG), produced from cattle dung, municipal solid waste, agricultural residue and industrial effluents, directly displaces imported natural gas. Biogas can be upgraded to Compressed Natural Gas (CNG), often called bio-CNG, through a purification and compression process. Raw biogas produced via Anaerobic Digestion of organic waste typically contains 50 to 70 percent methane, along with CO₂, H₂S, moisture and trace impurities. To convert it into CNG-grade fuel, the gas is required to undergo cleaning steps such as desulfurisation, removal of H₂S, CO₂ scrubbing using water washing, Pressure Swing Adsorption (PSA), or membrane separation, and drying. This upgrading process increases Methane concentration to above about 90 percent, improving calorific value and combustion efficiency. The purified gas is then compressed to high pressures of 200 to 250 bar to produce bio-CNG, which can be used as a renewable transportation fuel or injected into natural gas grids, offering a low-carbon alternative to fossil-based CNG.

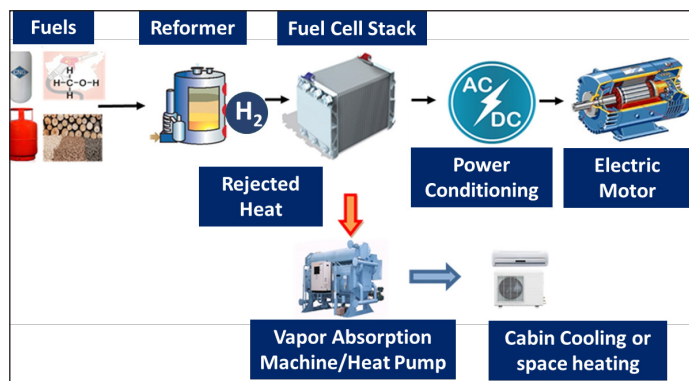
India's Sustainable Alternative Towards Affordable Transportation (SATAT) programme targets 5,000 Compressed Biogas (CBG) plants with a one percent CNG blending mandate in 2025, rising to five percent by 2028. The Galvanizing Organic Bio-Agro Resources Dhan (GOBARdhan) Scheme converts rural organic waste into biogas and bio-fertiliser simultaneously. India produces over 105 billion tonnes of organic waste annually, less than two percent of which is currently recycled.²⁶

Methanol Economy: India's Unconventional Fuel Frontier

While Ethanol receives extensive media attention, Methanol may represent India's most strategically distinctive alternative fuel opportunity. The NITI Aayog's Methanol Economy programme, launched in 2016 and overseen by an inter-ministerial committee, targets a structural transformation: converting India's vast reserves of high-ash coal, a resource too polluting and low-caloric for direct power generation, into a clean-burning and versatile liquid fuel through the Coal-to-Methanol synthesis route. This single insight turns a liability (some 100+ billion tonnes of high-ash coal that cannot efficiently be burned) into a strategic asset.

Methanol is a highly versatile fuel that can support both internal combustion engines (ICE) and electric drive systems, as shown in Figure 12. It can be converted into electricity with efficiencies of up to 75 percent, making it suitable for energy applications. Additionally, Methanol can be reformed onboard to produce hydrogen, which can then power fuel cells in commercial vehicles, offering a flexible pathway for cleaner transportation.

Figure 12: Methanol Fuel Reformer Developed Indigenously



Source: Authors

Fuelling the Future with Methanol-Derived DME

Methanol is converted to Dimethyl Ether (DME) by passing it over a solid acid catalyst at 250–350°C, where two Methanol molecules combine to form DME and water. This catalytic dehydration is efficient and produces DME for use as a clean fuel. When blended with Liquefied Petroleum Gas (LPG), Dimethyl Ether (DME) helps address the 46.6 percent import dependency on natural gas without requiring new vehicle infrastructure, potentially saving ₹6,000 crore annually in LPG imports. Converted for railway locomotives, it could save ₹26,000 crore each year on Indian Railways' ₹3 billion-litre diesel bill. Methanol-fuel cooking stoves, already piloted in Assam, reduce household fuel costs by 20 percent while nearly eliminating particulate emissions.

