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Data Driven Strategy For Smoother Energy Transition In The Power Sector

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Abstract: The announcement of India's net-zero target for 2070 has served as a strong and credible policy signal, fundamentally reshaping the national climate discourse and aligning domestic development priorities with long-term global decarbonization goals. By committing to net-zero emissions, India has not only underscored its intent to pursue a sustainable growth pathway but has also provided greater policy certainty to investors, industries, and sub-national governments, thereby accelerating momentum across climate-relevant sectors. Beyond its environmental significance, the net-zero commitment is catalysing new entrepreneurial opportunities by enabling SME participation, start-up innovation, and the emergence of green investment ecosystems across renewable energy, energy storage, grid services, and clean technologies. This paper seeks to examine the pathways through which India can realistically achieve its net-zero objective by 2070. It places particular emphasis on the power sector, which currently accounts for nearly 50 per cent of the country's total greenhouse gas emissions. Given this substantial contribution, the pace and scale of the transition from fossil-fuel-based generation to renewable and low-carbon sources will be decisive in determining the feasibility of the 2070 target. Without a significantly faster and more coordinated transformation of the electricity sector encompassing generation, transmission, distribution, and end-use electrification, the ambitious vision articulated by the Honourable Prime Minister risks becoming increasingly difficult to realise.

Key words: Energy Transition, Net Zero 2070, Power sector emissions, ESG goals, International Solar Alliance (ISA), Production Link Incentive scheme (PLI), Conference of Parties, Paris (COP 26)

1. Introduction

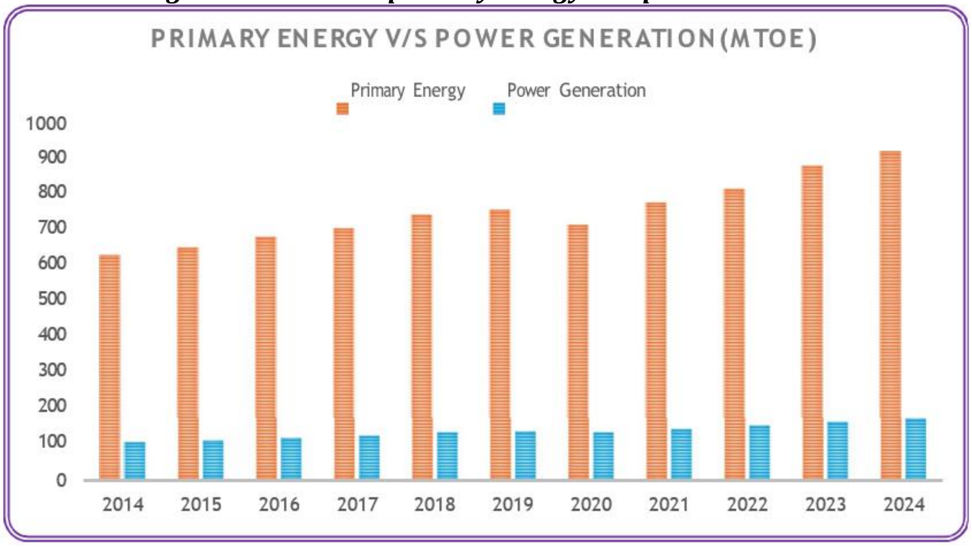
The concept of a sustainable energy transition refers to a structural shift in the way energy is produced, distributed, and consumed, moving away from carbon-intensive fossil fuels toward cleaner, low-carbon, and renewable energy sources. This transition is primarily driven by the urgent need to mitigate climate change, reduce greenhouse gas emissions, enhance energy security, and support long-term economic and environmental sustainability. For emerging economies such as India, the sustainable energy transition is not only an environmental imperative but also a development challenge, requiring a careful balancing of growth aspirations, affordability, and equity. At the same time, this transformation is increasingly recognised as a market-creating process that opens new entrepreneurial spaces for start-ups, SMEs, and private innovators across renewable generation, energy storage technologies, digital grid services, and clean energy solutions.

In India's context, the 26th Conference of Parties (COP26) represents a defining milestone in the country's decarbonisation trajectory. At COP26, the Honourable Prime Minister announced India's commitment to achieving net-zero emissions by 2070, signalling a decisive shift in national climate ambition. This announcement elevated India's role in global climate governance and provided a clear long-term direction for domestic policy, industrial strategy, and investment decisions across the energy ecosystem. By reducing policy uncertainty and signalling long-term demand for low-carbon solutions, the net-zero target has also strengthened investor confidence and encouraged private sector participation, particularly among energy start-ups and SMEs seeking to develop scalable, innovative business models in clean power, storage, and grid-support services.

The net-zero announcement at COP26 was followed by the formal submission of India's updated Nationally Determined Contribution (NDC) and its Long-Term Low Emissions Development Strategy (LTS) to the United Nations in 2022. Since then, India has undertaken a series of policy actions and institutional reforms, including the introduction of transformative domestic initiatives such as a national greenhouse gas emissions trading scheme. These measures reflect a growing alignment between international commitments and domestic policy execution. Collectively, such reforms are contributing to the creation of a more enabling market environment lowering entry barriers, stimulating innovation, and facilitating the participation of SMEs and private firms in renewable energy deployment, storage integration, and grid modernisation.

India continues to play a pivotal role in the evolving dynamics of the global energy system. Figure 1 shows the growth in primary energy demand v/s growth in electricity generation in the country. As one of the world's fastest-growing major economies, the country has witnessed sustained growth in primary energy demand averaging around 4 per cent annually over the past decade. Notably, electricity demand has expanded at an even faster rate of approximately 5 per cent, signalling deeper electrification of the economy and a gradual structural shift from manufacturing-led growth toward a more services-oriented economic model. This trend further reinforces the centrality of the power sector in India's sustainable energy transition and underscores its importance in achieving long-term net-zero objectives

Figure 1: Growth in primary energy and power demand



Source: Energy Institute - Statistical review of world energy 2025

India while continuing to meet its energy demand is on the right path for transition to renewable energy, though the coal remains the predominant energy source. Scientific literature suggests that the transition to 100% renewable energy can achieve reductions of over 40% in primary energy demand and over 25% in energy costs while reducing greenhouse gas emissions significantly and creating numerous jobs. However, there is disparity in clean fuel usage across different social strata and can defeat the Social Sustainable Development Goals in a bid to achieve just energy transitions

To strengthen rural electricity access, India is adopting decentralized energy systems and diversifying its power sources to reduce dependence on the central grid. Despite these efforts, infrastructural bottlenecks, fiscal constraints, and challenges in integrating distributed energy systems pose significant obstacles to achieving sustainability targets. As one of the world's largest energy consumers, India's actions are central to both national and global climate transition efforts. The objectives of this study are threefold:

- Status of Global and Indian power sector and energy transition
- Understand the challenges and opportunities for India's energy transition to achieve net zero target by 2070
- Understand the capital required for meeting such a transition

2. Literature Review

Multiple studies have thoroughly reviewed the literature on India's energy transition, highlighting the country's advancements in clean energy technologies and offering recommendations for optimising its existing resources to achieve climate goals (Durga et al., 2022; G.M. and S.R., 2022; Haldar et al., 2023).

Using digital and electronic databases, a comprehensive search for relevant research papers was conducted. The analysis comprised published studies examining the prospects and challenges of India's energy transformation. Since the Paris Agreement is regarded as a turning point in the global effort to combat climate change, only articles published from 2016 onwards were considered, given that the Agreement was adopted in 2015, to assess the current status of the energy transition.

Against this backdrop, the paper explores the critical role of technology in enabling the large-scale deployment of renewable energy sources such as solar, wind, and hydropower. It examines how advances in generation technologies, grid management systems, digitalisation, and energy storage are reshaping the feasibility and economics of renewable integration. Alongside technological drivers, the paper analyses the commercial, regulatory, and technical challenges that either facilitate or constrain the energy transition. In doing so, it places particular emphasis on the business dimensions of the transition, including capital requirements and investment risks.

In parallel with the growing literature on energy policy and technology, an expanding body of research within entrepreneurship and sustainability studies has examined how large-scale sustainability transitions create new market opportunities for entrepreneurs and small and medium enterprises (SMEs). The concept of sustainable entrepreneurship frames environmental challenges such as climate change and energy transition as drivers of opportunity recognition, innovation, and new venture creation, rather than solely as regulatory constraints (Dean and McMullen, 2007; Cohen and Winn, 2007). Within this perspective, the shift towards low-carbon energy systems enables entrepreneurial activity across renewable energy deployment, energy efficiency services, storage solutions, and digital energy platforms.

