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Green Economy & Renewable Energy @ Viksit Bharat 2047: A Comprehensive Study of Non-Conventional Energy Development from Beginning to Future in India's Sustainable Development

Dr. Arun Kumar Maurya
Assistant Professor, Department of Geography, C.S.N. P.G College, Hardoi
ORCiD: https://orcid.org/0009-0000-6501-9915

Abstract

India stands at a civilizational crossroads. Having graduated from a post-colonial agrarian economy to the world's fifth-largest GDP, it now charts an audacious course toward becoming a fully developed nation Viksit Bharat by 2047, its centenary of independence. Central to this journey is the transformation of its energy landscape: a deliberate, systematic pivot from a coal-dominated, import-intensive grid toward a diversified, domestically abundant and ecologically responsible renewable energy ecosystem. This paper offers a data-anchored investigation of India's non-conventional energy journey from the tentative institutional gestures of the 1970s to the bold Gigawatt ambitions of the 2020s examining solar, wind, small hydropower, biomass and emerging technologies such as green hydrogen and offshore wind. Juxtaposing these against conventional energy trajectories and embedding them within the macroeconomic logic of a green economy, the paper presents six original data tables and one visual chart. It concludes by mapping a credible, equitable pathway to a 1,000 GW renewable future by 2047, one that creates 10 million jobs, displaces 500 million tone’s of annual carbon emissions and positions India as a global green power in every sense of the phrase.

Keywords: Viksit Bharat 2047, Green Economy, Renewable Energy India, Solar Mission, Wind Energy, Green Hydrogen, Energy Transition, Climate Finance, Non-Conventional Energy Sources.

Introduction

Energy is the bloodstream of civilization. Every kilowatt-hour of electricity generated is a vote for a particular kind of future one powered by the warmth of ancient sunlight trapped in coal, or one animated by the living sunlight that bathes a billion-strong land every single day. India, the world's most populous nation as of 2023 and home to one of history's fastest-growing major economies, faces a paradox that is as profound as it is urgent: it must lift hundreds of millions more citizens out of energy poverty while simultaneously refusing to lock in the carbon emissions that would make the planet uninhabitable for those very citizens.

As of 2023–24, India's total installed electricity generation capacity stands at approximately 474 GW (Central Electricity Authority, 2024), of which nearly 57 per cent still originates from

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fossil fuels predominantly coal. And yet, within a single decade, the country has also become the world's third-largest solar power generator, deploying 71.6 GW of solar capacity at speeds that surprised even seasoned energy analysts (Ministry of New and Renewable Energy, 2023). Wind capacity stands at 44.7 GW. The story of how India arrived here and where it must go next, is the story this paper tells.

The concept of the Green Economy broadly defined as one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities provides the intellectual scaffolding for this study. Within India's specific context, it maps directly onto Prime Minister Narendra Modi's vision of Viksit Bharat (Developed India) by 2047: a vision that is explicitly and deliberately intertwined with clean energy self-reliance, green manufacturing, carbon market leadership and sustainable urbanisation.

Literature Review

The literature on India's energy transition has evolved considerably over the last decade, moving from narrow techno-economic assessments of individual technologies toward holistic, multi-disciplinary accounts of the sector's political economy. Sharma, Tiwari and Sood (2012) offered one of the earliest systematic reviews of India's solar sector, mapping strategies, policies and future potential at a time when installed solar capacity was negligible; their optimism about auction-based tariff discovery has since been validated by the tariff declines documented in the present paper.

More recent scholarship has taken a systems-level view. A review published in Renewable and Sustainable Energy Reviews (2024) frames India's coal phase-down as a risk-laden process shaped by economic and social dislocation, policy inconsistency and infrastructural bottlenecks, while simultaneously noting the rapid scale-up of solar and wind capacity under the National Action Plan on Climate Change and the country's Nationally Determined Contributions. Similarly, work appearing in Oxford Open Energy (2026) situates India's target of 500 GW non-fossil capacity by 2030 within a broader argument that the country's transition serves a dual climate-development agenda, pointing to sharp year-on-year growth in solar and wind additions as evidence of accelerating momentum.

A parallel strand of literature focuses on structural and institutional constraints rather than capacity growth. The Journal of Public and International Affairs (2024) highlights how cross-subsidy pricing within the electricity distribution segment continues to distort incentives and slow the sector's transition, even as India's leadership of the International Solar Alliance strengthens its position in attracting climate finance and foreign investment. A broader review of India's electricity transition covering 2011–2022 synthesises techno-economic, political, socio-technical and justice-oriented perspectives, arguing that a genuinely just transition requires attention to all four dimensions simultaneously rather than treating capacity addition as a sufficient policy goal.

State-level heterogeneity has also emerged as a research theme. A recent study employing an entropy-weighted composite index across Gujarat, Rajasthan, Karnataka and Maharashtra finds persistent variation in how effectively renewable capacity growth translates into actual fossil-fuel displacement, suggesting that national-level aggregates such as those in Table 2 of this paper can mask considerable sub-national disparity. Complementing this, research on the macroeconomic drivers of transition finds that energy consumption, environmental governance quality, foreign direct investment and green innovation are jointly significant determinants of transition speed, while long-run analyses confirm a strong positive elasticity between per-capita energy consumption and per-capita GDP growth in the Indian context.

Taken together, this body of literature converges on three broad conclusions that inform the present study: first, India's renewable capacity growth, while historically rapid, must be read alongside persistent structural constraints DISCOM finances, grid flexibility and land-use conflicts that determine whether capacity additions translate into genuine decarbonisation; second, sub-national and sectoral heterogeneity means that national targets such as those under Viksit Bharat 2047 require disaggregated, state-wise tracking rather than aggregate reporting alone; and third, a “just transition” lens attentive to coal-dependent workers and regions is now treated in the literature as integral to, rather than separate from, capacity-based energy planning. This paper builds on these insights by combining historical capacity-growth data with a forward-looking, target-based assessment of the Viksit Bharat 2047 framework, an angle that has received comparatively less quantitative treatment in the reviewed literature.

Research Methodology

Research Design

This study adopts a descriptive-analytical research design, supported by secondary quantitative and qualitative data, to trace the institutional evolution, technological growth, financial architecture and target-attainment trajectory of India's non-conventional energy sector. The approach combines historical-longitudinal analysis (for policy and capacity trends) with comparative target-benchmarking (for evaluating Viksit Bharat 2047 goals).