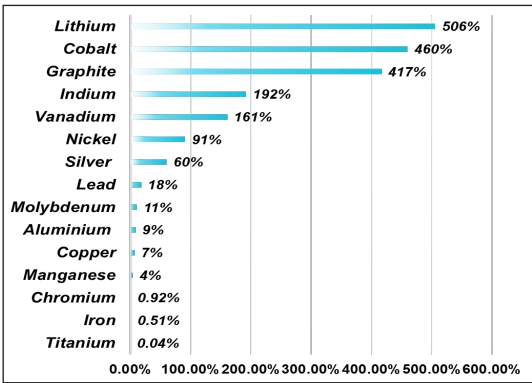
Marine Methanol applications are progressing at Cochin Shipyard, which is building Methanol-fuel vessels for the Inland Waterways Authority across India's 14,500 km of navigable waterways. The limit on carbon from marine fuels is being implemented through fuel carbon intensity standards set by the International Maritime Organization (IMO) under Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL). Instead of a fixed cap, these regulations define allowable greenhouse gas intensity per unit of fuel on a lifecycle (well-to-wake) basis, which will progressively

tighten over time. The targets indicate a reduction of about four percent by 2028, around 30 percent by 2035 and up to 65–80 percent by 2040, ultimately aiming for net-zero emissions by 2050.²⁷ This framework compels the shipping industry to gradually shift from conventional high-carbon fuels toward low and zero-carbon alternatives. In this context, Methanol is emerging as one of the most promising alternative fuels for CO₂ reduction, as it produces lower emissions compared to conventional marine fuels and can be derived from renewable sources such as Green Hydrogen and captured carbon, making it a practical and scalable option for cleaner maritime operations.

Critical Minerals: The Hidden Energy Security Dimension

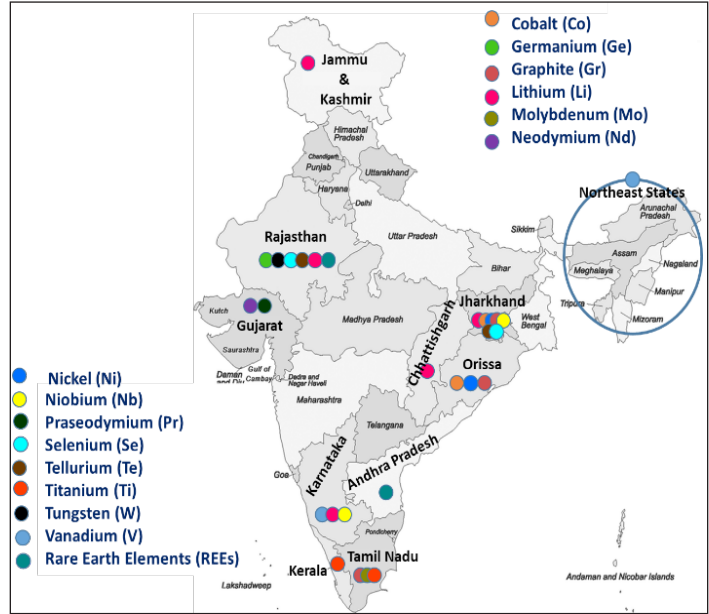
A wide range of metals and minerals (Figure 13) are essential for modern energy technologies. Lithium, Cobalt and Graphite are key materials for Lithium-Ion batteries used in electric vehicles and energy storage systems. Solar photovoltaic technologies are projected to consume a large share of Indium production, particularly for advanced panel materials such as Copper, Indium, Gallium and Selenide. Vanadium plays an important role in redox flow batteries for large-scale storage, while Nickel, Silver and Lead are widely used across batteries, electrolyzers and solar cells. Wind turbines also depend on materials like Molybdenum, while Chromium remains vital for steel manufacturing and structural support. Titanium-based steel alloys are crucial in geothermal systems that must withstand extreme heat and pressure. Demand for these metals and minerals from energy technologies is expected to increase by 2050, relative to their 2020 production levels, highlighting potential supply challenges and the importance of sustainable resource management.