Closely related to this is the literature on green innovation, which focuses on firm-level innovation aimed at reducing environmental impacts while enhancing economic performance (Rennings, 2000; Hockerts and Wüstenhagen, 2010). Studies published in sustainability and innovation journals highlight that long-term policy signals such as net-zero targets, renewable energy mandates, and carbon markets play a critical role in lowering uncertainty and incentivising private investment in clean technologies. In emerging economies, green innovation is frequently driven by SMEs and start-ups, which demonstrate greater flexibility in adapting technologies to local market conditions and regulatory environments.

A growing number of studies have also examined SME-led renewable energy models in Asia, documenting how decentralised generation, rooftop solar systems, mini-grids, and energy-as-a-service business models facilitate SME participation throughout the energy value chain (Lewis, 2014; Urban et al., 2018). Evidence from India and other Asian economies suggests that SMEs contribute not only to project development and installation but also to operations and maintenance, component manufacturing, and ancillary grid services. These contributions are increasingly recognised as critical for expanding renewable energy capacity, improving energy access, and supporting inclusive economic development.

Despite these advances, the existing literature reveals important gaps. While prior studies acknowledge the role of entrepreneurs and SMEs in energy transitions, limited research integrates long-term energy system projections with an explicit analysis of entrepreneurial opportunities, SME participation, and private investment mobilisation in the context of net-zero targets extending to mid-century and beyond. By incorporating long-term power sector scenarios and capital requirements, the present study extends the literature by linking India's energy transition to sustainable entrepreneurship, green innovation, and SME-driven development within the Asian context.

This paper distinguishes itself from existing literature in two important ways:

1. First, it presents long-term projections of power sector capacity requirements and associated CO_2 emissions extending up to 2070. Such granular, forward-looking analysis remains largely absent in published research, particularly for emerging economies. These projections are informed by the author's extensive professional experience of over two decades in both global and domestic energy markets, allowing for a more realistic assessment of demand growth, technology adoption, and emissions trajectories.
2. Second, the paper provides a detailed assessment of the capital expenditure required to achieve India's net-zero targets.

3. Research Methodology

This study adopts a quantitative, model-based research design grounded in secondary data analysis. The methodology emphasises scenario modelling, trend analysis, and projection- based simulations to evaluate pathways for energy transition in the power sector. No primary surveys or stakeholder interviews are undertaken.

The analysis relies on publicly available, verified datasets from national and international institutions, including:

- Government ministries and regulatory bodies (e.g., power, coal, renewable energy)
- National statistical agencies and grid operators
- International organisations (IEA, World Bank, IRENA, UNFCCC)
- Peer-reviewed academic literature and policy reports

The data spans historical time series (2014–2024) and is harmonised for consistency across sources. The modelling is then done for the years 2024 – 2070 in 5-year periods and two distinct scenarios are constructed:

- Business-as-Usual (BAU): Continuation of current policies and trends
- Aggressive Transition / Net-Zero Aligned Scenario: Rapid renewable deployment, coal phase-down, and efficiency improvements

Each scenario is defined by explicit assumptions on capacity growth rates, fuel shares and technology performance. The scenario-based approach adopted in this study also provides a structured framework for informing entrepreneurial decision-making, investment strategy, and SME market entry within the evolving power sector. By comparing outcomes under the Business-as-Usual and Aggressive Transition scenarios, the analysis highlights differences in market size, technology adoption timelines, capital requirements, and risk profiles across renewable generation, energy storage, and grid-related services. These scenario outcomes offer actionable insights for entrepreneurs and SMEs by indicating when and where demand for specific technologies and services is likely to emerge, the scale at which investment opportunities may materialise, and the degree of policy and market certainty associated with each pathway. In this way, the modelling results not only assess system-level feasibility but also support strategic planning for private firms, enabling more informed decisions on market entry, business model development, and long-term capital allocation in the context of India's energy transition.

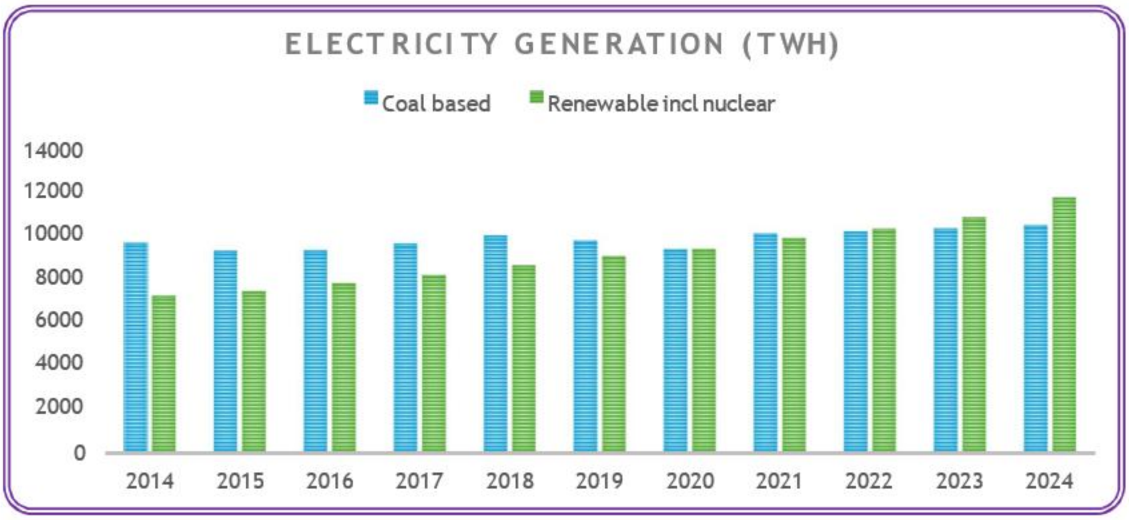
4. Data Analysis & Findings

4.1 Current Trends – Global v/s India Scenario

Over the last decade, the global energy landscape has undergone a profound transformation, shaped by heightened awareness of climate change, growing concerns over energy security, and an increasing urgency to transition toward sustainable and low-carbon energy systems. Energy transition research has consequently emerged as a central pillar of global climate action, informing policy design, investment strategies, and technology deployment pathways aimed at achieving national sustainable development objectives while simultaneously meeting international climate commitments.

As illustrated in Figure 2, globally electricity generation has expanded at an average rate of approximately 2.5 per cent per annum over the past decade, reflecting steady growth in demand driven by population increase, urbanisation, digitalisation, and economic expansion. However, this aggregate growth masks significant structural shifts within the generation mix. Coal-based power generation, traditionally the backbone of global electricity supply, has grown at a much slower pace of around 0.8 per cent per annum. In contrast, renewable energy has expanded far more rapidly, with growth rates approaching 5 per cent annually.

Figure 2: Electricity Generation (Coal v/s Renewables)



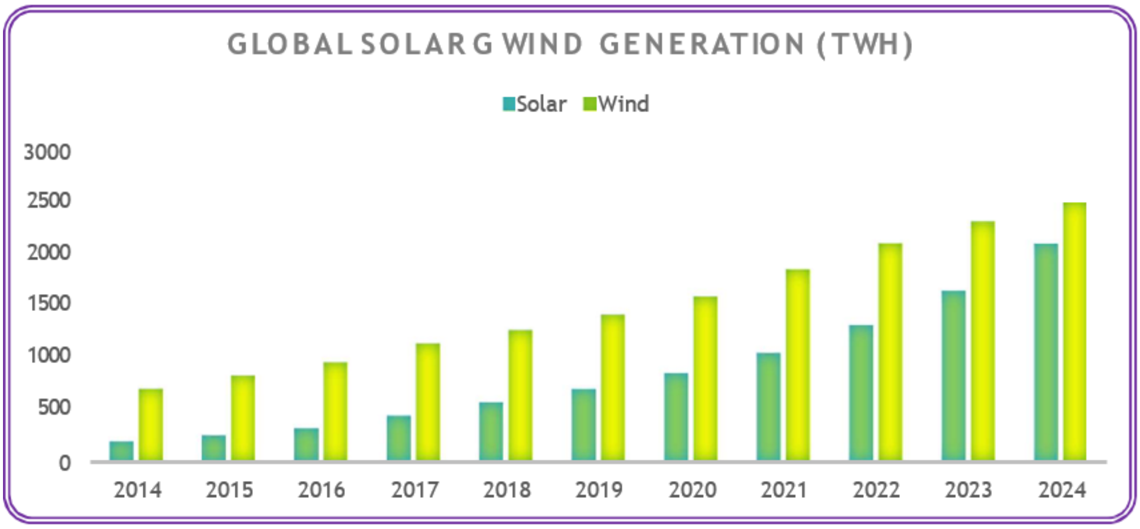
Source: Energy Institute - Statistical review of world energy 2025

This divergence highlights a decisive reorientation of investment and policy priorities away from fossil fuels and toward cleaner energy sources. Notably, since 2022, electricity generation from renewable sources has exceeded that from coal, marking a historic inflection point in the global power sector and underscoring the accelerating momentum of decarbonisation.

