VeK
POLICY ADVISORY & RESEARCH

INDIA'S RENEWABLE ENERGY LANDSCAPE

A Policy Note

MARCH 2025

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1 Background

As India accelerates its transition towards a sustainable future, its renewable energy (RE) sector has witnessed unprecedented growth. Renewable energy can be regenerated throughout time and is comprised of energy generated through the sun, wind, and geothermal heat. The restoration of the supply of these resources occurs naturally over time. Hence, they possess the capacity to persist despite human-induced depletion and are regarded as inexhaustible. Currently, India is largely dependent on fossil fuels for its power (47.40%), as shown in Figure 1.0.

Therefore, the promotion of RE becomes increasingly essential for India in a world facing growing geopolitical tensions, fossil-based energy supply chain risks, increasing dependency on fossil-fuel imports and the escalating challenges of climate change. Promotion and generation of renewable energy positively impacts climate change mitigation, access to pure energy, social and economic development, reduction of adverse health and environmental effects, and energy security.

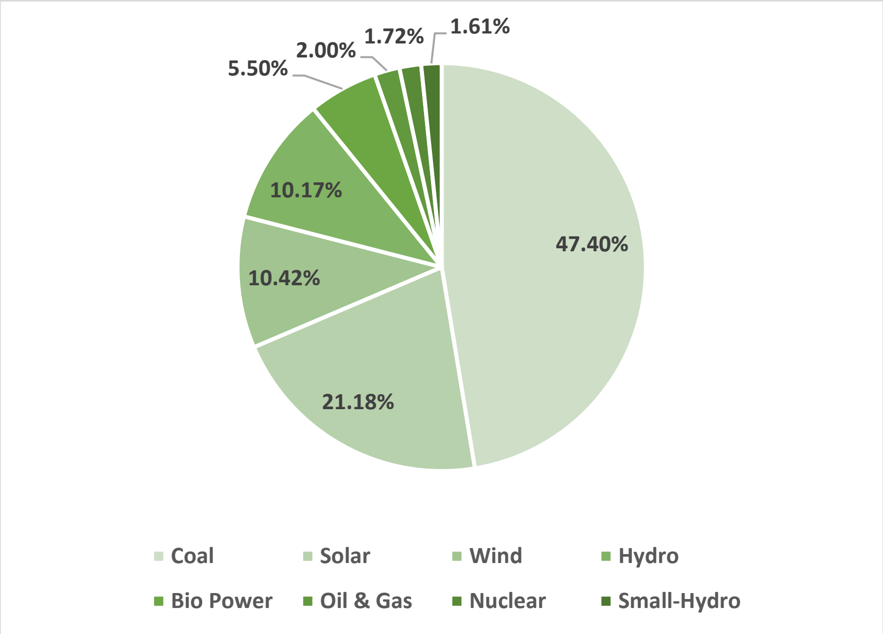

Figure 1.0 Power Sources as on 31st December 2024

Source: India's Climate and Energy Dashboard

The field of renewable energy has experienced rapid expansion, with consumption in the power, heat, and transport sectors expected to increase by nearly 60% between 2024 and 2030.[1] This growth will increase the share of renewables in global energy consumption to nearly 20% by 2030, up from 13% in 2023. Over three-quarters of this increase will come from renewable electricity generation, driven by strong policy support in over 130 countries, falling costs, and the rising adoption of electric vehicles and heat pumps.

[1] International Energy Agency. (2024). *Renewables 2024: Global overview*. https://www.iea.org/reports/renewables-2024/global-overview.

Global renewable electricity generation is forecasted to climb to over 17,000 TWh (60 EJ) by 2030, an increase of almost 90% from 2023. This would be enough to meet the combined power demand of China and the United States in 2030.

In keeping with global transitions, India is actively adopting and harnessing the potential of renewable energy sources. India has declared the objective of achieving carbon neutrality by the year 2070. Moreover, as stated by the Ministry of Power, the nation is anticipated to fulfil 62% of its energy demands by 2030 through the utilisation of 500 GW of non-fossil fuel sources.[2] In lieu of this goal, India has reached a milestone with the country's total renewable energy capacity crossing 200 GW (gigawatt).