Figure 13: 2050 (P) Demand from Energy Technologies as a Percentage of 2020 Production²⁸



India’s AI-energy nexus faces a less-discussed supply chain challenge in the form of critical minerals. AI hardware, like Graphics Processing Units (GPUs) and Tensor Processing Units (TPUs) used in data centres, depends on Cobalt, Lithium, Rare Earth elements and Gallium. India’s domestic reserves of these minerals (Figure 14) are limited, creating a potential substitution of one form of import dependency (fossil fuels) for another (critical minerals).

Figure 14: Domestic Reserves of Critical Minerals in India



Source: Authors

The government’s National Critical Minerals Mission aims to address this vulnerability through domestic exploration and international resource partnerships. India has initiated strategic mineral agreements with Australia, Argentina and several African nations.²⁹ Strengthening domestic critical mineral processing capabilities and securing long-term supply deals are vital to India’s strategic energy security.

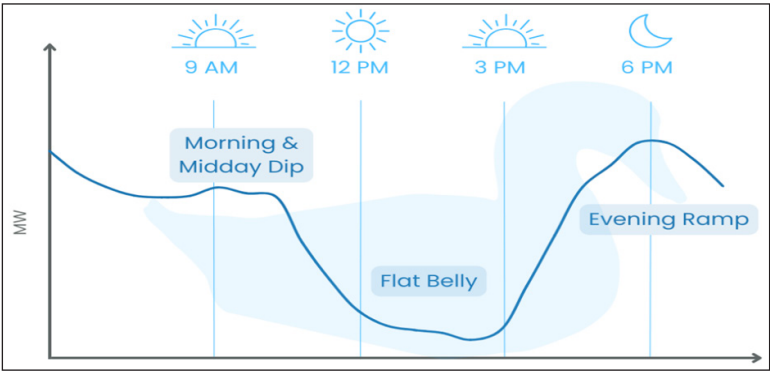
Artificial Intelligence and the Future of Energy Security

Modern Energy Solutions and Reliable Power Delivery

The increasing penetration of variable renewable energy is fundamentally transforming power system operation and daily load characteristics, particularly in

rapidly growing grids such as India. Figure 15 illustrates the duck curve, where net load $P_{net}(t) = P_{demand}(t) - P_{volatile\ renewable\ energy}(t)$ is strongly influenced by solar generation. As solar output rises during midday, net demand decreases sharply, forming the “flat belly”, which pushes conventional generators toward their technical minimum operating limits and may lead to renewable curtailment or inefficient partial loading of thermal units.

Figure 15: Navigating the Energy Surge Solving the Duck Curve



Source: Authors

This is followed by a steep evening ramp, characterised by a high ramp rate $\frac{dP}{dt}$, as solar generation declines while demand increases. The variability and uncertainty of solar and wind generation, due to their dependence on weather conditions, further complicate system operation by introducing forecasting errors and increasing the need for flexible and responsive grid management.