The global shift away from coal toward renewable energy signals expanding market opportunities for businesses, start-ups, and SMEs operating across the clean energy value chain. Rapid growth in solar and wind generation creates demand not only for generation assets but also for associated services such as project development, engineering, procurement and construction (EPC), operations and maintenance, digital monitoring, and energy analytics. For entrepreneurs, this structural transition lowers entry barriers into emerging clean-energy markets and enables the development of scalable business models aligned with long-term decarbonisation trends.

A more granular examination of renewable energy sources reveals even more striking trends. Solar and wind power have been the principal drivers of renewable growth over the past decade. Electricity generation from solar energy has recorded year-on-year growth of nearly 30 per cent, making it the fastest-growing source of electricity globally. Wind-based power generation has also expanded robustly, growing at an annual rate of approximately 14 per cent, as shown in Figure 3. These growth rates reflect rapid cost declines, technological improvements, supportive policy frameworks, and increasing investor confidence in renewable technologies.

Figure 3: Global Solar & Wind power generation



Source: Energy Institute - Statistical review of world energy 2025

As a result of this sustained expansion, global installed wind capacity has now surpassed 1,100 GW, while global solar capacity is approaching 1,900 GW. These figures underscore the scale at which renewables are being deployed and their growing role in meeting incremental electricity demand worldwide.

The exceptional growth rates observed in solar and wind power underline strong investor confidence and indicate favourable conditions for private capital mobilisation. For start-ups and SMEs, the rapid scaling of these technologies opens opportunities in component manufacturing, balance-of-system solutions, energy storage integration, and digital grid services. Capacity expansion at this scale also encourages innovation in financing models, such as energy-as-a-service and performance-based contracts, enabling smaller firms to participate alongside large developers.

Leading this expansion are countries such as **China** and **India**, which have emerged as central actors in the global renewable energy transition. China has been adding renewable capacity at an exceptional pace, with growth rates exceeding 30 per cent in recent years, driven by strong state support, large-scale manufacturing capacity, and ambitious decarbonisation targets. India, while starting from a lower base, has also demonstrated impressive momentum, with renewable capacity growing at around 22 per cent annually* This rapid expansion reflects India's dual objective of meeting rising electricity demand while reducing dependence on fossil fuels and limiting emissions growth.

Together, these trends indicate that the global energy transition is no longer incremental but structural in nature. The sustained acceleration of renewable energy deployment, particularly solar and wind, is reshaping power systems worldwide and laying the foundation for deeper decarbonisation across end-use sectors in the decades

Similar trend is visible in the Indian power sector as well. With a lot of push from the central Government the renewable based power capacity in the country has grown three times in the last decade. In the similar period the thermal capacity has grown by only 50%. As illustrated in Figures 4 and 5, renewable energy generation capacity in India has expanded at a significantly faster pace than thermal power capacity over the last decade, underscoring a clear structural shift in the country's power sector.

By 2024, installed renewable capacity had reached approximately 224 GW, nearly 94 per cent of the installed thermal capacity of about 237 GW. This represents a dramatic change from 2014, when renewable capacity stood at around 80 GW compared to thermal capacity of nearly 168 GW. In growth terms, renewable-based generation capacity has increased at a compound annual growth rate (CAGR) of about 11 per cent over the decade, while thermal capacity has grown at a much more modest rate of approximately 3.5 per cent. These trends clearly reflect policy prioritisation, declining renewable energy costs, and growing investor interest in clean energy assets.

India's faster growth in renewable capacity relative to thermal power reflects a policy-driven reorientation of the electricity market that is particularly relevant for SMEs and domestic entrepreneurs. Expanding renewable capacity has created new entry points for smaller firms in installation, operations and maintenance, grid interconnection services, forecasting, and decentralised energy solutions. The scale of capacity additions also supports the emergence of local supply chains, fostering SME participation in manufacturing, logistics, and service provision across renewable energy clusters.

Despite this rapid expansion in installed capacity, a substantial gap remains between capacity addition and actual electricity generation from renewable sources. Owing to the inherently intermittent nature of solar and wind power driven by weather conditions, diurnal cycles, and seasonal variability renewables currently account for only about 26 per cent of the electricity units generated compared to fossil-fuel-based sources. In contrast, thermal power plants, particularly coal-based units, operate at significantly higher capacity utilisation factors, enabling them to produce a disproportionately larger share of total electricity despite comparable installed capacity.

***Central Electricity Authority, Government of India**

Figure 4: India power generation capacity (GW)

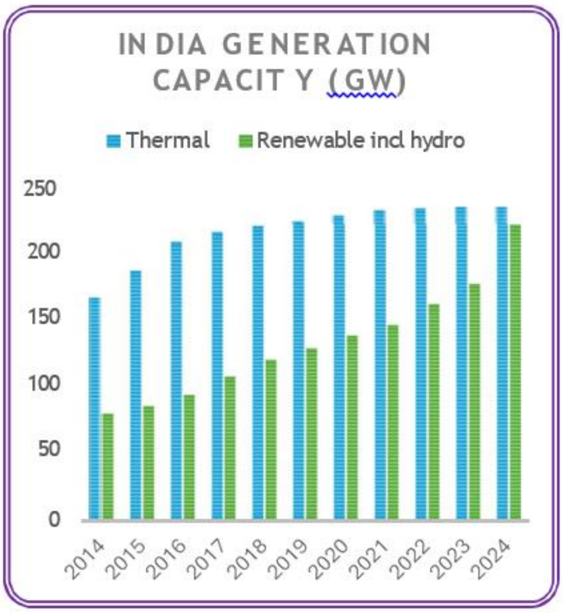
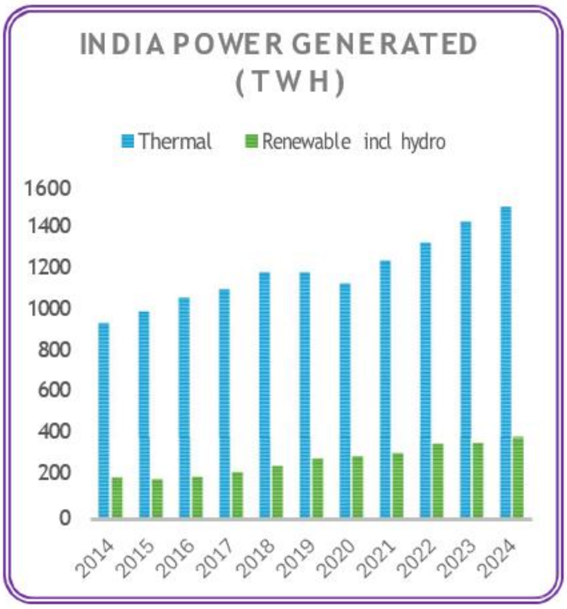


Figure 5: India power generation (TWH)



Source: Energy Statistics India 2024 (National Statistical Office, Government of India)

This divergence between installed capacity and energy output raises an important and often underappreciated implication for the energy transition. To meaningfully displace fossil-fuel-based generation and achieve parity in electricity output, renewable capacity would need to be scaled up to at least three to four times the level of thermal capacity, assuming current technology and system configurations. The requirement to install renewable capacity at three to four times the level of thermal capacity fundamentally reshapes the business landscape of the power sector. This scale-up generates sustained demand for complementary services such as energy storage, flexible generation, grid-balancing solutions, demand response, and digital optimisation platforms. For entrepreneurs and start-ups, these needs translate into opportunities to develop new business models focused on system integration, reliability services, and data-driven energy management, rather than generation alone. Such a scale-up has far-reaching consequences, not only in terms of the sheer magnitude of capital investment required but also in relation to system planning, grid integration, and operational reliability.

The need for renewable capacity at this scale introduces significant challenges. On the financial side, it implies unprecedented capital mobilisation for generation assets, along with parallel investments in transmission networks, energy storage systems, and grid-balancing infrastructure. On the technical and operational side, it raises concerns related to land availability, resource adequacy, grid congestion, forecasting accuracy, and the ability of the power system to absorb large volumes of variable renewable energy without compromising stability and reliability. Efficient evacuation of power from renewable-rich regions to demand centres further compounds these challenges.