According to the Central Electricity Authority, the total renewable energy-based electricity generation capacity, as of December 2024, stands at 203.18 GW, accounting for more than 46.3% of the country's total installed capacity. Additionally, when including nuclear energy, India's total non-fossil fuel capacity rose to 211.36 GW in 2024, compared to 186.46 GW in 2023. Continuing with this momentum, India is set to invest over US$ 360 billion in renewable energy and infrastructure by 2030, with US$ 190 billion to US$ 215 billion needed to achieve the 500GW target, and an additional US$ 150 billion to US$ 170 billion will be required for electricity transmission and storage.[3]

Aligning with the national goal of achieving 500GW, several states in India have emerged as leaders in renewable energy capacity, contributing significantly to the nation's progress. Rajasthan tops the list with an impressive 29.98 GW of installed renewable energy capacity, benefiting from its vast land and abundant sunlight. Following closely is Gujarat, which boasts a capacity of 29.52 GW, driven by its strong focus on solar and wind energy projects. Tamil Nadu ranks third with 23.70 GW, leveraging its favourable wind patterns to generate substantial energy. Karnataka rounds out the top four with a capacity of 22.37 GW, supported by a mix of solar and wind initiatives.

These achievements can be attributed to the policy changes, national laws, schemes and the continuous efforts of the central and state governments. Nevertheless, certain obstacles remain in fully realising the potential of renewable energy adoption in India (Figure 2.0). Transmission constraints, including bottlenecks within and between states, make it difficult to integrate renewable power into the grid efficiently. The lack of real-time generation data and accurate forecasting for solar and wind energy adds to grid management difficulties. Rising peak electricity demand from air conditioners and electric vehicles strains infrastructure, requiring costly upgrades.[4] Renewable energy sources also face curtailment issues, as coal and hydropower sometimes take priority in grid operations.

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[2] Kumar, V. 2023). Factors driving towards government's mission of achieving carbon neutrality by 2070. The Times of India. https://timesofindia.indiatimes.com/blogs/voices/factors-driving-towards-governmentsmission-of-achieving-carbon-neutrality-by-2070/

[3] Moody's. (2024, June 12). *Investment of $190-215 billion needed for India's 500 GW RE capacity: Moody's*. *Business Standard*. Retrieved from https://www.business-standard.com/industry/news/investment-of-190-215-bn-needed-for-india-s-500-gw-re-capacity-moody-s-124061200999_1.html

[4] International Energy Agency. (2021). *Renewables integration in India 2021*. https://iea.blob.core.windows.net/assets/7b6bf9e6-4d69-466c-8069-bdd26b3e9ed1/RenewablesIntegrationinIndia2021.pdf.

The renewable sector struggles with policy and financial hurdles, including complex taxation, high import dependence on solar components[5] and the need for large-scale manufacturing and storage infrastructure investment. In addition, curtailment has started to become a problem for many states, where production is essentially "turned down" to manage supply and demand and maintain grid stability. This leads to a waste of energy capacity. Moreover, these records are not available in the public domain, reducing transparency. The increasing solar and wind curtailment and lack of related policies are critical concerns for investors.

According to the Clean Energy Investment Trends 2020 report by the IEA and the Council on Energy, Environment and Water (CEEW), an investor's internal rate of return on solar PV projects declines by 160 basis points for every 2.5% production loss per year. The expectation of future curtailment can, therefore, significantly increase solar power purchase costs.[6]

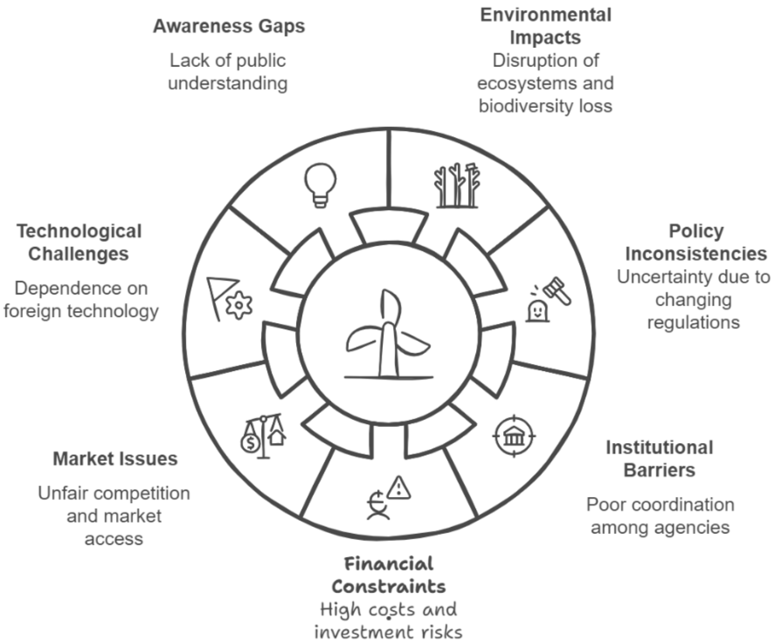

Figure 2.0 Challenges in the RE industry in India

To address challenges in its renewable energy sector, the Indian government has implemented several measures. These include permitting 100% Foreign Direct Investment under the automatic route[7], waiving Inter-State Transmission System charges for solar and wind projects commissioned by June 30, 2025[8], and developing Ultra Mega Renewable Energy Parks to provide land and transmission