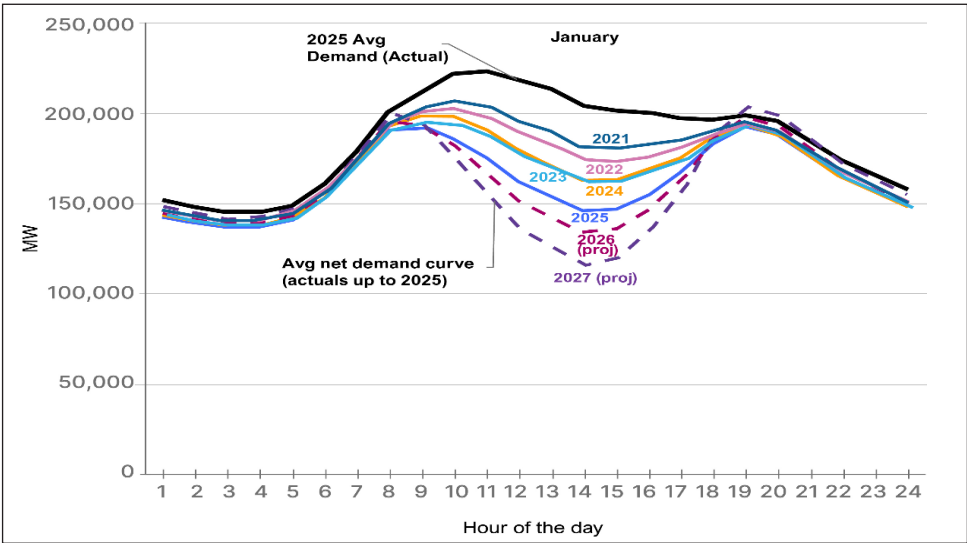
Figure 16 shows India’s electricity load curves from 2021 to 2027, highlighting a consistent daily pattern with a morning rise, midday dip and strong evening peak. Over time, the midday dip deepens and the evening peak becomes sharper due to higher renewable penetration. This increases net load variability, ramping stress and potential transmission congestion, especially during peak hours.

To address these challenges, advanced forecasting techniques powered by AI are becoming essential for reliable grid operation. AI-based models can predict solar irradiance and wind availability with forecast horizons of 12 to 72 hours, significantly improving accuracy and enabling pre-emptive balancing strategies. For example, thermal plants can be ramped up in advance of expected reductions in solar output, while hydropower can be scheduled to offset anticipated variability in wind generation. In addition, energy storage technologies such as pumped hydro, compressed air systems and battery energy

storage systems, including Lithium-Ion and flow batteries, play a critical role in balancing supply and demand by storing excess energy during low-demand periods and supplying it during peak hours. The deployment of smart meters and digital grid infrastructure further enhances real-time monitoring, demand forecasting and fault detection. Emerging solutions such as Virtual Power Plants integrate distributed energy resources like rooftop solar, storage systems and flexible loads into a unified and controllable system. Together, these technologies improve grid flexibility, reduce operational uncertainty, and ensure stable, efficient and reliable power delivery in modern energy systems. The true measure of India's energy progress lies in converting capacity into a consistent supply through smart grids, energy storage and dynamic demand-supply management.

The true measure of India's energy progress lies in converting capacity into a consistent supply through smart grids, energy storage and dynamic demand-supply management.

Figure 16: India's Electricity Load Curve (IEEFA)³⁰



AI as a Force Multiplier for Energy Security

In India, AI is becoming a key enabler of energy security by significantly improving demand forecasting accuracy. AI models analyse historical consumption, weather patterns, festivals, industrial activity and behavioural trends to predict electricity demand

with much lower error rates than traditional methods. This helps State Load Despatch Centres (SLDCs) reduce reserve margins, avoid costly emergency power purchases and improve overall grid efficiency.

India is also moving towards real-time AI-driven grid management, where systems monitor grid conditions continuously to detect faults, instability and irregular market behaviour. These platforms can process high-frequency data streams in milliseconds to prevent cascading failures and blackouts. With renewable energy capacity expected to grow significantly in the coming years, AI is increasingly becoming important for managing complexity, ensuring grid stability and enabling faster, data-driven decision-making across the power system.

Case Study: Tata Power Delhi Distribution Limited ³¹
Tata Power Delhi Distribution Limited (Tata Power-DDL), which supplies power to approximately 7 million residents in North Delhi, merged its Supervisory Control and Data Acquisition (SCADA) system, Distribution Management System (DMS), and Outage Management System (OMS) into a single AI-integrated platform. This Advanced Distribution Management System (ADMS) can suppress fault waves and restore supply within minutes rather than hours.

Predictive Maintenance for Critical Infrastructure

India’s electricity grid is physically vast. As of May 31, 2025, the country has 1,80,239 circuit kilometres of Extra High Voltage (EHV) transmission lines.³² Monitoring, maintaining and repairing this infrastructure using traditional inspection methods is expensive, slow and hazardous. AI-powered predictive maintenance systems use sensor data, satellite imagery, thermal imaging and historical failure records to identify components at risk of failure before they fail catastrophically.

