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Solar PV versus Wind Energy in India's Renewable Transition (2010–2025): Comparative Growth Trajectories, Cost Dynamics, and State-Level Concentration

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Abstract*— India's energy transition is among the most consequential globally, requiring simultaneous progress on energy security, climate goals, and access for 1.4 billion people. This paper provides a descriptive comparison (2010–2025) of India's two leading renewable technologies — solar photovoltaic (PV) and onshore wind — across growth trajectories, cost dynamics, state-level concentration, and alignment with SDG 7. Drawing on published capacity statistics from the International Renewable Energy Agency (IRENA) and India's Ministry of New and Renewable Energy (MNRE), the paper traces installed capacity growth, general cost trends under a standard levelized cost of electricity (LCOE) framework, and the geographic concentration of deployment across states. Solar PV grew from a negligible base in 2010 to roughly 90–106 GW by 2025, while wind expanded from about 13 GW to roughly 47–52 GW over the same period; both technologies are now understood to be cost-competitive with new coal generation in India. Three broad policy directions follow: continuing to scale solar PV in high-irradiance interior states, shifting wind policy toward repowering and hybridization in already-developed corridors, and evaluating procurement design beyond headline tariff. These observations are relevant to India's stated target of 500 GW of non-fossil capacity by 2030.

***Keywords*— India, renewable energy, solar PV, wind energy, energy transition, SDG 7.**

I. INTRODUCTION

India is at a turning point in its energy transition, not just for its own development, but for the world's climate [6]. Solar PV and wind capacity has increased from a modest level in 2010 to a combined total of more than 100 GW by the mid-2020s [1,2], while coal has sustained India's power sector since industrialization. Great reliance on imported fossil fuel puts the economy at the mercy of the volatile commodity markets, and the relatively high ash content of domestic coal is also a burden on policymakers, as is the overall health and environmental impact of combustion. In counter response, India has progressed with its renewable capacity vision over the last decade from 175 GW to its current target of 500 GW of non-fossil energy capacity by 2030 [37], [38], broadly matching the targets of UN Sustainable Development Goal 7 (Affordable, reliable and sustainable energy for all) [48], [49] and [50].

Solar and wind power have a similar objective of decarbonization but have different growth patterns, structure of investment, and geographic ranges [21, 34]. This paper has three contributions: it provides a descriptive 15-year comparison of the two technologies based on publicly available capacity and cost data; it links technology-specific trends with broad implications like investment activity, employment potential, and fossil-fuel displacement [1, 9]; and it points out the implications of renewable-energy deployment being concentrated on a relatively small number of states in India [29, 30].

The rest of the paper is organized as follows. Section 2 places the experience of India in the larger global context of publications related to the cost reduction and deployment of renewable energy. The data sources are described in Section 3, along with the levelized-cost-of-electricity framework to compare the two technologies. Section 4 chronicles the development of solar and wind energy and their pricing trends individually and subsequently compares them in a direct manner. Section 5 explores the geography of deployment at the state level; Section 6 considers the macroeconomic and SDG 7 implications; and Section 8 presents policy implications, concluding the paper, while acknowledging the key paper limitations in Section 7.

II. LITERATURE REVIEW

Since 2010, the price of renewables has experienced a dramatic decline on a global scale, and in most years in the last decade, the quantity of new power generation capacity installed globally has been increasingly dominated by solar PV and wind [11, 16]. Over the last decade and a half, the cost of utility-scale solar PV has dropped more rapidly (relative to the cost of wind) and, as a result of competitive auctions and increasing manufacturing scale, is now experiencing a significant technology-learning curve [12], [13], [14]-[17], [18]. Developing economies, including India,

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have utilized both technologies to bring on generation capacity, albeit at different rates, depending on the institutional and regulatory strength of each country, and without the long lead time of large thermal or hydro schemes [8], [15].

India launched the National Solar Mission in 2010, which created the policy framework for large-scale solar deployment and led to subsequent adaptations of grid codes to be able to accommodate variable generation. The general trend in the existing literature on the Renewable Energy (RE) sector in India is a shift from administratively fixed feed in tariff to competitive reverse auction for both solar and wind power during the study period and the uneven distribution of installed capacity among the states with a few states accounting for an undue share of capacity — typically Gujarat, Karnataka, Rajasthan and Tamil Nadu [3], [23], [30] and [34]. Studies of this space typically acknowledge that there is a need for complementary transmission investments as well as the growing need for flexible or dispatchable balancing resources to be able to integrate large quantities of variable renewable energy [43, 44, 45, 46]. Another theme in the literature on renewable-energy siting in India [31, 32, 33] is distributional and land-use issues associated with utility-scale solar and wind projects, such as impacts on agricultural and pastoral land use.