While the scale of investment and system complexity introduces operational and financial risks, it simultaneously expands opportunity spaces for innovative firms capable of addressing grid integration, forecasting, storage deployment, and transmission optimisation. SMEs and start-ups that can offer cost-effective, modular, and digitally enabled solutions are likely to play a critical role in mitigating system constraints while capturing emerging market opportunities created by the energy transition.

The paper addresses these issues in greater detail in its later sections, examining the investment requirements, system-level constraints, and technological solutions—such as storage, flexible generation, and grid modernisation—that will be critical to enabling renewable energy to effectively replace fossil-fuel-based power generation at scale

4.2 Emissions & Why Net Zero

There have long been divergent views and counterviews on whether greenhouse gas emissions pose an imminent and existential threat to our "Blue Planet." While scientific debates on pace, magnitude, and timelines may continue, the underlying principle remains largely unquestionable: clean air to breathe, safe water to drink, and unpolluted soil to grow food are fundamental to human well-being. These are not abstract environmental ideals but necessities for a healthy society. It is therefore both rational and ethical to pursue pathways that reduce pollution and environmental degradation. Beyond our own immediate welfare, we also bear a responsibility toward future generations to pass on a planet that is healthier and more resilient than the one we inherited from our parents and forefathers. A 1% increase in renewable energy usage results in a 0.8% decrease in emissions (Das et al., 2023).

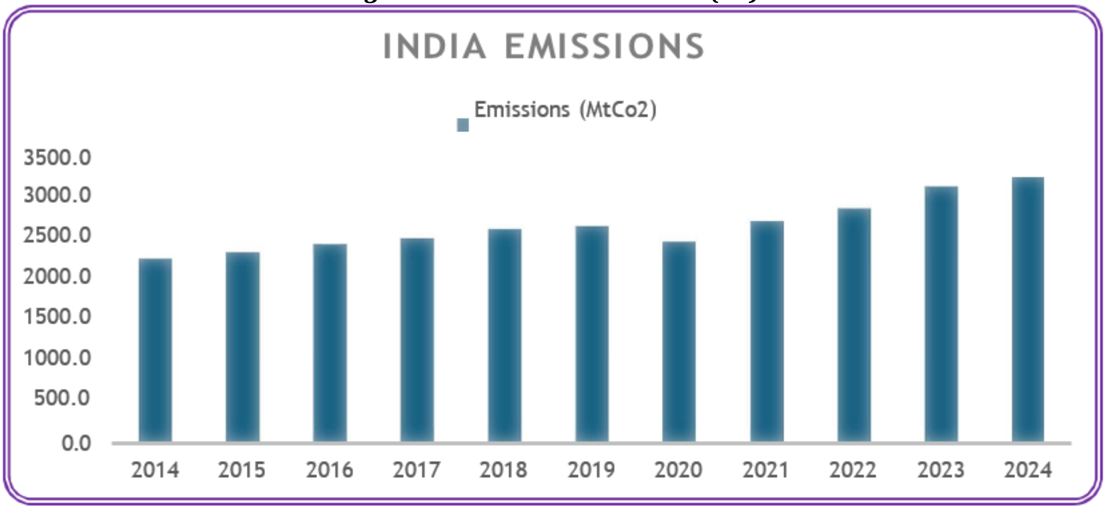
The demonstrated relationship between renewable energy adoption and emissions reduction has direct implications for corporate environmental, social, and governance (ESG) strategies. As emissions metrics increasingly influence investor decisions, access to capital, and corporate valuations, firms are under growing pressure to align operational practices with decarbonisation objectives. For companies operating in or sourcing from India, investments in renewable energy procurement, energy efficiency, and low-carbon technologies are no longer voluntary initiatives but integral components of ESG compliance and long-term risk management. This shift strengthens demand for clean energy solutions and reinforces market incentives for private-sector participation in emissions reduction. In this global context, **India** ranks among the largest emitters of greenhouse gases in absolute terms, largely reflecting the scale of its population and the size of its economy. However, India's per capita emissions remain among the lowest globally, owing to a large population base and relatively lower levels of energy consumption per individual. This distinction is critical in framing India's climate responsibility one that balances developmental imperatives with environmental stewardship.

India's commitment to achieving net-zero emissions by 2070 lies at the heart of the global climate change framework and represents a calibrated approach aligned with its stage of development. To make this commitment credible and achievable, policy focus must be directed toward sectors that are both the largest contributors to emissions and relatively easier to transition with optimal capital allocation and mature technological solutions. Equally important is ensuring that this transition has minimal adverse impact on living standards and lifestyles, particularly in a developing economy where affordability and access remain paramount concerns. The roadmap toward net-zero emissions by 2070 is therefore marked by significant gaps and challenges, requiring careful sequencing, prioritisation, and sustained policy support.

An examination of India's emissions trajectory (Figure 6) suggests that the transition path has been challenging. As the country aspires to become a developed nation by 2047—a vision articulated by the Prime Minister—economic growth will need to be underpinned by reliable, affordable, and increasingly clean energy systems. Given that the power sector alone contributes close to 50 per cent of India's total CO_2 emissions, early and decisive decarbonisation of this sector is indispensable for achieving long-term climate goals.

The centrality of the power sector in India's emissions profile positions entrepreneurs and start-ups as critical agents of change in achieving net-zero targets. Entrepreneur-driven adoption of clean technologies such as distributed solar, battery storage, energy management systems, and digital grid solutions enables faster diffusion of low-carbon innovations across the economy. By offering modular, scalable, and cost-effective solutions, entrepreneurial firms complement large-scale infrastructure investments and help translate national decarbonisation goals into implementable, market-based outcomes.

Figure 6: India CO2 emissions (Mt)

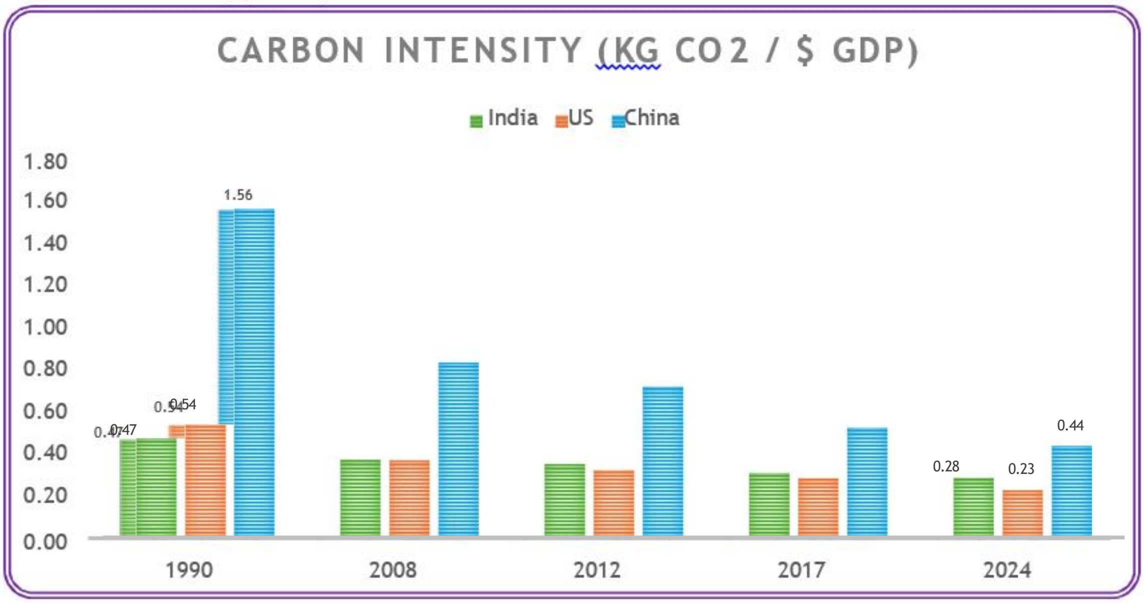


Source: IEA & Ministry of Power Government of India

However, the transition is not without friction. The trade-off between cost and affordability is particularly pronounced in developing economies such as India. At this stage of development, ensuring universal access to energy remains a pressing challenge, especially in the short to medium term. Over the past decade, India's total energy supply has grown at a compound annual growth rate (CAGR) of around 3.9 per cent, while carbon emissions have increased at a similar pace of approximately 3.8 per cent. This parallel growth reflects the close linkage between energy consumption and economic expansion during earlier stages of development.