Transformer failures and transmission line outages are among the costliest grid events in India. A single high-voltage transformer failure can trigger cascading outages affecting millions of customers. AI models trained on vibration data, oil analysis results, thermal signatures and load history can predict failures weeks in advance, allowing utilities to schedule maintenance at lower-cost intervals rather than respond to emergency breakdowns. Virtual Twin technology, AI-driven 3D representations of physical energy assets, allows operators to simulate maintenance scenarios, test grid configurations and model the impact of extreme weather events without touching live infrastructure.

Fossil Fuel Optimisation: Making Coal Cleaner Through Intelligence

Paradoxically, AI is also enhancing the efficiency of India's coal-fired power fleet, which remains central to the energy mix for the foreseeable future. Coal plant PLFs of 69.45 percent represent significant inefficiency; AI-driven combustion optimisation, boiler control and fuel logistics systems can reduce heat rates, improve plant availability and lower per-unit emissions even as absolute coal consumption may continue to rise.

This is crucial for energy security, as generating more kilowatt-hours from each tonne of coal lowers reliance on imports and prolongs the economic lifespan of existing infrastructure. The government has also initiated underground coal gasification trials (commenced June 2024) and coal liquefaction research, both of which involve complex chemical processes that benefit from AI-optimised control systems.

Oil and Gas: Exploration and Supply Chain Intelligence

India's oil and gas sector faces a structural challenge, as domestic reserves are limited and declining, whereas demand continues to grow. Crude oil reserves stand at 671.40 million tonnes, mostly concentrated in offshore western and Assam regions, while natural gas reserves total 1,094 Billion Cubic Metres (BCM). These reserves are not expanding at a pace commensurate with demand, making import dependency a structural feature rather than a temporary inconvenience.

AI is being deployed to improve the economics of domestic upstream exploration, analysing seismic survey data with greater speed and accuracy to identify prospective reservoir formations, optimising drilling parameters to reduce dry hole rates, and managing production from existing fields to maximise recovery factors. On the downstream side, AI systems manage refinery scheduling, crude blending optimisation and product distribution logistics for companies like Indian Oil, BPCL and Hindustan Petroleum Corporation Limited (HPCL), India's state-owned oil marketing companies, which together operate a refining network handling over 234 million tonnes of crude annually.

India's AI Boom: Rising Energy Security Concerns

Every AI application, from smart meter analytics to grid optimisation to predictive maintenance, runs on computing infrastructure that consumes electricity. India's AI ambitions, combined with its status as the world's most populous nation and one of the fastest-growing digital economies, are driving an unprecedented expansion of data centre capacity that poses a significant new challenge to energy security.

India’s data centre capacity has grown dramatically; from 0.375 GW in 2020, it reached 1.5 GW by 2025, according to the Ministry of Electronics and Information Technology (MeitY).³³ Demand is accelerating sharply. Global technology companies, including Google, Microsoft, Amazon and Meta, alongside domestic players such as Adani and Reliance, are planning investments of billions of dollars in new data centre campuses across India. According to the Institute for Energy Economics and Financial Analysis (IEEFA), India’s data centre capacity is expected to grow to nine GW by 2030, a more than six-fold increase in five years.³⁴ A Deloitte India report estimates that AI-driven data centres will require 40–50 terawatt-hours (TWh) of additional electricity annually by 2030, which is equivalent to the annual electricity consumption of a medium-sized European country.³⁵

India Data Centre Capacity (2020)	0.375 GW
India Data Centre Capacity (2025)	~1.5 GW
Projected Capacity (2030)	9 GW (IEEFA estimate)
Additional Electricity Needed by 2030	40–50 TWh/year (Deloitte)
Share of India’s Electricity by 2030	~3% (up from <1% currently)
Global Data Centre Demand (2030, IEA) ³⁶	~945 TWh (double 2024 level)
AI-Optimised Server Power Growth ³⁷	~30% per year (IEA)
India’s 5 Major Data Centre Hubs	Mumbai, Hyderabad, Delhi NCR, Bangalore, Chennai