The energy transition in India is mostly talked about in relation to SDG 7 [48], [49], [50] and the status of electrification is near universal, but can mask the ongoing challenges on the supply reliability side and on the financial health of the State electricity distribution utilities [6], [37]. Renewable energy sustainability monitoring frameworks are also well documented to prioritize capacity and generation aspects and provide less systematic attention to land-use and end-of-life issues like panel disposal [58]. While solar and wind energy are generally treated as similar energy sources, this paper examines them separately, as distinct technologies, which is a comparative analysis treatment that is not as common in other comparative state-level treatments of solar and wind as a single undifferentiated “renewable energy” category [29, 30].

Another strand of the broader literature considers the financing context for renewables investments in emerging markets as a whole. Cost of capital is also known to be a much higher proportion of total project cost for capital-heavy zero-fuel cost technologies such as solar and wind, than for fossil generation [50], [51] and differences in financing conditions at country or even state-level can make a significant difference in electricity delivered cost when underlying technology costs are comparable. This is especially true for India as the perceived risk premium on renewable-energy debt has been significantly higher than that of mature markets, and instruments that have been used for de-risking in the energy transition, such as partial credit guarantees and blended concessional finance, have been proposed to lower financing costs for the energy transition in developing economies [52]; evidence also exists for adjacent technologies like green hydrogen [53] that cost of capital is a first-order determinant of competitiveness.

III. DATA AND METHODOLOGY

The results of this study are based on publicly reported capacity data for India provided by the Ministry of New and Renewable Energy (MNRE), and international-level capacity and cost data provided by IRENA, cross-referenced with national-level renewable energy assessments in the literature [1], [2], [9], [36]. Data reported here should be interpreted as indicative of the underlying trend and not as precise point estimates due to Indian fiscal-year reporting (April-March) differing from the calendar-year reporting convention followed by most international agencies, and due to official data having been found to be biased toward undercounting rooftop and other distributed solar power.

In this paper, costs are compared by the standard method that is adopted in the energy-economics literature: the levelized-cost-of-electricity (LCOE) approach, which is the ratio of the present value of all project costs to the present value of all electricity produced during the project's operating life.

$$LCOE = \Sigma^{t}_{=0}{}^{N}[(I_t + M_t + F_t) / (1 + r)^t] \div \Sigma^{t}_{=1}{}^{N}[E_t / (1 + r)^t] \quad (1)$$

where I_t is the cost of investment in year t, M_t is the operations and maintenance cost, F_t is the fuel cost (which is not present for solar and wind), E_t is the electricity production, r is the discount rate, and N is the lifetime of the project in years. For renewable projects in India, the discount rate is typically estimated using a Weighted Average Cost of Capital with India's relatively high debt-to-equity ratio, higher cost of equity, and slightly lower pre-tax cost of debt, which are, overall, in line with a nominal WACC of high single digits to low double digits over the course of the study. Some illustrative capacity factors of 18%-20% are commonly used for solar and wind generation in India, respectively, compared to a materially higher capacity factor for coal generation [14], [17].

Finally, the cost comparisons in this paper are presented as general, order-of-magnitude conclusions – that is, both technologies had become cost competitive with new coal generation in India by the early 2020s under a variety of reasonable financing and operating assumptions [37], [38] – rather than as an accurate point estimate based on any single study. Capacity numbers mentioned here also exclude off-grid and very small-scale renewables (VSSRs) which are well below 1 MW, so total deployment and the contribution of these technologies to energy-access will be somewhat underestimated [9].