Objectives of the Study

1. To trace the historical and institutional evolution of non-conventional energy policy in India, from the establishment of DNES (1976) to the present-day Ministry of New and Renewable Energy framework.
2. To analyse technology-wise growth trends in solar, wind, small hydro, biomass and green hydrogen relative to conventional (coal, gas, nuclear) energy sources.
3. To examine the green finance architecture supporting India's energy transition, including green bonds, FDI and institutional lending.
4. To evaluate India's current standing against the quantified 2030 and 2047 targets under the Viksit Bharat framework.

Nature and Sources of Data

The study relies entirely on secondary data drawn from official government and institutional publications, ensuring reliability and consistency of figures. Primary sources include the following:

- Central Electricity Authority (CEA) Installed Capacity Reports, March 2024.
- Ministry of New and Renewable Energy (MNRE) Annual Reports, Strategic Plan 2030

and Policy Archives.

- NITI Aayog India Energy Security Scenarios (IESS 2047).
- Reserve Bank of India (RBI) Report on Currency and Finance.
- Indian Renewable Energy Development Agency (IREDA) Annual Reports.
- International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) global comparative datasets.
- Climate Policy Initiative (CPI) India's Climate Finance Landscape reports.
- Press Information Bureau (PIB) official policy and target-related releases.
- Relevant peer-reviewed journal articles (2012–2026) on India's energy transition, policy evolution and green finance, as discussed in the Literature Review.

Analytical Approach

Data were organised into time-series and cross-sectional tables (Tables 1–6) to address each objective in turn. For Objective 1, policy milestones from 1976 to 2024 were compiled chronologically (Table 3) to map the institutional trajectory from DNES to MNRE. For Objective 2, capacity figures across five time points (2005, 2012, 2018, 2022, 2023) were compared across renewable and conventional sources (Tables 1 and 2) to compute growth multiples for instance, the extent to which solar capacity growth outpaced conventional capacity growth over the same period. For Objective 3, green finance indicators (green bonds, FDI, budgetary allocation, IREDA disbursals) were tabulated against their 2030 and 2047 targets (Table 6) to assess the scale-up required in climate finance flows. For Objective 4, current (2023) figures for renewable capacity, green hydrogen production, EV penetration, energy intensity, RE share, green economy GDP share and RE-sector employment were benchmarked against 2030 and 2047 targets (Table 4) using a gap-analysis method, wherein the required annual rate of addition or growth was calculated and compared against the actual pace achieved in the most recent reporting year (2022–23 capacity additions).

Scope and Period of Study

The study covers the period from 1976 (institutional origin of non-conventional energy policy) to 2024, with data current as of the December 2023/March 2024 CEA and MNRE reporting cycles and forward-looking analysis extending to the 2030 interim milestone and the 2047 Viksit Bharat horizon.

Limitations of the Study

The study is based entirely on secondary, government-reported data; independent verification of figures was not undertaken. Projections and targets for 2030 and 2047 are drawn from official government and NITI Aayog scenario documents rather than independent econometric forecasting and are therefore subject to future policy, technological and financing revisions. The gap-analysis method applied under Objective 4 assumes a broadly linear progression toward targets; actual capacity addition, financing and policy trajectories may follow a non-linear path. State-wise and sectoral heterogeneity (DISCOM financial health, land availability, manufacturing capacity) is discussed qualitatively rather than through a formal disaggregated statistical model. The rapidly evolving nature of India's energy policy landscape means some figures may require updating beyond the data cut-off used in this paper.

The Conventional Energy Foundation: Coal, Gas and Nuclear

Coal: The Reluctant Giant

For seven decades after independence, coal was India's indispensable but uncomfortable partner. Rich coal seams in Jharkhand, Odisha, Chhattisgarh and West Bengal collectively known as the Gondwana coalfields provided cheap, accessible and domestically abundant fuel. By 2023, India's coal-based installed capacity stood at approximately 233,460 MW, producing nearly 75 per cent of all electricity units generated in the country(Central Electricity Authority, 2024). Coal India Limited (CIL), the world's largest coal producer, extracted over 893 million tonnes in 2023–24, breaking its own record for the fifth consecutive year (Ministry of Finance, 2023). However, coal's dominance is a Faustian bargain. India's coal power plants emit approximately 1.1 billion tonnes of CO_2 annually, making the power sector alone responsible for nearly half the country's total greenhouse gas emissions (Centre for Research on Energy and Clean Air, 2023). Beyond climate, coal's air pollution costs are staggering the Centre for Research on Energy and Clean Air (CREA) estimated in 2023 that coal-linked particulate matter contributed to over 900,000 premature deaths annually in India (Centre for Research on Energy and Clean Air, 2023). Plant load factors have also been declining, averaging 64 per cent in 2022–23, partly due to the intermittent shutdowns that occur when wind or solar generation floods the grid (Central Electricity Authority, 2024).

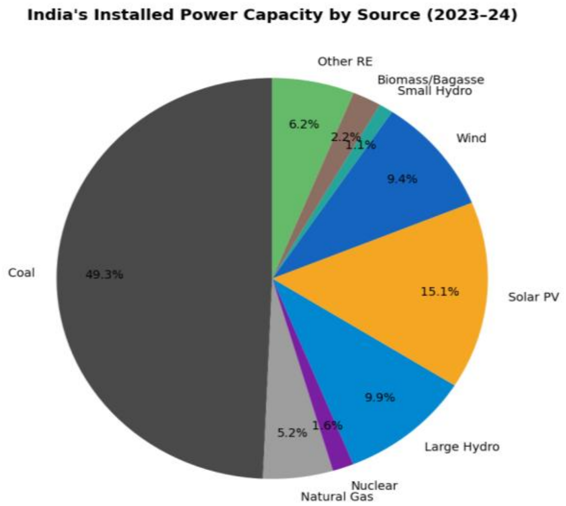
Natural Gas: The Bridging Fuel that Couldn't Bridge

Natural gas was theorised, particularly after the KG-D6 basin discoveries of 2002, as the clean-ish transition fuel that would ease India off coal. A natural gas-based plant emits roughly 40–50 per cent less CO_2 per unit of electricity than coal (International Energy Agency, 2023). Yet India's gas story has been one of perpetual underperformance. Installed gas-based capacity of 24,824 MW operates at a paltry 22–25 per cent plant load factor (PLF) among the lowest in the world (Central Electricity Authority, 2024) because domestic gas production fell sharply after 2010 and imported LNG prices have remained stubbornly high. Today, gas-based plants are essentially stranded assets kept on standby for grid balancing.