Looking ahead, as India advances toward a more mature economic structure, energy intensity—and consequently emissions growth—is expected to decouple from GDP growth and increase at a much slower pace than historically observed. This expectation is supported by comparative data on carbon intensity trends across major economies. As illustrated in Figure 7, carbon intensity per dollar of GDP has declined steadily in **India**, **United States**, and **China**. Notably, China and India have demonstrated a faster rate of decline, reflecting structural shifts, improvements in energy efficiency, and the growing role of cleaner energy sources.

Figure 7: Carbon Intensity per $ of GDP



Source: Energy Institute Statistical Review, 2025

These trends present an encouraging picture for the global environment. Declining carbon intensity and tightening regulatory expectations are increasingly shaping innovation behaviour among small and medium enterprises (SMEs). As emissions reporting requirements, carbon pricing mechanisms, and ESG-linked supply chain standards expand, SMEs face growing compliance obligations. In response, many firms are adopting clean technologies and energy-efficient processes not only to meet regulatory requirements but also to enhance competitiveness and access green finance. This compliance-driven innovation dynamic positions SMEs as both contributors to emissions reduction and beneficiaries of the net-zero transition through improved productivity, resilience, and market access. They suggest that future economic growth in major economies can be progressively less carbon-intensive, offering hope that development and decarbonisation need not be mutually exclusive. If sustained and reinforced through coherent policy and technological innovation, this trajectory strengthens the case for a greener and more sustainable global growth pathway in the decades ahead

To foster and fasten this transition the Government of India has implemented a coordinated set of policy measures to accelerate renewable energy deployment as a central element of its net- zero transition.

4.3 Policy Level Support

A strong emphasis on solar energy lies at the heart of India's strategy to decarbonise its power sector while simultaneously enhancing energy security and sustaining long-term economic growth. Solar power offers India a unique convergence of advantages: abundant domestic resource availability, rapidly declining technology costs, scalability across utility-scale and distributed applications, and minimal exposure to fuel price volatility. By prioritising solar energy, India seeks not only to reduce emissions from electricity generation but also to lessen its dependence on imported fossil fuels, thereby strengthening macroeconomic resilience and improving balance-of-payments stability.

India's leadership role in the **International Solar Alliance (ISA)** further reinforces this strategic direction. Through the ISA, India has positioned itself as a global champion of solar energy by facilitating international cooperation, promoting technology diffusion, and enabling innovative financing mechanisms for solar deployment, particularly in developing and tropical countries. This platform enhances India's diplomatic influence in climate governance while accelerating the global scale-up of solar power as a key mitigation solution. (Table 1)

At the domestic policy level, one of the most significant initiatives aimed at strengthening the clean energy ecosystem is the **Production Linked Incentive Scheme (PLI)**. The PLI scheme is designed to boost domestic manufacturing capacity across the solar value chain, including modules, cells, and upstream components. By reducing reliance on imports and fostering globally competitive manufacturing capabilities, the scheme supports job creation, supply- chain resilience, and cost competitiveness, all of which are critical for sustaining large-scale renewable deployment. In parallel, the rapid expansion of grid-scale solar parks across multiple states has enabled economies of scale, streamlined land acquisition, and facilitated the efficient integration of low-carbon electricity into the national grid.

Beyond strengthening domestic supply chains, the Production Linked Incentive (PLI) scheme has significant implications for entrepreneurship and SME-led manufacturing in the clean energy sector. By offering performance-linked financial incentives, the scheme lowers entry barriers for new and expanding firms, enabling start-ups and SMEs to invest in solar module manufacturing, component assembly, and upstream technologies. The resulting expansion of domestic manufacturing capacity supports the emergence of entrepreneurial ecosystems, fosters innovation in production processes, and creates opportunities for smaller firms to integrate into globally competitive renewable energy value chains.

Table1: India's international initiatives to address climate change

Initiative	Details	India's Role
International Solar Alliance (ISA)	The ISA was established by India and France in 2015. It is a treaty-based organization with 119 members. It aims to unlock USD 1 trillion in solar investments by 2030, supporting 9.5 GW solar capacity projects. ISA offers USD 50,000 grants to LDCs and SIDS, with 19 solar projects underway as of 2024, has trained 4,000 professionals globally, and set up STARC centres in Ethiopia and Somalia.	India co-founded ISA. It provides technical, financial, and capacity-building support and promotes solar energy projects in member countries, especially LDCs and SIDS
One World, One Sun, One Grid (OWOSOG)	Led by India and the UK, aims to globally interconnect solar energy systems in three phases: a regional grid (Phase 1), integration with Africa's resources (Phase 2), and full	As one of the leaders of the OSOWOG initiative, India is driving the interconnection of solar energy systems to ensure

	global interconnection targeting 2600 GW by 2050 (Phase 3)	global renewable energy distribution
Leadership Group for Industry Transition (LeadIT)	Launched by India and Sweden in 2019. It brings together countries and companies for Paris Agreement goals. The second phase (2024-2026) focuses on inclusive industry transition, low carbon technology co-development, and financial support for emerging economies	India as a co-founder of LeadIT promotes inclusive and sustainable industry transition and shapes global policy frameworks and supports low-carbon technology development for emerging economies

Source: P. Prajapati et al, 2025

India's leadership in the International Solar Alliance (ISA), combined with the domestic development of large-scale solar parks, has played a crucial role in fostering SME-led value chains across the solar ecosystem. While ISA facilitates technology transfer, capacity building, and access to finance at the international level, solar parks create concentrated hubs of activity that lower transaction costs for developers, suppliers, and service providers. These platforms enable SMEs to participate in project development, engineering services, installation, operations and maintenance, logistics, and ancillary services, thereby embedding smaller firms across multiple stages of the solar value chain.

Collectively, these initiatives demonstrate India's active engagement with its **Nationally Determined Contributions (NDCs)** and highlight a growing alignment between domestic energy policies and international climate commitments. The coherence between national targets and global obligations has helped improve policy credibility and investor confidence, contributing to a sharp acceleration in renewable energy deployment.

As a result, India's renewable energy market—particularly the solar sector—has witnessed remarkable growth, with installed capacity more than doubling in less than four years. This expansion has been underpinned by a robust policy framework that includes fiscal incentives, competitive reverse-auction tariff mechanisms, and targeted financial schemes aimed at reducing project risk. Together, these measures have enhanced project bankability, attracted substantial private and institutional investment, and firmly positioned renewable energy as a central pillar of India's long-term net-zero pathway.

Collectively, India's renewable energy policies ranging from fiscal incentives and competitive bidding mechanisms to targeted financial schemes have significantly reduced market entry barriers for green start-ups. By improving revenue visibility, reducing policy risk, and standardising procurement processes, these measures enable new firms to compete alongside established players. For early-stage clean-tech ventures, such policy support improves access to finance, enhances project bankability, and accelerates the commercialisation of innovative technologies and business models within the renewable energy sector.

Despite these enabling conditions, India's energy transition policy also faces significant structural and implementation challenges. The country has committed to an ambitious expansion of renewable energy capacity, targeting 500 GW by 2030, alongside a pledge to ensure that at least 50 per cent of electricity generation is sourced from renewables by the same year, consistent with its commitments under the **Glasgow Climate Pact**. However, achieving this target remains highly challenging. With total renewable capacity currently at around 250 GW, doubling capacity within the next five years would require an unprecedented pace of additions. Historically, India's best annual capacity addition has been approximately 30 GW, implying a significant scaling-up of execution capability, supply chains, and financing.

Moreover, reaching the 500 GW target would necessitate investments of nearly USD 200 billion in the generation sector alone, excluding the substantial capital required for transmission, distribution, energy storage, and grid modernisation. Mobilising this level of investment at speed, while maintaining affordability and system reliability, represents one of the most formidable challenges in India's energy transition. Addressing these constraints will require coordinated policy action, innovative financing structures, and accelerated deployment of enabling technologies to ensure that ambition is matched by implementation capacity

4.4 Outlook (future scenarios) - Power Generation Capacity

Now that the baseline has been established through an examination of historical trends in power generation, associated emissions, and the trajectory of India's energy transition, the analysis turns to the forward-looking requirements of the power sector in enabling the achievement of

the net-zero emissions target by 2070.
From an entrepreneurial perspective, the two scenarios represent distinct market landscapes. The BAU scenario reflects a lower-opportunity environment with slower market expansion and higher uncertainty for new firms, while the Aggressive scenario represents a high-opportunity landscape with stronger demand signals, higher innovation intensity, and greater scope for SME and start-up participation.