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IV. GROWTH AND COST TRAJECTORIES

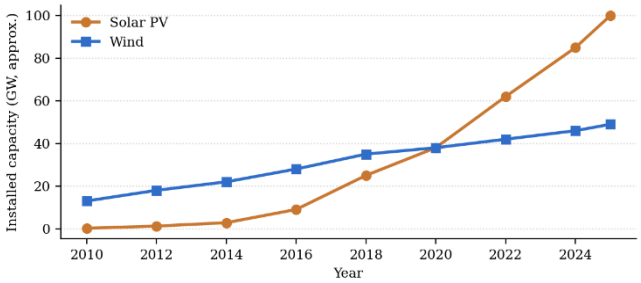


Fig. 1. Approximate installed capacity growth, 2010–2025 (illustrative, based on general published trends).

Solar PV. Solar accounted for a negligible share of India's generation mix when the National Solar Mission launched in 2010, with early generation costs well above those of coal [4], [35]. Early projects were modest in scale but established an operating track record that gave financiers confidence to lend against future projects and gave equipment suppliers confidence that India was a market worth long-term investment in [30]. The 2015–2020 period saw a rapid acceleration in installed capacity, driven by the shift to competitive reverse auctions and the development of large, utility-scale solar parks that reduced per-project risk and transaction costs [3], [20]. By the mid-2020s, installed solar capacity had reached roughly 90–106 GW according to published MNRE and IRENA statistics, with the great majority still ground-mounted utility-scale, though rooftop and distributed solar have also grown substantially off a small base [19]. Domestic module-manufacturing capacity expanded considerably over the same period, supported by government production-linked incentive schemes intended to reduce reliance on imported equipment. Solar's per-unit generation cost is understood to have fallen very substantially between 2010 and the early 2020s, consistent with the broader global solar-PV learning curve [12], [13], [17], with auction-discovered tariffs dropping to levels at or below the cost of new coal generation by around 2017.

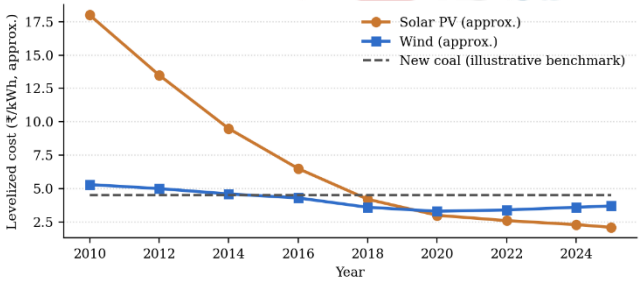


Fig. 2. Approximate generation-cost trend for solar PV and wind versus new coal, 2010–2025 (illustrative, consistent with general trends in [3], [17], [20]).

Wind. Wind entered 2010 with roughly 13 GW installed, built on a longer commercial history than solar in India, supported historically by state-level feed-in tariffs and accelerated-depreciation tax incentives, and concentrated in a handful of states with strong, consistent wind resources [22], [24], [26]. The shift toward competitive reverse auctions in the mid-2010s, mirroring the approach used for solar, changed the pricing model for new wind capacity and is generally understood to have temporarily slowed the pace of new installation as developers adjusted to auction-based risk allocation [21], [23]. Wind capacity reached roughly 47–52 GW by the mid-2020s, with the sector increasingly oriented toward wind-solar hybrid projects that share transmission infrastructure [41], [42], and early exploratory work on offshore wind potential off India's western and southern coasts [10]. Unlike solar, average wind tariffs have not shown a continuous downward trend since the late 2010s, reflecting supply-chain costs, larger turbine capital expenditure, and land-acquisition constraints that are more binding for wind than for ground-mounted solar [25].

Table 1. Approximate comparative metrics for solar PV and wind in India, 2010–2025, consistent with published capacity statistics [1], [2], [21]. Figures are order-of-magnitude approximations rather than precise point estimates.

Metric	Solar PV	Wind Energy
Installed capacity, 2010	~0.2 GW	~13 GW
Installed capacity, 2025	~90–106 GW	~47–52 GW
Approx. growth, 2010–2025	Very high (~100×)	Moderate (~4–5×)
Cost trend, 2010–2025	Steep, sustained decline	Decline, then partial plateau
2025 status vs. new coal	At or below coal cost	At or near coal cost

Solar's cost per unit of generation started the period well above wind's but is understood to have converged with, and eventually undercut, wind's cost by the early 2020s — an asymmetric convergence in which solar caught up with wind first, and both technologies subsequently converged toward, and then below, the cost of new coal generation [3], [30]. Generation profiles for the two technologies remain broadly complementary in a seasonal sense: solar output peaks around midday, while wind resources in much of India are historically stronger during the monsoon season, a complementarity that has motivated policy support for combined wind-solar hybrid projects [41], [42].