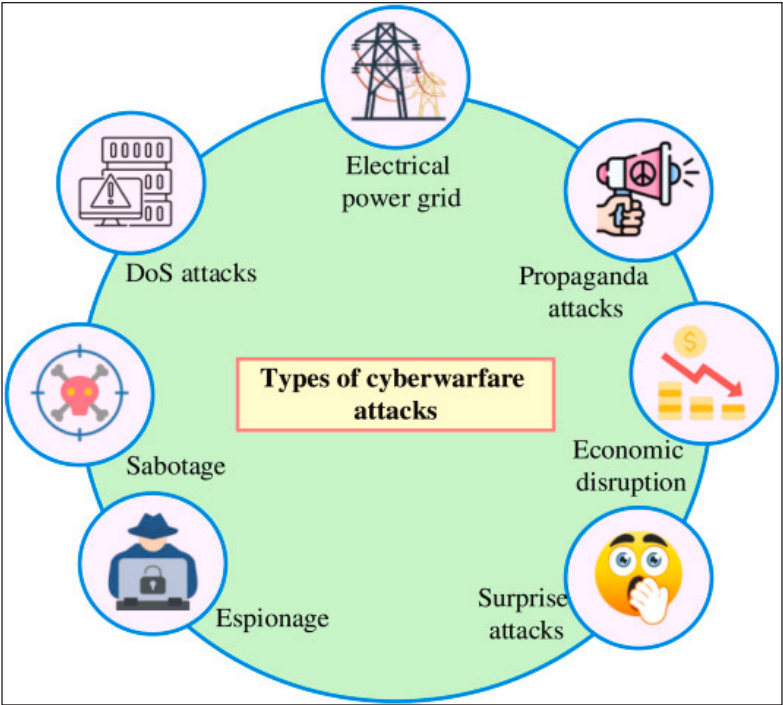
India’s data centre hubs—Mumbai (61), Hyderabad (33), Delhi NCR (31), Bangalore (31) and Chennai (30) — are concentrated in urban cores where the grid is already stressed. An average data centre consumes as much power as an aluminium smelter or ~100,000 homes. Clusters like Mumbai’s Navi Mumbai zone risk overwhelming local transmission. Data traffic has grown 30-fold since FY 2017 due to smartphones, Over-The-Top (OTT) platforms, digital payments and e-commerce. Meeting this demand requires not just more power generation but a costly, land-intensive overhaul of city transmission and distribution networks.

AI: The Dual-Edge Sword
AI offers transformative potential for India's energy transition: better grid management, reduced curtailment, predictive maintenance and smarter demand response. But AI data centres could consume an additional 40–50 TWh of electricity annually by 2030, equivalent to all of Sri Lanka's current electricity consumption. Managing this paradox — harnessing AI's benefits while containing its energy appetite — is among India's most pressing policy challenges.

Cybersecurity: The Invisible Threat to Energy Infrastructure

AI’s dual role in energy security extends into the domain of cybersecurity, where the technology simultaneously creates new threats and provides new defences. The IEA’s 2025 report highlighted that cyberattacks on energy utilities have tripled globally in four years, with AI enabling automated reconnaissance, customised malware and rapid vulnerability detection beyond human capability.³⁸ According to cybersecurity reports by the Data Security Council of India (DSCI), the power and energy sector accounted for around 29 percent of all malware detections in 2024, with over 15,000 malware incidents recorded across more than 2,000 endpoints, underscoring persistent targeting of utilities and grid systems.³⁹ The Indian Computer Emergency Response Team (CERT-In) reported a sharp increase in nationwide cyber incidents affecting multiple sectors, and during Operation SINDOOR, nearly 200,000 cyberattack attempts were detected and thwarted against the power grid and other critical systems. India also faces 30-40 major cyber-attacks daily on infrastructure, like the power sector.⁴⁰ Complexity and frequency of modern cyber warfare attack methodologies are depicted in Figure 17.