[5] Solar91. (n.d.). *Reviving local solar industries: India reimplements import restrictions on solar PV modules*. https://www.solar91.com/blog/reviving-local-solar-industries-india-reimplements-import-restrictions-on-solar-pv-modules/.
[6] Council on Energy, Environment and Water. (2020). *Clean Energy Investment Trends 2020*. CEEW Centre for Energy Finance. https://www.ceew.in/cef/solutions-factory/CEEW-CEF-clean-energy-investment-trends-2020.pdf
[7] Press Information Bureau. (n.d.). *100% FDI in renewable energy sector: Government initiatives*. https://pib.gov.in/PressReleasePage.aspx?PRID=2101785.
[8] Ministry of Power. (n.d.). *Order B.4.3*. https://powermin.gov.in/sites/default/files/uploads/Orders/B.4.3.pdf.

infrastructure on a plug-and-play basis[9]. A comprehensive transmission plan has also been prepared to integrate over 500 GW of renewable energy capacity by 2030[10]. The government is also promoting energy storage solutions through financial incentives and regulatory measures to enhance grid stability and reduce curtailment of renewable power.

Further sections will delve into sector-specific performance, challenges, and opportunities while analysing policies at the national and state levels.

2 Sectors of RE

Renewable energy can be classified into various categories depending on the source of material used. Solar energy, the most dominant form, is generated from sunlight converted into electricity by photovoltaic cells. Wind energy is typically harnessed with large turbines or turbine arrays in open water or on mountain ridges, but the country is also starting usage of smaller-scale wind energy applications. Hydropower relies on the flow of water to generate energy and is one of the oldest and largest renewable energy sources.[11]

The breakdown of radioactive particles in the earth's core produces geothermal energy, which can be used for everything from bathing and heating buildings to producing electricity.

Biofuels are organisms grown specifically as a fuel source, like trees for burning wood or ethanol, which is made from corn[12]. While biofuels are technically renewable because we can always plant more trees, they aren't the cleanest option since they require combustion to produce energy.[13] Sometimes, a combination of these energies is also produced in a specific ecosystem called hybrid energy.

Data shows that solar energy has the highest potential at 750 GW, followed by wind power at 102 GW. Bio-power and small hydropower have significantly lower potential, at 25 GW and 20 GW, respectively.

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[9] Press Information Bureau. (2024, October 5). *Government announces new initiatives to boost renewable energy sector*. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1989807.
[10] India Brand Equity Foundation. (n.d.). *India eyes 500 GW renewable power by 2030*. https://www.ibef.org/news/india-eyes-500-gw-renewable-power-by-2030.
[11] U.S. Department of Energy. (n.d.). *Hydropower basics*. https://www.energy.gov/eere/water/hydropower-basics.
[12] U.S. Energy Information Administration. (n.d.). *Geothermal energy explained*. https://www.eia.gov/energyexplained/geothermal/.
[13] Southern New Hampshire University. (n.d.). *Types of renewable energy*. https://www.snhu.edu/about-us/newsroom/stem/types-of-renewable-energy.

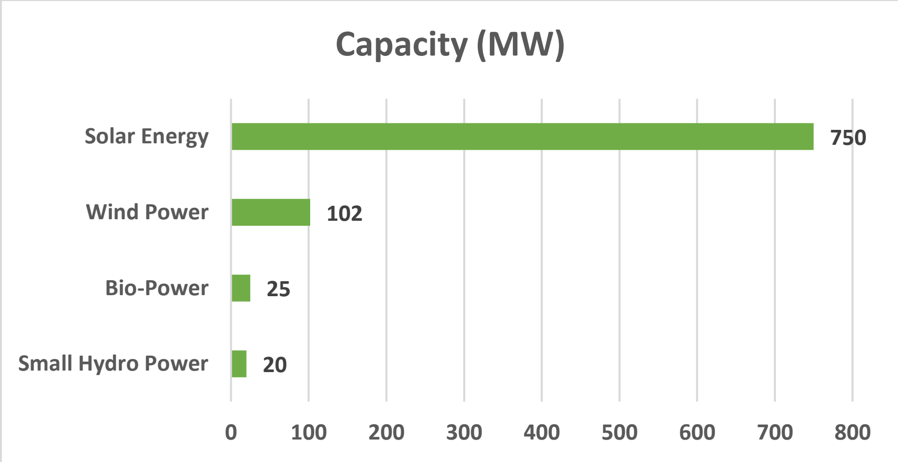

Figure 3.0 RE Potential in India

Source: Ministry of Statistics and Programme Implementation, GOI

The government has implemented various schemes and policies to promote these renewable energies at the centre and state level, making India the fourth largest in terms of installed capacity of renewables.[14]