Nuclear: The Quiet Contributor

India's nuclear programme, initiated under Homi Bhabha in the 1950s, has followed a three-stage strategy designed to exploit the country's vast thorium reserves. With 7,480 MW of installed capacity across 22 reactors at seven sites, nuclear contributes a modest but reliable 3 per cent of electricity generation (NITI Aayog, 2022). Nuclear is carbon-free, highly reliable and capacity-factor-dense (operating at 80–85 per cent). The government has committed to expanding to 22,480 MW by 2031, including the large-scale Jaitapur plant and a fleet of indigenous Pressurised Heavy Water Reactors (PHWRs) (NITI Aayog, 2022). The current energy mix across India's installed capacity (as of early 2024) is captured in Table 1 below.

Figure 1: India's Installed Power Capacity by Source (2023–24)



Source: Central Electricity Authority (CEA), Installed Capacity Report, March 2024. RE = Renewable Energy.

Origins of Non-Conventional Energy: From DNES to MNRE

The Institutional Genesis (1970s–1990s)

It is tempting to date India's renewable energy story to the dramatic solar auctions of the 2010s, but its true roots stretch back to a quieter era. The 1970s oil crises brutally exposed India's dependence on imported crude, forcing policymakers to look inward. In 1976, the Department of Non-Conventional Energy Sources (DNES) was established under the Ministry of Science and Technology a small, underfunded, but symbolically significant gesture toward energy diversification.

DNES spent its early years promoting biogas digesters for rural households, solar cookers, wind pumps for irrigation and small hydroelectric schemes for remote hill communities. These were not grid-scale interventions; they were micro-energy solutions. By 1992, the department was elevated to full ministerial status as the Ministry of Non-Conventional Energy Sources (MNES). This elevation signalled a shift in governmental thinking: renewable energy was no longer a fringe concern but a legitimate policy domain deserving dedicated resources, legislative attention and diplomatic visibility.

Policy Architecture: From Incentives to Markets (2000s–2010s)

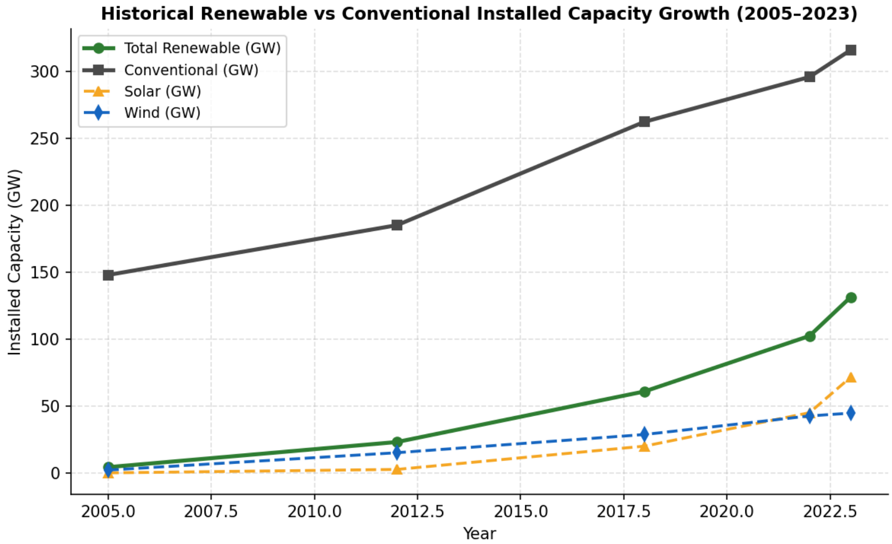
The Electricity Act of 2003 was a watershed. It opened the generation sector to private investment, established independent electricity regulatory commissions in each state and crucially introduced the concept of Renewable Purchase Obligations (RPOs), requiring electricity distribution companies to source a fixed percentage of power from renewable sources. This was India's first market-based instrument for renewable energy.

The National Action Plan on Climate Change (NAPCC, 2008) added a climate dimension to what had hitherto been a largely energy-security narrative. Under NAPCC, eight National Missions were launched, the most consequential of which was the Jawaharlal Nehru National Solar Mission (JNNSM, 2010), with an initial target of 20 GW of solar power by

2022(Government of India, 2023). The target seemed fantastically ambitious at the time India had just 0.02 GW of solar capacity. It was not only met; it was surpassed fourfold.

figure 2 below traces the historical growth of India's renewable energy capacity from 2005 to 2023, contrasted with conventional capacity expansion over the same period.

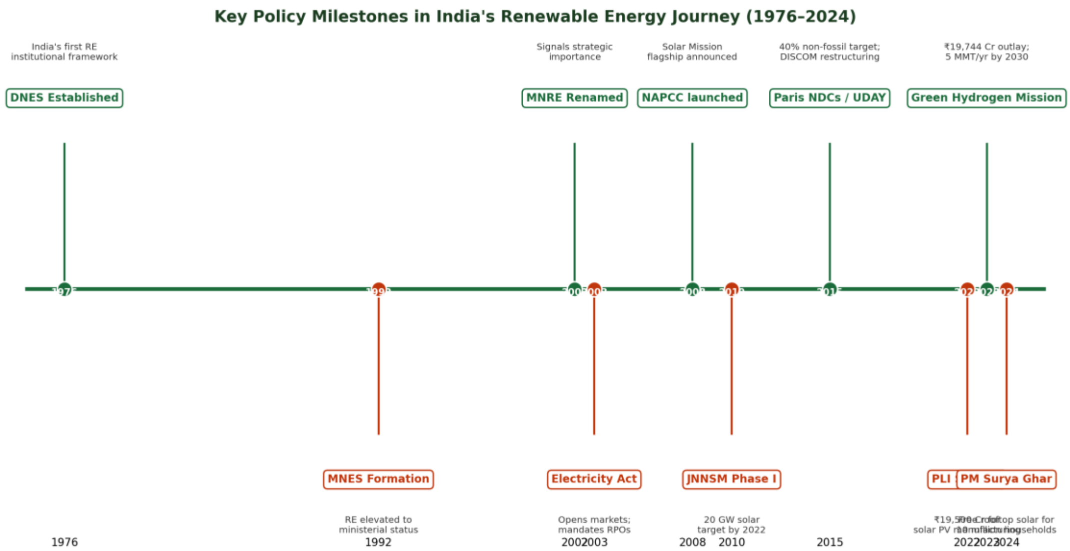
Figure 2: Historical Renewable vs Conventional Installed Capacity Growth (GW)



Source: CEA Annual Reports 2005–2023; MNRE Annual Reports; BP Statistical Review of World Energy 2023. *2023 data as of December 2023.