Domestic Manufacturing and Grid Integration:

Over the study period, wind generally entered with a more established domestic manufacturing base in turbine production than solar had in module manufacturing [21], [26], though solar's domestic manufacturing capacity has expanded rapidly in the final years of the period under government incentive schemes. Grid integration of wind capacity, which is often located in remote coastal or

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semi-arid areas, typically requires more long-distance transmission investment than ground-mounted solar sited closer to demand centers [25], [45]. Continued development of wind-solar hybrid projects and dedicated transmission corridors linking resource-rich states to demand centers is widely viewed as important to maintaining grid stability as combined renewable penetration increases [43], [44], [46].

V. STATE-LEVEL DEPLOYMENT PATTERNS

Renewable deployment in India remains geographically concentrated in a relatively small number of states, with a handful of states accounting for the large majority of both solar and wind installed capacity [29], [2]. Rajasthan and Gujarat are generally understood to be among the leading states for solar deployment, alongside Karnataka, Tamil Nadu, and Telangana [20], [34]; Tamil Nadu and Gujarat are generally leading states for wind, alongside Karnataka, Maharashtra, and Rajasthan [26], [27]. In most of these states, technical resource potential — the theoretical maximum installable capacity given land and wind/solar resource availability — substantially exceeds actual deployment [29], [36], indicating that resource availability alone does not determine where capacity gets built. States with weaker transmission infrastructure or lower electricity demand growth sometimes show a high renewable *share* of their generation mix despite comparatively low absolute installed capacity, since a small amount of renewable capacity can represent a large share of a small overall grid. Differences in state-level policy design, land-acquisition procedures, and institutional capacity built up over decades appear to explain much of the variation in deployment across states with broadly similar underlying resource endowments [5], [30] — for example, states with a longer history of supportive renewable-energy policy tend to have built the institutional capacity (permitting processes, grid-connection procedures, and investor relationships) that newer entrant states are still developing [27]. This suggests that two states with comparable solar irradiance or wind speeds can nonetheless show markedly different installed capacity depending on land-acquisition rules, power-purchase-agreement design, and the pace of grid-connectivity investment [31], [32].

VI. MACROECONOMIC IMPLICATIONS AND SDG 7

In the early 2020s, the cost of utility scale solar had been estimated to be approximately equal to the cost of new coal generation in India, and by this time, the prices of solar and wind auctions were generally recognized to be on par with the variable operational cost of many existing coal power plants, thereby limiting the volatility of state electricity distribution companies' exposure to fuel prices in the future [3], [30]. Financial costs are also a significant factor in the project economics in India, and in general are recognized to be somewhat higher than in other mature renewable-energy markets [50, 51] and so reducing the effective cost of capital (for example, via credit guarantees or blended finance) for renewable projects would be a significant factor in reducing delivered electricity costs [52]. Compared to wind projects, solar projects are also more dependent on imported equipment, and for this reason tend to be more sensitive to currency exchange rate fluctuations than wind projects are [21]. SDG 7.1 (universal energy access) has been met with near universal household electrification in India, but a significant proportion of recent grid scale renewable capacity additions seem to be to existing connections rather than to extension to previously unconnected households, and management of periods of high solar output is sometimes via curtailment rather than redistribution to underserved sections of the grid [48], [49]. Remaining reliability gaps can also be understated based on access data: if a household is "connected" there is potential for frequent supply interruptions [6]. In India, the proportion of non-fossil generation capacity has increased significantly since 2010, while the proportion of non-fossil generation has increased at a slower pace, as lower capacity factors of the renewables compared to the coal plant obscure the material impact of renewables on the generation figure when using capacity-based statistics on renewable-energy generation [37], [38]. Further growth in renewables generation and investment in grid modernization and energy storage will also likely be needed to meet SDG 7.2 more fully, as the transport and industrial energy demand for heat is much more dependent on fossil fuels than electricity demand is. SDG 7.3 (energy efficiency) has a similar aspect related to capacity additions, in that it relies more on demand-side measures like efficient appliances, building codes, and industrial process improvements [49, 50], rather than the supply-side. This paper does not seek to quantify any efficiency gains since it compares solar and wind, but the effect of generation-side decarbonization and demand-side efficiency gains will likely grow in significance as the low-cost, high-impact generation-side renewable capacity additions dwindle and the efficiency gains will become more difficult to achieve.