2.1 Solar Energy

India is endowed with vast solar energy potential. About 5,000 trillion kWh per year of energy is used in India's land area, with most parts receiving 4-7 kWh per sqm per day.[15] Solar photovoltaic power can effectively be harnessed, providing huge scalability in India. Solar also provides the ability to generate power on a distributed basis and enables rapid capacity addition with short lead times. The National Institute of Solar Energy (NISE) has assessed the country's solar potential of about 748 GW, assuming 3% of the wasteland area to be covered by Solar PV modules. From an energy security perspective, solar energy is the most secure of all sources since it is abundantly available. Theoretically, a small fraction of the total incident solar energy (if captured effectively) can meet the entire country's power requirements by addressing India's energy security concerns.

Solar energy has had a visible impact on the Indian energy scenario during the last few years. According to the CEA, the country's cumulative PV installed capacity reached 97.9 GW in 2024, with 24.5 GW newly added, more than doubling compared to 2023.[16]

[14] Government of India. (2024). *Renewable energy initiatives and progress report*. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2024/10/20241029512325464.pdf.
[15] Ministry of New and Renewable Energy. (n.d.). *Solar overview*. https://mnre.gov.in/en/solar-overview/.
[16] TaiyangNews. (2024). *India's solar PV capacity exceeds 92 GW*. https://taiyangnews.info/markets/india-solar-pv-capacity-exceeds-92-gw.

Figure 4.0 Solar Pump Installation 2021-2024

Source: PIB

Moreover, the solar industry was the second largest employer, employing approximately 318,600 people, with 238,000 in grid-connected solar, representing an increase of 18% from 2022. Another 80,000 jobs were in the off-grid sector, while the solar heating and cooling sector employed 17,000 people.

Acknowledging its affirmative impacts, solar energy has taken a central place in India's National Action Plan on Climate Change with the National Solar Mission (NSM), launched on 11 January 2010. NSM is a major initiative of the Government of India with active participation from States to promote the adoption of solar energy.

The Government of India have launched various schemes to encourage the generation of solar power in the country, like Solar Park Schemes, VGF Schemes, CPSU Schemes, Defence Schemes, Canal bank & Canal top Schemes, Bundling Schemes, Grid Connected Solar Rooftop Schemes, etc. Among them is the notable PM Surya Ghar Muft Bijli Yojana**,** a Central Government Scheme that aims to provide free electricity to one crore households in India who opt to install rooftop solar electricity units. This scheme had been allocated INR 75,000 Crore and provides up to residential households are eligible for a subsidy of INR 30,000 per kilowatt for the first 2 kw and an additional INR 18,000 for subsequent 3kw. Apart from enabling the diversification of energy sources and reducing dependence on fossil fuels, the increased adoption of RTPVs benefits consumers and distribution companies (DISCOMs). However, it might adversely impact the DISCOMs' finances since consumers would generate their own power, resulting in the loss of consumer base for DISCOMs. On the other side, it also gives an opportunity for financial institutions to step in since the average Indian household would still not be able to afford to pay INR 1.78 Lakhs upfront. Owing to this scheme, there has been a 10x increase in average solar panels in India (Figure 5.0).

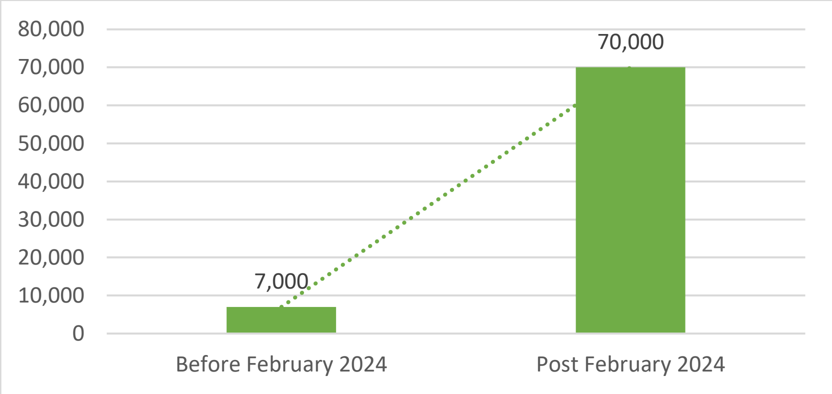

Figure 5.0 Impact of PM Surya Ghar Muft Bijli Yojna (Solar Panels)

Source: PIB

Another central government scheme, PM KUSUM, also known as "Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan," is aimed at promoting solar energy in agriculture by providing subsidies to farmers for installing solar-powered irrigation pumps and grid-connected solar power plants on their land, essentially reducing their dependence on diesel and allowing them to sell excess electricity generated to the grid, thereby increasing their income; the scheme consists of three components: setting up small solar power plants, installing standalone solar pumps, and solarising existing grid-connected agricultural pumps.[17] Apart from the two schemes, the government has taken several steps to promote solar energy in the country. These include[18]:

1. Waiver of Inter-State Transmission System (ISTS) charges for inter-state sale of solar and wind power for projects to be commissioned by 30th June 2025,
2. Declaration of trajectory for Renewable Purchase Obligation (RPO) up to the year 2029-30,
3. Notification of standards for deployment of solar photovoltaic systems/devices,
4. Setting up of Project Development Cell for attracting and facilitating investments,
5. Standard Bidding Guidelines for a tariff-based competitive bidding process for procuring Power from Grid-Connected Solar PV and Wind Projects.
6. The government has issued orders that power shall be dispatched against a Letter of Credit (LC) or advance payment to ensure timely payment by distribution licensees to RE generators.
7. Notification of Promoting Renewable Energy through Green Energy Open Access Rules 2022.
8. Launch of Green Term Ahead Market (GTAM) to facilitate the sale of Renewable Energy power, including Solar power, through exchanges.

Despite the Indian government's initiatives to bolster domestic solar manufacturing, the industry continues to face significant challenges, primarily due to its reliance on imports. To fully grasp these difficulties, it's essential to understand the solar panel production supply chain.

[17] India Brand Equity Foundation. (n.d.). *PM-KUSUM Yojana*. https://www.ibef.org/government-schemes/pm-kusum-yojana

[18] Press Information Bureau. (2024). *Government initiatives to boost renewable energy capacity in India*. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1989807.

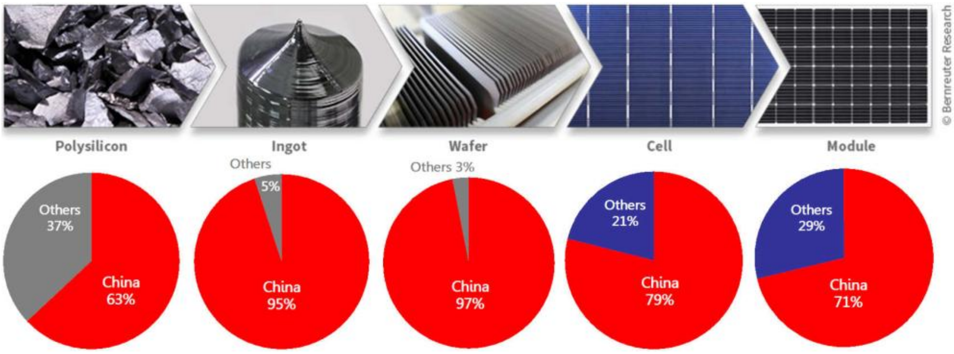

Figure 6.0 Solar Panel Production Supply Chain and Dominance of China

Source: Bernreuter Research

The components of the supply chain include:

- Polysilicon Production: The process begins with mining and purifying silica to produce high-purity polysilicon.
- Ingot Formation: Polysilicon is melted and formed into cylindrical ingots.
- Wafer Production: These ingots are sliced into thin wafers.
- Solar Cell Manufacturing: Wafers are processed into solar cells through doping and layering techniques.
- Module Assembly: Multiple solar cells are assembled into modules or panels.

China dominates the supply chain, controlling over 80% of the manufacturing stages, including polysilicon, ingots, wafers, cells, and modules.[19]. This dominance has led to significant cost advantages; for instance, Chinese companies can produce solar panels for just US$0.16 to US$0.18 per watt, whereas European manufacturers produce them at US$0.24 to US$0.30 per watt, and U.S. manufacturers at US$0.28 per watt[20].

India's dependence on imports is evident, with 53% of solar cell imports and 63% of solar PV module imports coming from China as of January 2023-24[21]. Over the past five years, India has imported US$11.17 billion worth of solar components.[22] Furthermore, India produced only 60,000 tons of polysilicon in comparison to China's 6.6 million tons in 2023.[23]

The report says while the imposition of tariff barriers like basic customs duty (25% and 40% on Chinese cells and modules, respectively) has increased the cost-competitiveness of domestic cells and modules, the impact is partly offset by a steep fall in global module prices over the last two years and Imported

[19] International Energy Agency. (2022). *Solar PV global supply chains: Executive summary*. Retrieved from https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary

[20] Myllyvirta, L. (2023, February 20). *China's dominance in solar panel manufacturing leaves Europe and U.S. with tough choices*. *Financial Times*. Retrieved from https://www.ft.com/content/929b71e6-dbda-4e84-90a7-a20bf5cd2d20

[21] Ministry of Commerce and Industry, Government of India. (2024, February 15). *Press release: India's merchandise trade statistics for January 2024*. Retrieved from https://commerce.gov.in/wp-content/uploads/2024/02/PIB-Press-Release-January-2024-1.pdf

[22] Ministry of New and Renewable Energy, Government of India. (2024, February). *Details of solar panels imported to India during 2019-20 to 2023-24*. Retrieved from https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1983772

[23] Policy Circle. (2024, January 10). *India's dependence on Chinese solar imports: Challenges and the way forward*. Retrieved from https://www.policycircle.org/industry/solar-industry-chinese-dependence/

modules remain cheaper than domestic modules by 8-10% despite the applicable duties.[24] Figure 7 shows that imported modules with Basic Custom Duty(BCD) are cheaper than domestically produced modules.