The numbers in Figure 2 tell a compelling story. While conventional capacity grew by approximately 2.1 times between 2005 and 2023, total renewable capacity grew by an astonishing 30-fold, driven almost entirely by solar's leap from near-zero to over 70 GW. Wind followed a steadier but still impressive trajectory, tripling over the period.

Figure 3: Key Policy Milestones in India's Renewable Energy Journey



Source: MNRE Policy Archives; PIB Press Releases; Ministry of Finance Budget Documents 2024.

Technology-by-Technology Analysis of Non-Conventional Energy

Solar Energy: From Desert Dreams to Urban Rooftops

India's solar story is one of the most extraordinary industrial policy successes of the twenty-first century. Starting with a National Solar Mission target of 20 GW by 2022, India progressively revised this upward first to 100 GW, then effectively beyond as the economics became irresistible. In 2014, a utility-scale solar plant in India cost approximately ₹8–9 crore per MW to build. By 2023, competitive auctions were delivering capacity at costs as low as ₹3.5–4 crore per MW, a decline of over 55 per cent in under a decade. At ₹2.49 per unit (USD 0.03), the tariff discovered in the landmark Bhadla Solar Park auction of 2020 sent shockwaves through global energy markets.

Geographically, solar development has been concentrated in the sun-drenched northwestern and southern states. Rajasthan, with its vast Thar Desert receiving 5.5–6.5 kWh/m²/day of solar irradiance, has emerged as the capital of India's solar empire, hosting over 18.7 GW of installed capacity (Government of India, 2023; Ministry of New and Renewable Energy, 2024). The Ultra Mega Solar Parks programme, which pools land, transmission and evacuation infrastructure for large-scale developers, has been instrumental in unlocking this potential. PM Surya Ghar, launched in 2024, aims to extend solar's reach deep into the residential sector by subsidising rooftop systems for 10 million households.

Wind Energy: The Veteran Renewables Champion

Wind energy was India's first large-scale commercial renewable technology, with Tamil Nadu emerging as the pioneer state in the 1980s and early 1990s, hosting clusters of small wind turbines along its breezy coastal ridges. The Indian Wind Energy Association dates the first commercial installations to 1986. By the mid-2000s, India had a wind industry with a genuine manufacturing ecosystem companies like Suzlon Energy and ReGen Powertech became globally competitive.

India's wind resource is geographically concentrated: the western coast (Gujarat, Maharashtra), the southern peninsula (Tamil Nadu, Karnataka andhra Pradesh) and the Rajasthan desert plateau collectively account for over 85 per cent of installed capacity. The technical wind potential at 100-metre hub heights is estimated at 695 GW onshore and a vast offshore potential exceeding 127 GW along the coastline (National Institute of Wind Energy, 2023). Offshore wind, still at nascent stage in India, is poised to become a major growth vector with the government's 30 GW offshore target by 2030 and a dedicated viability gap funding (VGF) mechanism.

Small Hydro and Biomass: The Forgotten Pillars

Small hydropower (up to 25 MW) and biomass-based energy are often overshadowed by solar and wind's dramatic growth but remain critical to rural energy access, grid decentralisation and waste utilisation. India has over 5,013 MW of installed small hydro capacity, concentrated in Himalayan states like Himachal Pradesh, Uttarakhand, Jammu and Kashmir and the northeastern states. The total identified potential for small hydro is approximately 21,135 MW, of which less than 25 per cent is exploited a significant untapped resource (Ministry of New and Renewable Energy, 2024).

Biomass and cogeneration plants, primarily based on agricultural residues (rice husk, sugarcane bagasse, cotton stalk) and urban solid waste, contribute approximately 10,244 MW of installed capacity(Ministry of New and Renewable Energy, 2023). Bagasse-based cogeneration in Maharashtra and Uttar Pradesh has become a model for agro-industrial synergy sugar mills sell electricity to the grid during the crushing season, generating additional revenue and reducing open burning of crop residue. India's total biomass power potential is estimated at over 28,000 MW.

Green Hydrogen: India's Next Frontier

Green hydrogen produced by electrolyzing water using renewable electricity represents perhaps the most consequential emerging technology in India's clean energy transition. Unlike electricity, hydrogen can decarbonise sectors where electrification is difficult or expensive: steel, cement, ammonia synthesis, long-haul transportation and industrial heat. India launched its National Green Hydrogen Mission in January 2023 with an outlay of ₹19,744 crore, targeting production capacity of 5 million metric tonnes per year (MMT/yr) by 2030 (Government of India, 2023).

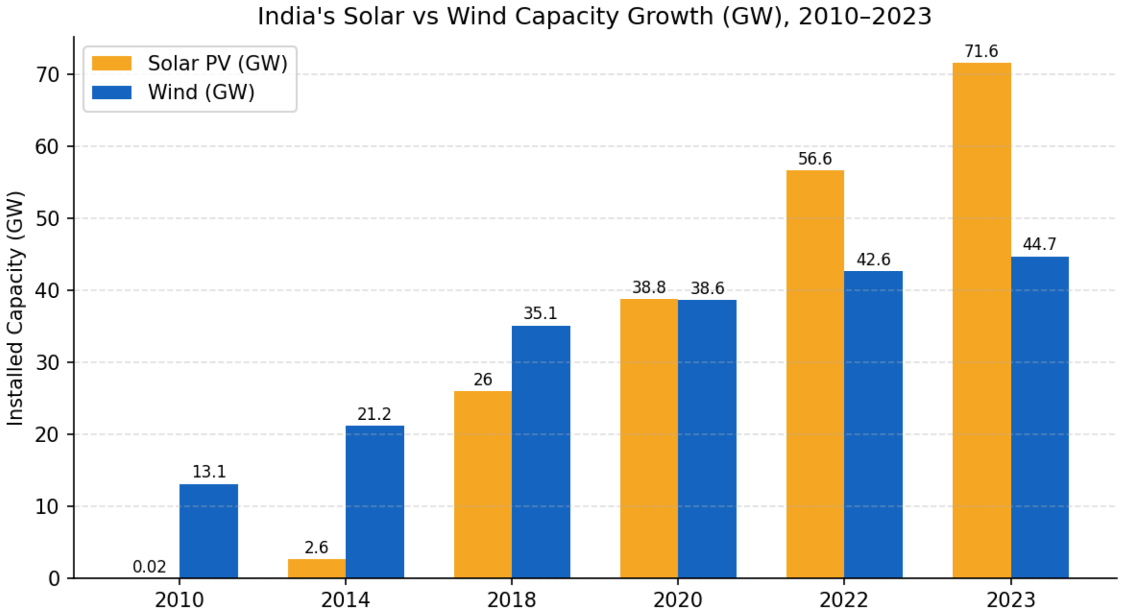
The economic rationale is powerful. India consumes approximately 6 MMT of hydrogen annually today, almost all of it 'grey' (from natural gas) or 'brown' (from coal) (Government of India, 2023). Replacing this with green hydrogen would eliminate roughly 50 million tonnes of CO_2 annually. Beyond domestic substitution, India harbours genuine ambitions to become a global green hydrogen exporter, leveraging its cheap solar and wind resources to produce hydrogen at below USD 1/kg by 2030 below the cost of grey hydrogen in Europe. The Adani-TotalEnergies partnership, NTPC's Simhadri pilot and ACME Group's export-focused projects in Rajasthan are early indicators of this emerging industrial ecosystem.