This section of the paper draws on long-term energy system modelling extending to 2070 and is structured around two distinct scenarios: a **business-as-usual (as-is) scenario** and an **aggressive transition scenario**.

The as-is scenario reflects a continuation of existing policies, investment patterns, and technology deployment rates, broadly consistent with historical trends in capacity addition, fuel mix evolution, and efficiency improvements. In contrast, the aggressive scenario assumes a substantially accelerated pace of decarbonisation, driven primarily by rapid and large-scale deployment of renewable energy technologies. The divergence between the two scenarios arises from markedly higher rates of solar and wind capacity addition in the aggressive pathway—levels that exceed anything observed historically and require a step change in planning, financing, manufacturing capacity, and grid integration.

By comparing these scenarios, the modelling framework captures the scale of transformation required in the power sector, highlighting differences in installed capacity, generation mix, emissions trajectories, and system flexibility requirements over time. The aggressive scenario underscores the necessity of overcoming structural and institutional constraints to enable faster renewable adoption, including land availability, transmission expansion, storage deployment, and market reforms. Together, these scenarios provide a structured basis for assessing the feasibility, risks, and policy implications of alternative pathways toward achieving net zero by 2070, while illustrating the critical role of the power sector as the backbone of economy-wide decarbonisation

4.4.1 Business As Usual (BAU) Scenario

India's rapid economic expansion over the past few decades has been accompanied by a commensurate increase in energy demand, reflecting rising incomes, urbanisation, industrialisation, and the growing penetration of electricity across sectors. This structural linkage between economic growth and energy consumption is expected to persist—and potentially intensify—over the coming decades as India aspires to transition into a high-income economy while simultaneously improving energy access and quality of life. In this context, a rigorous assessment of future electricity demand and power sector requirements becomes critical for designing coherent economic, energy, and environmental strategies aligned with long-term decarbonisation goals.

To anchor this analysis, it is useful to begin with near- and medium-term policy targets before extending the assessment to the long-term forecast horizon ending in 2070. The Government of India has repeatedly articulated its ambition to significantly scale up renewable energy deployment, most notably through the publicly stated target of achieving 500 GW of installed renewable power capacity by 2030, up from the current level of approximately 225 GW. Complementing this capacity-focused objective is the parallel commitment to ensure that at least 50 per cent of electricity generation is sourced from renewables by 2030, compared with the current share of around 26 per cent. Together, these targets signal a decisive shift in the structure of India's power sector within a relatively short timeframe.

To model this shift, this challenge is decomposed into two distinct but interrelated dimensions:
installed generation capacity and **actual electricity generation**. This distinction is essential because installed capacity does not translate linearly into electricity output, particularly in the case of renewable energy technologies. The effective conversion of capacity into generation depends on factors such as resource availability, intermittency, plant load factors, and operational efficiency. For solar and wind power, these factors result in capacity utilisation rates typically in the range of 20–25 per cent under Indian conditions. In contrast, conventional thermal power plants can achieve effective utilisation rates of up to 60 per cent or higher. Consequently, achieving a given share of electricity generation from renewables requires a disproportionately higher share of installed capacity compared to thermal sources.
Under the BAU scenario, opportunities for entrepreneurs and SMEs remain limited, as slower capacity growth and weak system integration constrain market size. Returns are moderate, policy uncertainty remains higher, and innovation is largely incremental.

To simulate this transition in a robust manner, the analysis adopts a set of clearly defined assumptions drawn from a synthesis of existing academic literature, official government projections, and the author's professional judgement informed by extensive experience in the energy sector. These assumptions are:
a) The total power capacity continues to grow at

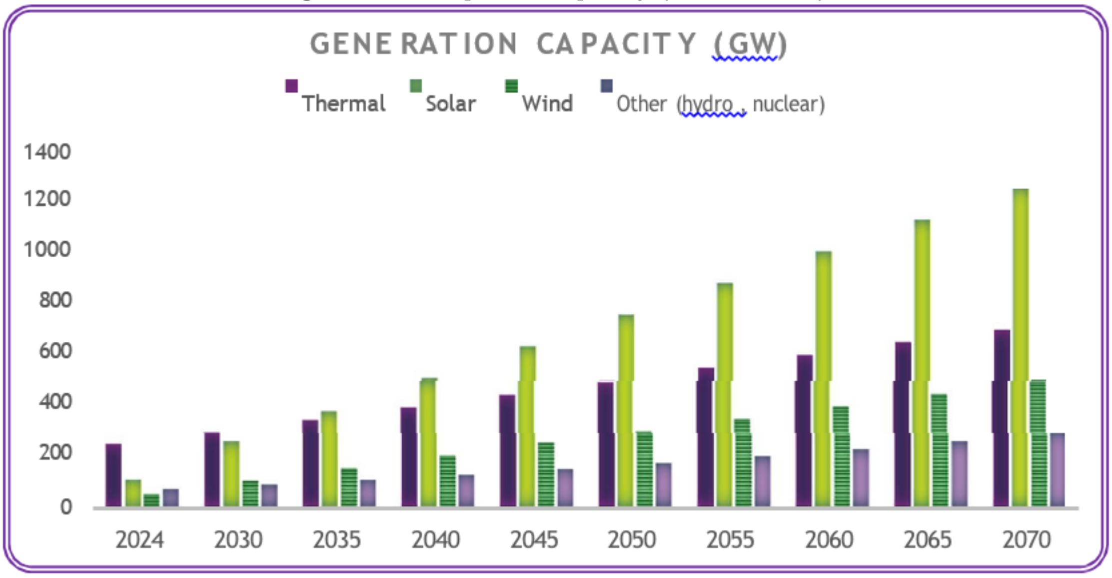
close to 5% till 2040. This is in line with historical growth over the last decade. Post 2040 the growth slows down to less than 3%. This will happen because as the economy moves towards a more developed one the energy intensity will decrease.

b) Coal based generation capacity grows at a much slower rate of less than 3% during the entire projection period i.e. till 2070

c) Renewable capacity grows at a faster pace of slightly below 5% with Solar and Wind based capacity growing at a higher than 5% rate.

The result of this projection is shown in Figure 8. The total power capacity by 2070 becomes over 2700 GW a nearly 6-fold increase from current capacity whereas renewable capacity grows to over 2000 GW a nearly 10-fold increase. Also, in terms of capacity mix the proportion of coal v/s renewable changes from the current ratio of 53:42 to 25:75 by 2070. This is a significant step towards de carbonising the power sector and moving closer to the net zero target

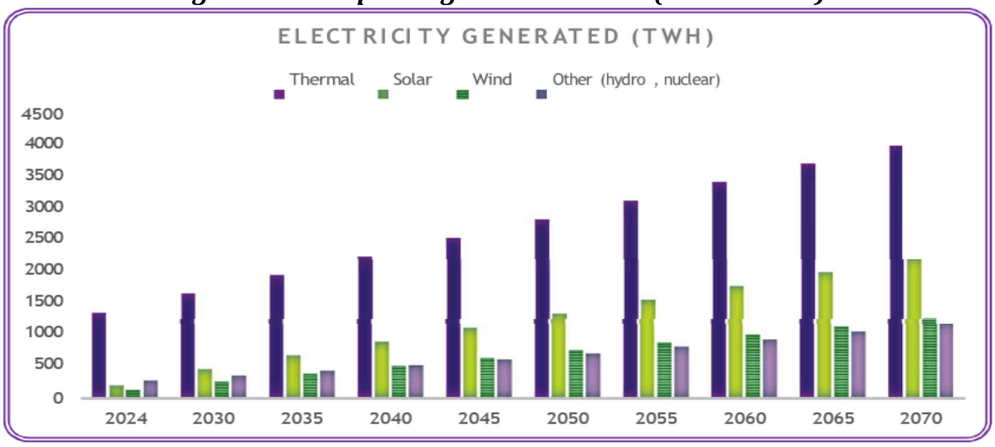
Figure 8: India power capacity (2024 – 2070)



Source: Model developed by author

However, the expansion of installed capacity by itself is insufficient to address the complexity of the power sector transition. As illustrated in Figure 9, despite the substantial growth in renewable capacity, electricity generation from renewable sources will account for only about 55 per cent of total electricity output by 2070. This is significantly below the estimated 70–75 per cent share of renewable generation that would be required for the power sector to align with a net-zero emissions pathway. The gap between installed capacity and energy output highlights a fundamental structural challenge: the marginal contribution of additional renewable capacity diminishes unless accompanied by complementary investments and system-level interventions

Figure 9: India power generation TWH (2024 – 2070)



Source: Model developed by author

Bridging this gap necessitates a combination of measures aimed at enhancing the effective contribution of renewables to the electricity mix. These include large-scale deployment of energy storage technologies, expansion and strengthening of transmission networks to smooth regional variability, improved forecasting and dispatch mechanisms, and the development of flexible generation and demand-side response capabilities. Without such enabling infrastructure and market reforms, renewable capacity additions risk leading to curtailment, inefficiencies, and continued reliance on fossil-fuel-based generation for balancing and reliability. From a business perspective, the BAU pathway offers fewer incentives for new service-based models such as storage, flexibility, and digital grid solutions, limiting market entry for start-ups and SMEs.