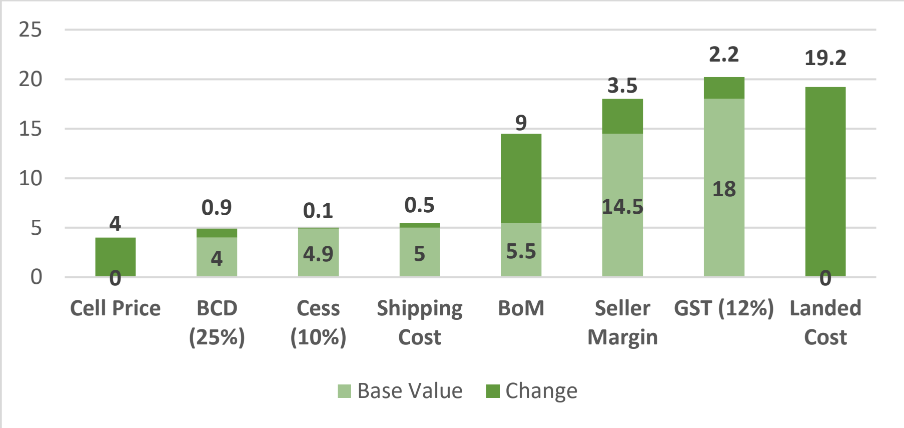

Figure 7: Domestic Modules using Imported cells (with 25% BCD) (Percentage)

Source: MNRE, Industry Sources, CareEdge Ratings

This reliance poses challenges, including exposure to supply chain disruptions and geopolitical risks. More importantly, in the PV module supply chain, it can take years to build new facilities. The further up the supply chain (further left on the graphic above), the longer the building time, which includes steps like siting, permitting, construction, interconnection and commissioning.

Addressing these issues requires India to enhance its domestic manufacturing capabilities across all stages of the solar supply chain, reduce dependence on imports, and foster a self-sustaining solar industry. This becomes increasingly important owing to the Western countries shifting their import sources away from China due to their China Plus One strategy, providing Indian domestic companies a lucrative opportunity to export the modules. However, even for the exporters, the global scenario paints a grim picture since average module prices are expected to remain high until the supply-demand balance improves, especially given the limited availability of imports.

As countries develop their own local manufacturing supply chains and trade restrictions continue to tighten, relying on exports as a long-term growth strategy for manufacturers is highly risky.[25] In such cases, India will have to trade carefully, building its domestic market as well as securing its supply chain of PV cells.

2.2 Wind Energy

India has a wind power potential of 1,163.86 GW at 150 metres above ground level. However, only 6.5% of this wind potential is used at the national level, contributing 48.16 GW (Figure 8.0) out of the total capacity of 217.62 GW of renewable energy capacity reached, with the majority being onshore, while the offshore wind capacity is still relatively small, with a recent increase in installations, bringing

[24] PV Magazine India. (2024, December 20). *India's solar PV cell manufacturing capacity to reach 60 GW by FY 2027*. https://www.pv-magazine-india.com/2024/12/20/indias-solar-pv-cell-manufacturing-capacity-to-reach-60-gw-by-fy-2027/.

[25] Mercom India. (2024, February 19). *India's module manufacturing capacity crosses 64 GW in 2024*. Retrieved from https://www.mercomindia.com/india-module-manufacturing-capacity-2024

the total offshore capacity to approximately 3.7 GW as of 2024[26]. India added 3.4 GW of new wind capacity in 2024, with Gujarat (1.250 GW), Karnataka (1.135 GW), and Tamil Nadu (0.980 GW) leading the way. These states accounted for 98% of the new wind capacity additions, highlighting their continued dominance in wind power generation.