India's Global Climate Leadership: The International Solar Alliance

Beyond domestic capacity addition, India has positioned itself as an architect of global solar diplomacy through the International Solar Alliance (ISA), launched jointly with France at the UNFCCC COP21 in Paris in 2015. Headquartered in Gurugram, the ISA is among the first treaty-based international organisations to have its headquarters in India and today counts over 120 member and signatory countries (International Solar Alliance, 2024). Its mandate is to mobilise USD 1,000 billion in solar investment by 2030 across member nations, many of them small and vulnerable developing economies in Africa, the Pacific and the Caribbean that lack India's manufacturing and financing scale.

For Viksit Bharat 2047, the ISA serves a dual function. Domestically, it reinforces India's credibility as a rule-maker rather than a rule-taker in global climate governance, complementing hard capacity targets with soft-power leadership. Internationally, ISA-linked programmes such as the One Sun One World One Grid (OSOWOG) initiative envision a trans-continental solar grid, an ambition that, if realised, would allow India's western and southern solar belts to export surplus daytime generation to time-zone-shifted partner grids. This positions India's renewable energy story not merely as a domestic decarbonisation project but as an instrument of foreign policy and South-South cooperation.

Figure 4: India's Solar vs Wind Capacity Growth (GW) 2010 to 2023



Source: Central Electricity Authority (CEA), Ministry of New and Renewable Energy (MNRE), 2023. *Data as of March 2024.

Green Economy and Viksit Bharat 2047: Targets, Trajectories and Transformations

Defining the Green Economy in the Indian Context

The UNEP (2011) definition of a Green Economy one that results in improved human well-being and social equity while reducing environmental risks resonates deeply with India's development philosophy. India's version of the Green Economy is not a luxury add-on to growth; it is constitutionally embedded in the Directive Principles of State Policy, which mandate the protection of the environment and increasingly operationalised through economic instruments: green bonds, carbon markets, Extended Producer Responsibility (EPR) regulations and Production-Linked Incentives (PLIs) for clean technology manufacturing.

India's Long-Term Low-Carbon Development Strategy (LT-LEDS), submitted to the UNFCCC in November 2022, lays out a comprehensive decarbonisation roadmap consistent with net-zero by 2070 (United Nations Framework Convention on Climate Change, 2022). Its Nationally Determined Contributions (NDCs), updated in 2022, commit to a 45 per cent reduction in the emissions intensity of GDP by 2030 (Government of India, 2022) (compared to 2005 levels) and achieving 50 per cent of cumulative installed electric power capacity from non-fossil fuel sources by 2030 (Government of India, 2022) a target India is on track to meet, or possibly surpass, by 2027.

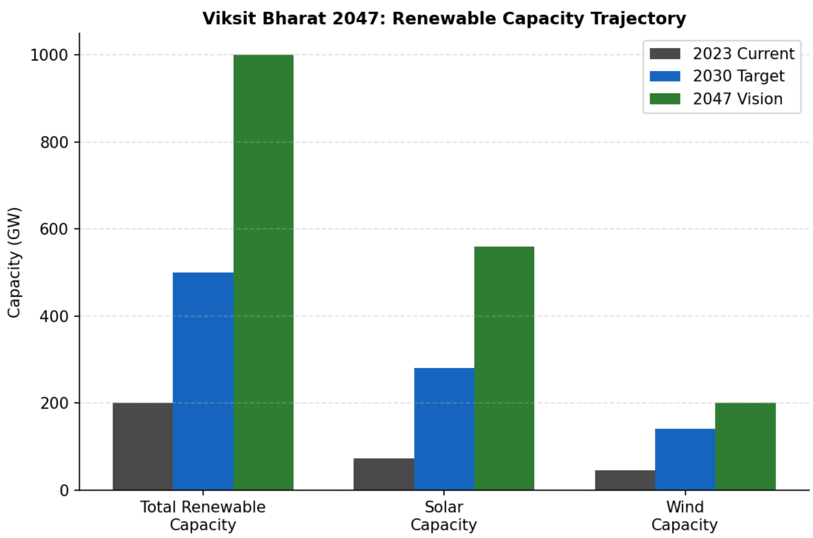
The Viksit Bharat 2047 Energy Vision: Quantified

Table 1 presents the quantified energy and green economy targets under India's Viksit Bharat 2047 framework, contrasted with 2023 actuals and 2030 interim milestones.

Table 1: Viksit Bharat 2047 Energy & Green Economy Targets vs Current Status

Parameter	Current (2023)	2030 Target	Viksit Bharat 2047
Total Renewable Capacity	200 GW (2023)	500 GW (2030)	1,000 GW (2047)
Solar Capacity	72 GW (2023)	280 GW (2030)	560 GW (2047)
Wind Capacity	45 GW (2023)	140 GW (2030)	200 GW (2047)
Green Hydrogen Production	Negligible	5 MMT/yr	25 MMT/yr
EV Penetration (share)	~5% (2023)	30% (2030)	80% (2047)
Energy Intensity Reduction	Baseline 2005	45% reduction	65% reduction
Net Zero Emissions	N/A	N/A	2070 (committed)
RE share in Power Mix	~43% (2023)	60% (2030)	80%+ (2047)
Green Economy GDP share	~3%	7%	15%
Jobs in RE sector	~0.9M (2023)	3M (2030)	10M (2047)