4.4.2 Aggressive Scenario

The Aggressive scenario creates a significantly more attractive opportunity landscape for firms, driven by faster renewable deployment, clearer policy signals, and larger addressable markets, supporting higher returns and stronger private investment. This scenario models a markedly more ambitious pathway for India's power-sector transition, premised on achieving at least 70% of electricity generation from renewable sources well before the net-zero horizon. The approach embeds stronger structural shifts in capacity addition, technology mix, and long-term demand dynamics, reflecting both policy intent and techno-economic feasibility.

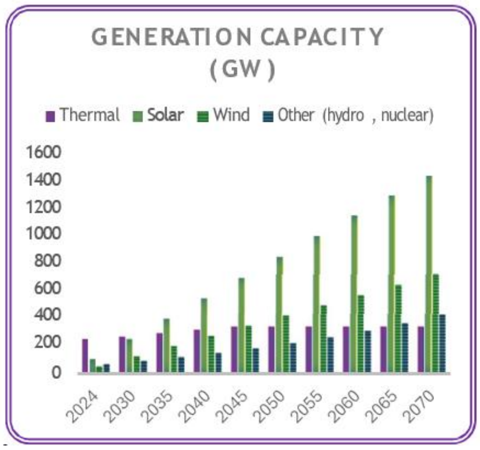
First, overall power capacity expansion is assumed to remain robust in the medium term, growing at close to 7% per annum until 2040. This phase corresponds to sustained economic expansion, rapid urbanisation, and rising electrification of end-use sectors such as transport and industry. Beyond 2040, however, the growth rate moderates to below 3%, consistent with India's transition towards a more mature, developed economy. As income levels rise and technologies improve, energy intensity of GDP is expected to decline, dampening the rate of incremental electricity demand despite continued economic growth.

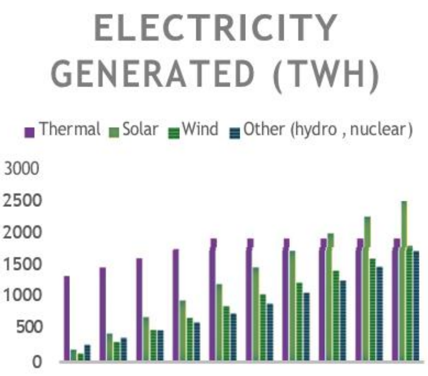
Second, coal-based generation capacity follows a deliberately constrained trajectory. Thermal capacity growth is limited to less than 3% annually until 2045, after which no additional coal capacity is assumed. From 2045 to 2070, coal capacity remains constant, implying a gradual decline in its relative importance as older plants retire and cleaner sources dominate new additions. This assumption reflects tightening environmental constraints, rising carbon costs, and the increasing competitiveness of renewables combined with storage and flexibility solutions. Higher renewable penetration under this scenario increases innovation intensity, creating strong demand for storage, grid-balancing, forecasting, and digital energy services. This expands entry opportunities for start-ups and SMEs with scalable, technology-driven business models.

Third, renewable energy capacity expands at a significantly faster pace, growing at just under 5% annually, with solar and wind capacity increasing at close to 6%. These technologies form the backbone of the transition due to their scalability, declining costs, and alignment with India's resource endowments. Accelerated deployment is supported by improvements in grid integration, storage, and forecasting, enabling higher penetration without compromising system reliability.

The outcome of these assumptions, illustrated in Figure 10 & 11, is a profound transformation of India's power system. By 2070, total installed capacity is close to 3,000 GW, representing nearly a seven-fold increase over current levels. Within this, renewable capacity surpasses 2,600 GW, **a** twelve-fold expansion, underscoring the dominance of clean energy in the future system. The capacity mix shifts dramatically, with the coal-to-renewable ratio changing from approximately 53:42 at present to 12:88 by 2070. This structural realignment constitutes a major step towards deep decarbonisation of the power sector and places India firmly on a net- zero–compatible trajectory.

Figure 10: India power capacity GW (2024 – 2070) *Figure 11: India power generation TWH (2024 – 2070)*





Source: Model developed by author

Crucially, this capacity transition also translates into generation outcomes. Renewable electricity generation exceeds the 70% threshold, indicating that the net-zero objective is nearly realised within this scenario, even before accounting for residual emissions offsets or carbon capture solutions. Among renewables, solar energy emerges as the dominant contributor, with installed solar capacity approaching 1,500 GW by 2070. While this scale may appear ambitious given the current installed base of roughly 100 GW in 2024, recent evidence suggests that it is well within India's technical potential.

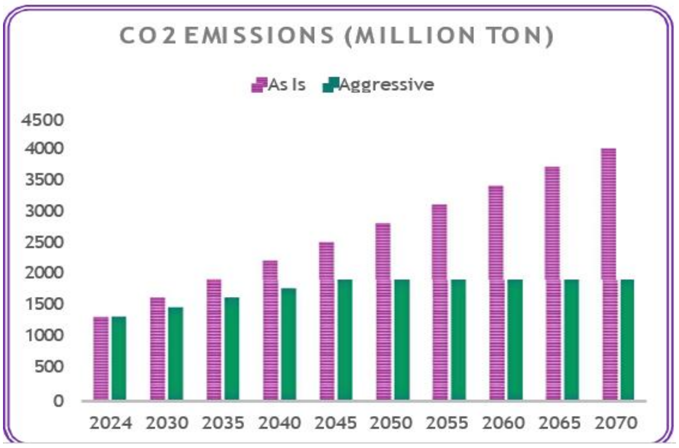
A recent macro-level assessment by The Energy and Resources Institute **(TERI)**—titled *"Reassessment of Solar Potential in India: A Macro-level Study"* (June 2025)—provides strong empirical support for this outlook. The study estimates India's total solar potential at approximately 10,830 GW, identifying substantial untapped opportunities across both conventional deployments (such as utility-scale and rooftop systems) and innovative applications, including agrivoltaics, floating solar, and infrastructure-integrated installations. This reassessment reinforces the plausibility of large-scale solar expansion and validates the central role assigned to solar power in this aggressive transition scenario.

Overall, the scenario demonstrates that with sustained policy commitment, technological progress, and system-level planning, India can achieve a high-renewables electricity system that is consistent with long-term net-zero ambitions while supporting economic growth and energy security

4.4.3 Outlook (future scenarios) – CO2 Emissions & Capital Requirement

The comparative assessment of the two power sector transition scenarios clearly indicates that a continuation of the current, business-as-usual growth trajectory is unlikely to be sufficient to meet India's long-term commitment of achieving net-zero emissions by 2070. While incremental improvements in efficiency and moderate additions to renewable capacity can slow the rate of emissions growth, they fall short of delivering the structural transformation required in the electricity sector. Consequently, a substantially more aggressive strategy focused on accelerated renewable capacity addition becomes not just desirable, but necessary.