VII. LIMITATIONS

Data Limitations:

Conclusions in this paper depend on the consistency and completeness of centrally and state-reported capacity data. Decentralized rooftop solar in particular is widely understood to be underreported relative to official figures, since much of it is installed and metered outside the utility-scale reporting pipeline [19]. Auction-discovered tariffs, while a useful and transparent price signal, likely understate the full economics of a project once land acquisition, transmission connection delays, and counterparty payment risk are taken into account [9]; these hidden costs are difficult to quantify systematically across projects.

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Methodological Limitations:

National average capacity factors used in LCOE calculations obscure significant seasonal and regional variation in solar irradiance and wind speed across India's diverse geography [36]. LCOE as a metric also omits grid-integration, balancing, and storage costs [18], and does not capture the reduction in marginal value that occurs as variable renewable-energy penetration rises past a meaningful share of total generation [45], [46]; reported LCOE figures should therefore be read as generation-cost estimates rather than full system-cost estimates.

Scope Limitations:

The findings in this paper are tied to the 2010–2025 policy and market environment and may not generalize cleanly to the 2030s, which is likely to feature new policy instruments such as green-hydrogen mandates and round-the-clock renewable-plus-storage tenders [53]. This paper also treats state-level variation in deployment descriptively rather than through a formal statistical model of its institutional and geographic drivers [30], which remains a natural direction for future quantitative research.

VIII. CONCLUSIONS

Solar PV and wind have followed structurally different growth paths in India over 2010–2025, not merely different rates of growth along a similar path. Solar's growth appears to have accelerated fairly consistently across the period — from initial policy architecture, through rapid auction-driven cost declines, to consolidation as a highly competitive source of new generation [3], [4], [20] — while wind's growth appears to have slowed for reasons that look more institutional than resource-based: land acquisition, transmission bottlenecks, and utility-side implementation constraints [23], [25], rather than any shortage of viable wind sites [36]. This suggests the gap between the two technologies could widen further unless wind-specific policy shifts toward repowering older installations and expanding hybrid wind-solar projects [41], [42]. Wind's existing turbine-manufacturing base and decades of grid-code experience remain assets that such a policy shift could build on rather than discard [21], [26].

Apparent cost convergence between the two technologies masks an underlying asymmetry in generation timing: solar output peaks at midday while wind output in much of India is historically stronger during the monsoon, and simple LCOE comparisons do not fully price the grid-level value of generation timing or firm capacity [17], [18]. Hybrid wind-solar projects that share transmission infrastructure are one practical response to this asymmetry [41], [42]. Geographically, wind deployment remains concentrated in a handful of coastal and semi-arid states, while solar has spread more broadly into high-irradiance interior states as well, giving solar something of a structural siting advantage going forward [29], [34].

Three general policy directions follow from this comparison: continuing to scale solar PV, particularly in high-irradiance interior states with limited wind resource; shifting wind-specific policy from greenfield capacity growth toward repowering, hybridization, and targeted inter-state transmission investment [41], [45]; and considering procurement-design reforms that weigh time-of-generation and firm-capacity value alongside headline tariff, though such reform would require more detailed system-adequacy analysis than this paper undertakes [37], [38]. Across 2010–2025, the binding constraint on India's renewable-energy transition appears to have shifted from policy ambition, to generation cost, and increasingly toward dispatch and grid-integration capacity — both solar PV and onshore wind are now broadly cost-competitive, and continued progress will likely depend on transmission and market-design reforms keeping pace with the deployment that this cost competitiveness has enabled [56], [57].

Looking beyond 2025, the next phase of India's renewable-energy transition will likely be shaped less by the relative cost of solar and wind generation — which this paper argues has already largely converged — and more by the pace of complementary investment in transmission, storage, and demand-side flexibility needed to absorb rising shares of variable generation [56], [57], [59]. Full energy-system transition pathways modeled elsewhere for India suggest this shift toward system-level, rather than purely generation-cost, constraints are likely to define the 2030s [37], [38], [56].

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