Figure 5



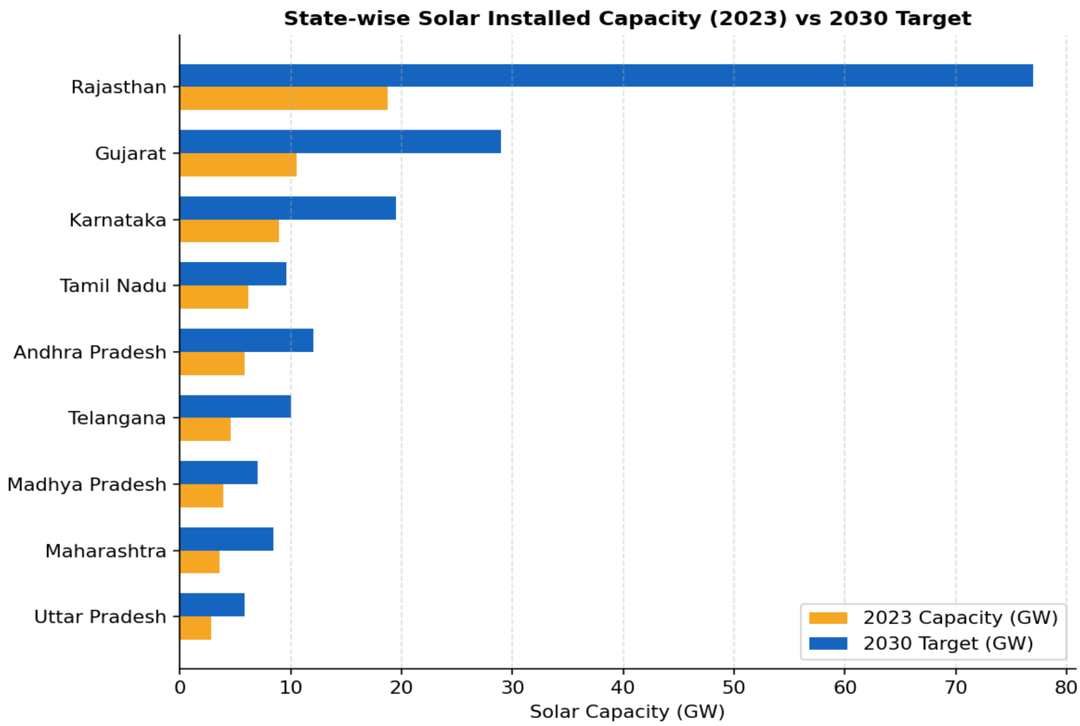
Source: Ministry of New and Renewable Energy Strategic Plan 2030; National Green Hydrogen Mission 2023; NITI Aayog India Energy Security Scenarios (IESS 2047); PIB Official Releases.

The ambition embedded in Table 4 is staggering in its scope. To go from 200 GW of renewable capacity in 2023 to 1,000 GW by 2047 implies adding an average of 34 GW of renewable capacity every single year for the next 24 years. India added approximately 18.5 GW in 2022–23 so the required pace is roughly double the current installation rate. This is achievable but will demand sustained policy continuity, grid modernisation investments of USD 70–80 billion and the development of an indigenous manufacturing base for solar panels, wind turbines, electrolyzers and advanced batteries.

State-wise Solar Deployment: Geography is Destiny

India's solar endowment is geographically skewed, with the northwest and the Deccan plateau enjoying dramatically higher irradiance than the northeast, the Indo-Gangetic Plain and the Western Ghats. Figure 6 presents the state-wise solar installed capacity alongside 2030 targets.

Figure 6 : State-wise Solar Installed Capacity and 2030 Targets (MW/GW)



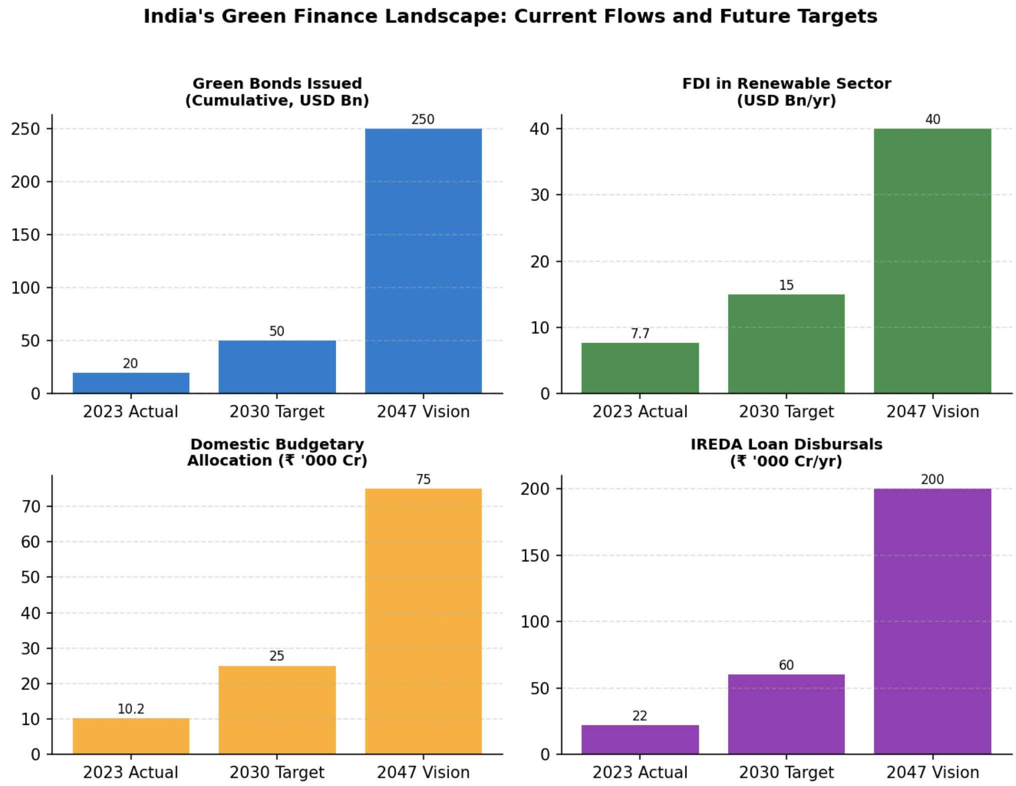
Source: MNRE State-wise Data, December 2023; CEA Regional Power Committees; State Renewable Energy Development Agency reports.

Green Finance: Mobilising Capital at the Scale of the Climate Crisis

Energy transition at the scale India envisions is not merely a technological challenge it is above all a financial one. The International Energy Agency (IEA) estimated in 2023 that India needs approximately USD 293 billion in clean energy investment between 2023 and 2030 to meet its climate goals (International Solar Alliance, 2024). Mobilising this capital from domestic institutions, multilateral development banks, sovereign wealth funds and private markets is the defining challenge of Indian climate finance.