Figure 17: Different Attack Methodologies in Cyber-warfare⁴¹



The Defence Imperative and Policy Foundations

As India integrates AI into its power sector, through real-time data systems, smart meters, automated dispatch, and interconnected grid controls, it also expands its cyberattack surface. Every smart meter becomes a network endpoint and AI-driven grid platforms become potential targets. A proposed national system processing grid data at 40-millisecond resolution will greatly improve visibility but also increase systemic cybersecurity risks.

This makes AI-enabled cyber defence essential, including anomaly detection, automated isolation of compromised systems and continuously updated threat intelligence. While regulators such as the Central Electricity Regulatory Commission (CERC) and the Ministry of Power are developing cybersecurity frameworks, their implementation across state and private utilities remains uneven. These risks emerge alongside major national programmes driving digital transformation in the energy sector. The Revamped Distribution Sector Scheme (RDSS) is modernising infrastructure through smart meters and automation, the National Smart Grid Mission is advancing AI-enabled grid systems, and the Perform, Achieve and Trade (PAT) Scheme is increasingly using AI for energy efficiency monitoring. Together, these initiatives are building a smarter energy ecosystem while making cybersecurity a critical foundation for India's AI-powered grid future.

India's energy transition is being propelled by large-scale government initiatives that integrate AI, digitalisation and smart infrastructure to create a sustainable and intelligent power ecosystem.

Conclusion

The transformation of India's energy system through AI should be viewed not just as a technological upgrade but also as a major restructuring of national capacity. Energy sovereignty in the twenty-first century is closely linked to computational sovereignty. Having control over generation facilities, fuel supply chains and grid infrastructure is no longer enough; resilience and independence are contingent on the ability to analyse data, forecast system behaviour and optimise operations in real-time across interconnected networks. In this context, AI acts as the central layer that integrates physical infrastructure with digital intelligence, helping India manage complexity on a national scale.

The strategic advantage of AI in energy lies in transforming uncertainty into manageable risk. AI helps anticipate renewable intermittency, fuel price swings, climate

disruptions, and cyber threats, reducing the need for large reserves, cutting losses, improving asset utilisation and lowering investment costs, ultimately boosting economic stability and competitiveness. AI also enables a shift from centralised to decentralised energy systems by coordinating millions of distributed assets, such as rooftop solar, batteries, Electric Vehicles (EVs) and hydrogen hubs, in real time, enhancing resilience and maintaining critical services.

Developing AI domestically strengthens national security by protecting sensitive grid data from foreign dependence and cyber threats. Environmentally, AI optimises operations to cut emissions while sustaining growth, aligning India's economic development with global decarbonisation goals. Success requires institutional coordination, forward-looking regulation, workforce training and public investment. By integrating AI across generation, transmission, distribution, storage, mobility, hydrocarbons and hydrogen, India can achieve a resilient, self-reliant and sustainable energy system by 2047, characterised not just by capacity expansion but by intelligent mastery of the energy landscape.

From the above, it is clear that India remains heavily dependent on imported fossil fuels, placing a significant burden on its foreign exchange reserves and raising concerns about national sovereignty and energy security. Ongoing geopolitical tensions, particularly those involving Iran, the United States and Israel, underscore the risks associated with excessive reliance on imported fuels such as natural gas, LPG and Piped Natural Gas (PNG).

In this context, India needs to strengthen its domestic energy capabilities by expanding its coal-based energy options. Technologies such as coal-to-gas, coal-to-chemicals and coal-to-liquids offer promising pathways for producing a range of energy products, including syngas, synthetic natural gas, Methanol, Dimethyl Ether (DME), Sustainable Aviation Fuel (SAF), diesel and fertilisers. Although coal alone may not meet the country's entire energy demand, it can play a crucial role within a diversified energy mix. Therefore, India should adopt a mission-mode approach to develop and deploy clean coal technologies for converting coal into multiple energy products, thereby reducing import dependence and enhancing long-term energy security.

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