Figure 12: India power sector Co2 emissions Million Tonnes (2024 – 2070)

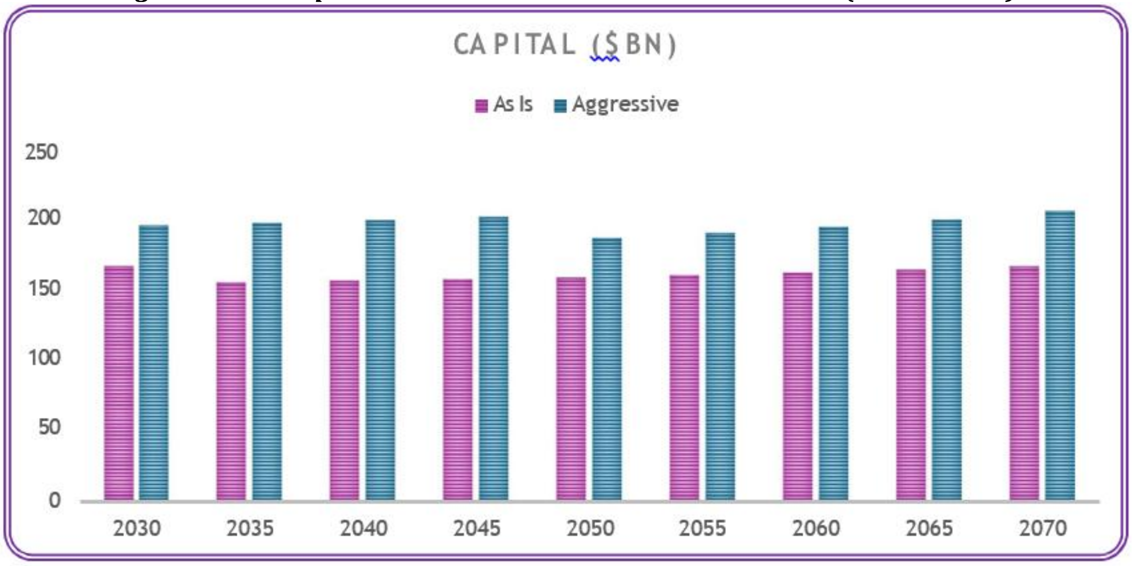


As illustrated in Figure 12, carbon dioxide emissions from India's power sector are currently estimated at nearly 1,400 million tonnes per annum. Under the as-is scenario, which broadly reflects existing policies and historical capacity expansion trends, these emissions are projected to rise almost threefold, reaching close to 4,000 million tonnes by 2070. Such an outcome would significantly undermine India's net-zero ambitions, even if emissions intensity per unit of electricity improves over time. In contrast, the aggressive transition scenario demonstrates a markedly different trajectory. Despite total installed power capacity expanding by nearly seven times over the same period to meet rising electricity demand, power sector emissions increase only to around 2,000 million tonnes—representing an increase of roughly 50 per cent from current levels. This decoupling of capacity growth from emissions growth highlights the central role of large-scale renewable deployment in bending the emissions curve.

These results strongly suggest that India must pursue an all-out expansion of renewable power capacity—particularly solar and wind—if it is to align the power sector with the national net- zero vision articulated by our honourable Prime Minister. However, such a transition is not without significant challenges. Rapid renewable scale-up raises complex technical issues related to grid stability, intermittency, and system flexibility; operational challenges associated with forecasting, balancing, and dispatch; financial challenges linked to capital mobilization, cost of capital, and long-term tariff sustainability; and social challenges, including land use, employment transitions, and regional equity. Despite these hurdles, the moral and developmental imperative to safeguard environmental sustainability for future generations makes this transition unavoidable.

From an investment perspective, achieving this ambitious transformation entails a massive mobilization of capital. The cumulative investment required in the power generation sector alone is estimated to be close to USD 2 trillion by 2070. Importantly, this figure excludes additional investments needed for strengthening transmission and distribution networks, deploying large-scale energy storage solutions, and enabling advanced digital and grid- management technologies—all of which are critical complements to high renewable penetration. Under the business-as-usual pathway, annual investment requirements are estimated at just over USD 32 billion. In comparison, the aggressive transition scenario necessitates a step-up in annual investments to nearly USD 40 billion, as shown in Figure 13. While this represents a significant increase, the associated benefits—in terms of emissions moderation, energy security, reduced fossil fuel dependence, and long-term economic resilience—arguably far outweigh the incremental financial burden.

Figure 13: India power sector Co2 emissions Million Tonnes (2024 – 2070)



Source: Model developed by author

5. Discussion

Beyond aggregate capital expenditure estimates, the financing of India's energy transition increasingly depends on the mobilisation of private capital through green finance instruments and entrepreneurial investment channels. Green finance mechanisms such as green bonds, sustainability-linked loans, blended finance structures, and climate-focused credit lines are increasingly bridging the gap between limited public funding and the substantial capital required for renewable energy deployment, energy storage, and grid modernisation. These instruments reduce financing costs while aligning investor incentives with long-term decarbonisation objectives, a trend strongly emphasised in India's net-zero transition pathway (Singh et al., 2024).

Venture capital and private equity have emerged as critical sources of finance for clean energy start-ups and innovation-driven firms, particularly in distributed solar, battery storage, electric mobility, and digital energy solutions. Unlike conventional project finance, venture capital enables early-stage innovation, risk-taking, and rapid commercialisation of scalable technologies, reflecting broader global investment patterns in clean energy systems (International Energy Agency, 2023).

For small and medium enterprises (SMEs), access to affordable and patient capital remains a significant constraint. While utility-scale renewable projects often attract institutional investors, SMEs involved in manufacturing, installation, operations and maintenance, and energy services face challenges related to collateral requirements, high borrowing costs, and limited access to formal financial markets. Addressing these barriers through targeted credit guarantees and concessional financing is essential for expanding SME participation across India's energy value chain (Ministry of Statistics & Programme Implementation, 2024).

Entrepreneurs play a central role in mobilising private capital by converting policy frameworks and market opportunities into bankable projects. Innovative financing models such as energy-as-a-service, pay-as-you-go systems, and public–private partnerships reduce upfront costs for consumers while improving project viability for investors, particularly in decentralised and off-grid energy systems where traditional financing approaches remain inadequate (Energy Institute, 2025). Finally, financial inclusion remains a crucial but frequently overlooked aspect of energy entrepreneurship. Improving access to financial resources for first-time entrepreneurs, rural businesses, and small-scale energy service providers can facilitate the wider adoption of renewable energy technologies while promoting inclusive economic growth and strengthening long-term energy security.

6. Conclusion & Challenges in Transition

In summary, the scenario analysis shows that India cannot achieve its net-zero target through slow and incremental change. Meeting this goal will require strong policy decisions, long-term financial support, and coordinated action across institutions to rapidly scale up renewable energy and transform the power sector over the coming decades.

India's transition to renewable energy faces several challenges arising from social, political, economic, and structural factors. At present, only a small share of India's total energy capacity comes from renewable sources. Public awareness of renewable energy remains limited, and policy support has not always been sufficient, and another significant hurdle is the lack of governmental policies supporting this sector. While India has launched multiple initiatives to expand renewable energy, offer subsidies, and promote low-carbon industries, critics argue that current efforts and investments in solar, wind, and storage technologies are still not enough to meet the net-zero target by 2070.

A) Dependence on fossil fuels - India remains heavily dependent on coal, which continues to dominate electricity generation. Reducing coal use is difficult because it supports local economies and provides affordable and reliable power (Sharma et al., 2021). The challenge is further intensified by global climate commitments that require a gradual phase-out of coal and massive investments—estimated at several trillion dollars—over the coming decade

B) Economic and social barriers - The energy transition carries significant economic and social risks. Job losses in the fossil-fuel sector and unequal sharing of transition costs could disproportionately affect rural and low-income communities (Haldar et al., 2023). Coal- dependent states such as Odisha, Jharkhand, and Chhattisgarh will need greater investment in education and skill development to support workforce transition. Expanding renewable energy is especially important, as higher renewable use is directly linked to lower carbon emissions

C) Technological and infrastructure challenges - The transition also requires improvements in energy efficiency, electrification of end uses, and decarbonisation of electricity generation. While these steps help avoid long-term carbon lock-in, they are often expensive in the early stages. New solutions such as decentralized energy systems, smart grids, peer-to-peer energy trading, and blockchain offer promise, but they also introduce challenges related to infrastructure readiness and regulatory frameworks (Gupta et al., 2023)

Despite these challenges, India has significant opportunities for energy transformation. Supportive economic conditions, policy reforms, and technological innovation can help reduce dependence on fossil fuels and expand renewable energy sources such as solar and wind, which are expected to become increasingly cost-competitive in the future. Beyond technological deployment and policy reform, the findings of this study underscore the critical role of entrepreneurs and small and medium enterprises (SMEs) as key enablers of India's energy transition. The scale and complexity of the transition require not only large public investments but also widespread private-sector participation, particularly from start-ups and SMEs operating across renewable energy generation, energy storage, digital grid services, and clean-tech innovation. Entrepreneurs are well positioned to translate policy signals and market demand into innovative business models, localised solutions, and scalable services that accelerate renewable adoption while supporting job creation and inclusive growth. To fully realise this potential, policymakers in India and other Asian economies must prioritise supportive regulatory frameworks, access to green finance, targeted incentives, and skill development programmes that lower entry barriers and reduce risk for energy entrepreneurs. Strengthening green investment ecosystems, improving SME access to capital, and aligning climate policies with entrepreneurship development strategies will be essential to fostering sustainable entrepreneurship and ensuring a just, resilient, and market-driven energy transition across Asia.

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