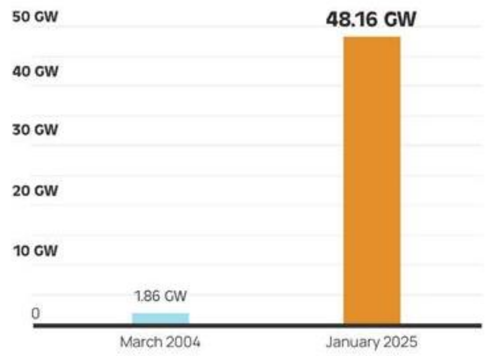

Figure 8.0 India's Installed Wind Capacity in 2025

Source: MNRE

To further bolster the wind energy market, the Indian government has implemented several key initiatives, such as the CCDC Wind Initiative. Launched in June 2020, the Centralized Data Collection and Coordination (CCDC) Wind Initiative aims to enhance wind resource assessment through accurate data collection and research. This initiative has facilitated the identification of over 50 potential wind energy sites nationwide, contributing to the development of over 10 GW of new wind energy capacity between 2020 and 2024.

Additionally, in 2024, the Union Cabinet approved a ₹7,453 crore Viability Gap Funding (VGF) scheme to kick-start India's offshore wind energy sector, marking a major step toward the country's renewable energy targets. The initiative will establish India's first offshore wind projects with a total capacity of 1 GW, split between 0.5 GW each off Gujarat and Tamil Nadu coasts. The scheme allocates ₹6,853 crores for project development and ₹600 crores for port infrastructure upgrades to support logistics.

The VGF support aims to lower the cost of power generated from offshore wind projects, making them viable for purchase by Distribution Companies (DISCOMs). While private developers will execute the projects through a transparent bidding process, Power Grid Corporation of India Ltd (PGCIL) will handle power evacuation infrastructure, including offshore substations.

The 1 GW projects are expected to generate around 3.72 billion units of renewable electricity annually, reducing 2.98 million tonnes of CO_2 emissions each year over a 25-year span. Beyond environmental benefits, the scheme will build a strong ecosystem for offshore wind energy, paving the way for an additional 37 GW of capacity and attracting investments of approximately ₹4,50,000 crore. This

[26] TotalEnergies. (n.d.). *Onshore and offshore wind energy: Technology and potential in India*. Retrieved February 26, 2025, from https://totalenergies.in/blogs-publications/onshore-and-offshore-wind-energy-technology-and-potential-india

initiative supports India's ocean-based economy and reinforces its commitment to a sustainable and green energy future[27].

The government also provides incentives, funds and subsidises for wind energy projects. The following fund and non-fund-based schemes are available in the Wind Sector[28] that provides both direct funding and credit support. Fund-based schemes include long-term project financing, short-term loans for developers and suppliers, and bridge loans to cover delays in receiving subsidies. Developers can also get loans against future revenue streams, such as Generation-Based Incentive (GBI) receivables, or opt for top-up loans when additional funds are needed. Government bodies and power companies can access short-term loans, and developers can transfer their existing loans for better repayment terms.

Non-fund-based schemes focus on credit guarantees, bond financing, and letters of credit to improve project viability. Additionally, financial support is provided for transmission projects to ensure efficient grid integration of wind energy. These initiatives help reduce financial risks, improve access to capital, and drive the growth of India's wind energy sector.

Despite India's significant wind energy potential and the government's efforts, the sector faces several challenges that hinder its expansion[29]. The country's wind resources are primarily concentrated in specific regions such as Tamil Nadu, Gujarat, Maharashtra, and Rajasthan. As the sector grows, land availability in these areas becomes increasingly scarce, limiting further development.

Additionally, wind turbines pose a threat to local wildlife, particularly birds and bats, which can collide with the spinning blades. Another major challenge is the high cost associated with wind energy, including the expense of turbines, installation, and grid connection, though costs have been gradually declining. Furthermore, wind turbines have a limited lifespan of around 20-25 years, and decommissioning them presents environmental concerns, particularly due to the difficulty in recycling their composite-material blades.

Offshore wind energy, while offering immense potential, comes with its own set of obstacles. These projects require specialised vessels, equipment, and complex installation techniques, making them significantly more expensive and challenging than onshore wind farms. Many offshore projects are located in deep waters, necessitating floating turbines, a technology that is still in the experimental stages. Overcoming these challenges will be crucial to fully harnessing India's wind energy potential.

2.3 Hydro Energy

Hydropower essentially uses water's kinetic energy to produce energy. Projects can be classified as large hydro, small hydro (2 to 25 MW), micro-hydro (up to 100 kW), or mini-hydro (100 kW to 2 MW). Small and large hydropower projects are the two general categories into which hydropower projects fall. Hydro projects in India that have a station storage of up to 25 MW are classified as Small Hydro Power (SHP) projects.