India issued its first Sovereign Green Bond in January 2023, raising ₹16,000 crore at competitive rates (Indian Renewable Energy Development Agency, 2024). Green bond issuances by corporates and state governments have cumulatively crossed USD 20 billion (CPI, 2023). The Indian Renewable Energy Development Agency (IREDA), listed on the NSE in November 2023, has emerged as the dedicated financial backbone of the sector. International mechanisms the Just Energy Transition Partnership (JETP), the Green Climate Fund (GCF) and bilateral lines from Germany's KfW and Japan's JBIC are supplementing domestic flows. Table 6 summarises the green finance landscape.

Figure 7: India's Green Finance Landscape Current Flows and Future Targets



Source: RBI Handbook on Indian Economy 2023; IREDA Annual Report 2023–24; CPI Climate Finance Landscape Report India 2023.

India in Global Context: A Comparative Perspective

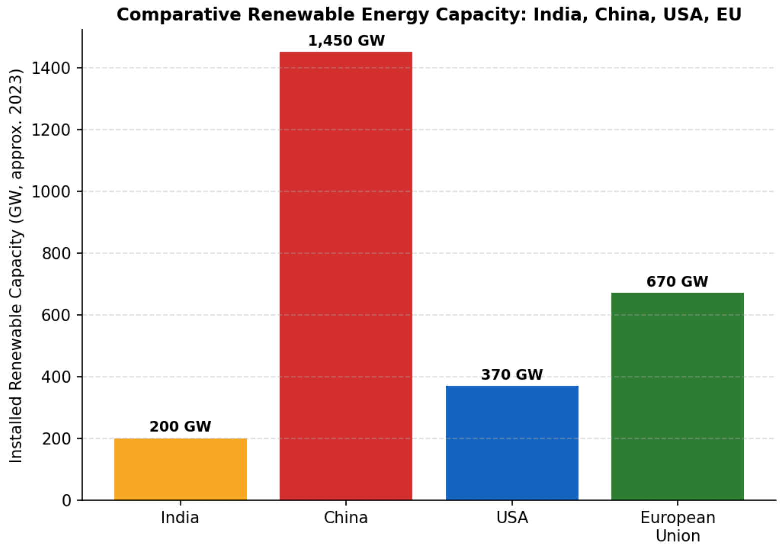
No assessment of India's renewable energy ambitions is complete without situating them alongside the world's other major economies. China, the United States and the European Union each pursue energy transitions of comparable scale but along markedly different pathways, shaped by their respective resource endowments, industrial bases and political economies. Table 7 presents a comparative snapshot of installed renewable capacity, 2030 targets and net-zero commitments across these four blocs.

Table 2: Comparative Renewable Energy Position India, China, USA and EU

Parameter	India	China	USA	European Union
Renewable Capacity (2023, GW, approx.)	200	1,450	370	670
2030 Renewable Target	500 GW non-fossil	Continued scale-up under 14th/15th Plans	100% clean electricity by 2035 (stated aim)	42.5% RE share (Fit for 55 package)
Net-Zero	2070	2060	2050 (federal target, policy-	2050

Commitment			dependent)	
Dominant RE Technology	Solar	Solar and Wind (world's largest manufacturer)	Wind and Solar	Wind (onshore and offshore)
Key Constraint	Grid flexibility, DISCOM finances	Curtailment, grid congestion	Permitting delays, transmission siting	Energy security post-2022, grid interconnection

Figure 8



Source: IEA (2023), IRENA (2023), BP Statistical Review of World Energy (2023) and national government climate strategy documents; figures are indicative approximations for comparative purposes rather than precisely reconciled statistics, given differing national accounting conventions.

Several observations follow. First, China's absolute renewable capacity dwarfs India's by a factor of roughly seven, reflecting both its earlier start and its dominant position in global solar and battery manufacturing supply chains a position India's PLI scheme explicitly seeks to challenge, if only partially, by 2030. Second, India's 2070 net-zero target is a full decade later than China's and two decades later than the US and EU commitments, a sequencing that reflects India's lower historical per-capita emissions and its continued development imperatives, a position India has consistently defended in international climate negotiations under the principle of common but differentiated responsibilities. Third, unlike the US and EU, where wind energy plays a co-equal or dominant role, India's transition remains disproportionately solar-weighted, which increases its exposure to the seasonal and diurnal intermittency challenges discussed elsewhere in this paper. India's comparative advantage lies less in manufacturing scale, at least for now and more in the sheer pace of capacity addition relative to its starting base and in its ability to position itself as a bridge between the developed and developing world within global climate diplomacy.

Challenges and Structural Constraints

Grid Modernisation and Energy Storage

Perhaps no challenge is more technically urgent than the need to transform India's grid into a flexible, intelligent network capable of managing the variability of wind and solar. Currently, India's grid is engineered around 24/7 baseload coal and hydro plants. As solar reaches 30, 40, 50 per cent of installed capacity, the grid will experience dramatic midday generation surpluses and steep evening demand ramps phenomenon energy system modellers call the 'duck curve.' Managing this requires large-scale battery storage, pumped hydro expansion, demand response programmes, interconnected regional grids and smart metering for 300 million consumers.

India's Battery Energy Storage System (BESS) capacity is currently under 200 MW a tiny fraction of what will be needed (World Bank, 2023). The government's Viability Gap Funding scheme for 4,000 MWh of BESS announced in 2023 is a start, but the 2030 requirement is estimated at 60–80 GWh of storage a 300-fold scale-up (World Bank, 2023). Pumped hydro, of which India has 4,745 MW installed and an estimated 100+ GW of potential in its Himalayan and Deccan geography, will be an important complement.

Land, Water and Ecosystem Trade-offs

Solar parks require substantial land. A rough rule of thumb, per MNRE (2023) siting norms, is 4–5 acres per MW for ground-mounted utility-scale solar. At 280 GW of solar capacity by 2030, this implies roughly 8–10 million acres of land a significant demand in a land-scarce country where agriculture employs 45 per cent of the workforce. The solution lies not in competitive land use but in complementary configurations: agri-voltaic systems where crops grow beneath elevated solar panels; canal-top solar (India has 80,000 km of irrigation canals); floating solar on reservoirs; and the aggressive deployment of rooftop solar on 250 million buildings.

Case in Point: Land-Use Tensions in Renewable Deployment

The Bhadla and Pavagada solar parks, among India's largest, were developed on land classified as revenue wasteland, minimising direct agricultural displacement. By contrast, wind and transmission-line projects in parts of Gujarat and Rajasthan have periodically encountered opposition from pastoralist and farming communities over grazing-land access and compensation adequacy, while the Great Indian Bustard conservation litigation before the Supreme Court has required rerouting or undergrounding of transmission lines in bustard habitat in Rajasthan and Gujarat. These episodes illustrate that land-use conflict in India's renewable build-out is not a uniform phenomenon but varies sharply by land classification, ecological sensitivity and the strength of local consultation processes underscoring why agri-voltaic, canal-top and rooftop configurations are increasingly favoured over greenfield land acquisition.

Manufacturing Self-Reliance: Avoiding the Solar Import Trap

India imports approximately 80–85 per cent of its solar photovoltaic cells and modules, predominantly from China (International Renewable Energy Agency, 2023). This dependence creates geopolitical vulnerability and suppresses domestic value creation. The PLI scheme for solar PV manufacturing, with an incentive outlay of ₹19,500 crore, aims to create 65 GW of fully integrated manufacturing capacity by 2026 (Ministry of Finance, 2023). Early results are promising Adani Solar, Waaree Energies and Reliance's green energy venture have announced multi-GW manufacturing expansions. Wind turbine manufacturing is already largely indigenised, with Siemens Gamesa, GE Vernova and Inox Wind operating large factories in India.

Solar Panel Waste and the Circular Economy Imperative

A challenge that receives comparatively little policy attention, but which will grow steadily more pressing as India's solar fleet ages, is end-of-life panel waste. Solar photovoltaic modules typically carry a useful life of 20 to 25 years; given that the bulk of India's utility-scale solar capacity was installed after 2015, the resulting wave of decommissioned panels is expected to begin in earnest through the early-to-mid 2030s and grow substantially thereafter as capacity scales toward 560 GW by 2047. Estimates by the International Renewable Energy Agency suggest India could accumulate several hundred thousand tonnes of cumulative solar panel waste by 2030, rising into the millions of tonnes by 2050, if current disposal practices persist (International Renewable Energy Agency, 2024).

India's e-waste and battery-waste management rules have begun to be extended toward photovoltaic modules, but a dedicated, Extended Producer Responsibility-based solar panel recycling framework remains at an early stage compared with the EU's more mature WEEE-linked PV recycling regulations. Building domestic recycling capacity for silicon, glass, aluminium framing and silver contacts is not merely an environmental obligation but a potential manufacturing opportunity, given India's simultaneous push for solar PV manufacturing self-reliance under the PLI scheme recovered materials could, over time, feed back into the same domestic supply chains the PLI scheme seeks to build.

Distribution Sector Financial Health

India's electricity distribution companies (DISCOMs) the crucial last-mile connectors between power generators and consumers carry an accumulated financial loss of approximately ₹6 lakh crore (USD 72 billion) as of 2023 (Ministry of Power, 2022). DISCOMs sign power purchase agreements with renewable generators; if a DISCOM is financially distressed, it may delay payments, curtail renewable generation, or default on contracts as has happened episodically in states like Rajasthan, Uttar Pradesh and Tamil Nadu. Until DISCOM finances are robustly restructured and retail electricity prices aligned with supply costs, the clean energy transition will remain hostage to the weakest link in the value chain.

Skilling the Green Workforce

The Viksit Bharat 2047 target of 10 million renewable-sector jobs cannot be met through capacity addition alone; it requires a parallel and deliberate skilling ecosystem. The Suryamitra Skill Development Programme, run by the National Institute of Solar Energy (NISE) under MNRE, has so far trained several hundred thousand technicians in solar panel installation, operations and maintenance (MNRE, 2023), but this remains a fraction of the workforce that 560 GW of solar capacity by 2047 will require across installation, maintenance and eventual decommissioning. Similar gaps exist in wind turbine servicing, battery manufacturing and green hydrogen electrolyser operations, none of which yet have skilling programmes at a scale commensurate with stated capacity targets.

A further complication is geographic and social mismatch: much of India's renewable capacity is being built in states such as Rajasthan and Gujarat, while a significant share of the workforce that will need to transition out of coal is concentrated in the eastern states of Jharkhand, Odisha and Chhattisgarh. Bridging this mismatch through targeted vocational training, portable skill certifications and deliberate industrial siting of green manufacturing in coal-transition districts is, as much as any single capacity target, central to ensuring that the benefits of Viksit Bharat's energy transition are broadly and equitably shared.

Conclusion: Toward a Green, Prosperous and Sovereign India

The story of India's non-conventional energy development, told across the preceding sections, is a story of institutional learning, technological leapfrogging and the quiet but consequential accumulation of green industrial capability. It begins in a small government department in 1976, passes through the transformative decade of the 2010s when India went from energy afterthought to global clean energy leader and arrives at 2024 with the confidence of a nation that has proven to itself and to the world that ambitious clean energy targets are not fantasies but blueprints.

The Viksit Bharat 2047 framework provides the overarching civilizational ambition within which the energy transition is nested. A nation of 1.6 billion (by 2047) aspiring to a per capita income of USD 12,000–15,000 will consume electricity at three to four times today's per capita levels. Meeting that demand entirely from clean sources 1,000 GW of renewable capacity, 25 MMT/yr of green hydrogen, 80 per cent electric vehicles, nearly net-zero building stock is the defining engineering and policy challenge of the coming quarter-century.

Several structural transitions must simultaneously accelerate. The coal fleet must be progressively retired not abruptly, given employment and energy security dependencies, but systematically, beginning with the oldest, least efficient plants. Grid infrastructure must be modernised at a pace and scale unprecedented in India's history. Green manufacturing ecosystems for solar, wind, batteries, electrolyzers and fuel cells must be built not as import substitution but as genuine export-competitive industries. Green finance flows must be multiplied tenfold, with domestic and international capital channelled through transparent, investible and credible frameworks.

Perhaps most importantly, the transition must be just. Coal workers in Jharkhand, Odisha and Chhattisgarh concentrated in some of India's most economically marginalised communities cannot be left behind. A comprehensive Just Transition framework, with reskilling programmes, social protection floors and active industrial policy to bring new green industries into coal-dependent districts, is as essential to the success of Viksit Bharat as any megawatt target.

India has already demonstrated what many thought impossible: that a developing country can simultaneously grow its economy, reduce energy poverty and lead the world in renewable energy deployment. In the process, it has rewritten the global narrative about the alleged tradeoff between development and decarbonisation. The next chapter from 200 GW to 1,000 GW, from coal dependence to green energy sovereignty will be harder, costlier and more complex. But if the first chapter is any guide, it will also be more inspiring than anyone currently dares to predict.

Viksit Bharat 2047 is not simply a political slogan. Grounded in the numbers, the institutions, the technologies and the human ingenuity catalogued in this paper, it is the most ambitious and consequential development project on earth. The world will be watching and, if India succeeds, learning.

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