[27] Press Information Bureau. (2024, June 12). *Union Government approves policy framework for offshore wind energy development*. Retrieved February 22, 2025, from https://pib.gov.in/PressReleasePage.aspx?PRID=2098441

[28] Indian Renewable Energy Development Agency. (n.d.). *Wind Energy*. Retrieved February 22, 2025, from https://www.ireda.in/wind-energy

[29] KP Energy. (n.d.). *Challenges and Opportunities in Wind Energy Production Market*. Retrieved February 22, 2025, from https://kpenergy.in/challenges-opportunities-wind-energy-production-market

• Micro: up to 100 KW
• Mini: 101 KW to 2 MW
• Small: 2 MW to 25 MW
• Mega: hydro projects with installed capacity ≥ 500 M
• Thermal projects with installed capacity ≥ 1500 M

With more than two-thirds of all renewable electricity produced worldwide, hydropower is currently the most popular renewable energy source. The installed hydropower capacity worldwide increased by 26 GW in 2021 to 1360 GW.

India's hydropower sector holds substantial promise, with an estimated potential of approximately 133 gigawatts (GW) for large hydro projects and an additional 21.13 GW for small hydro projects.[30]

The hydropower market in India is poised for growth and is driven by the need for renewable and reliable energy sources. The government's focus on sustainable development and energy security has led to increased investments and policy support in the sector. Notably, private sector players like the Adani Group have announced plans to develop significant domestic and international hydroelectric capacities, aiming for 10 GW of overseas hydroelectric projects in the coming years.[31]

The Indian government has implemented several initiatives to promote hydropower development. These include policy measures to facilitate project approvals, financial incentives, and infrastructure development support. The MoP has issued an order to waive ISTS charges on the transmission of electricity generated from new hydropower projects to bring hydro energy at par with solar and wind, which already had this waiver. This would be applicable for a period of 18 years from the date of commissioning.[32] This step is expected to provide a boost to the hydro sector, which will also help improve India's water security and bring development benefits to hilly states, particularly concentrated in regions with high untapped potential, such as the northeastern states, which collectively offer a potential capacity of 55.92GW.[33]

Despite the promising potential, the hydropower sector faces challenges that hinder its full development. These challenges include environmental concerns, land acquisition issues, and the displacement of local communities. Additionally, the high initial capital investment and long gestation periods make hydropower projects less attractive to investors compared to other renewable energy sources.

The northeastern region of India stands out with substantial untapped hydropower potential. However, development in this area has been slow due to infrastructural bottlenecks, geopolitical

[30] NITI Aayog. (n.d.). *Hydro Power Potential*. India Climate Energy Dashboard. Retrieved February 22, 2025, from https://iced.niti.gov.in/energy/fuel-sources/hydro/potential
[31] *Renewable Watch*. (2024, September 26). *Tapping Potential: Challenges and Opportunities in the Hydropower Sector*. Retrieved February 22, 2025, from https://renewablewatch.in/2024/09/26/tapping-potential-challenges-and-opportunities-in-the-hydropower-sector/
[32] Press Information Bureau. (2022, November 17). *Power sector reforms in India: Enabling a sustainable and robust energy future*. https://pib.gov.in/PressReleasePage.aspx?PRID=1880517
[33] Observer Research Foundation. (2023, May 12). *Exploring the hydropower potential in India's Northeast*. Retrieved from https://www.orfonline.org/research/exploring-the-hydropower-potential-in-indias-northeast-61853

sensitivities, and ecological considerations. Addressing these issues through targeted policies and regional cooperation is essential to unlock the region's hydropower capabilities.

To advance the hydropower sector, a multifaceted approach is necessary. Streamlining regulatory processes, offering financial incentives, and ensuring community engagement can mitigate some of the existing challenges. Investing in modern technologies and infrastructure will also enhance project viability and efficiency. Collaborative efforts between the government, private sector, and local communities are crucial for sustainable hydropower development.[34]

State-wise, regions like Himachal Pradesh, Uttarakhand, and Jammu & Kashmir have made notable progress, with operational capacities of 56.16%, 29.93%, and 27.4% of their respective potentials. In contrast, the northeastern states have only harnessed about 3.62% of their potential, highlighting a significant opportunity for growth in that region.[35]

Despite much advancement, hydropower faces several challenges, including significant environmental impacts such as deforestation, biodiversity loss, and disruption of river ecosystems. Large projects often lead to the displacement of communities, causing social and economic hardships. In geologically sensitive areas like the Himalayas, projects are vulnerable to natural disasters, as seen in the 2021 Uttarakhand floods and 2023 heavy rains causing revenue losses. Climate change further threatens water availability and operational stability. Additionally, regulatory gaps, high initial investments, long gestation periods, and technological and maintenance challenges add to the complexities. To ensure sustainability, transparent planning with community involvement is essential.[36]

In summary, while India has made strides in developing its hydropower resources, a considerable portion remains untapped. Addressing the existing challenges through comprehensive policies and strategic investments can maximise the country's hydropower potential, contributing to energy security and sustainable development.

2.4 Hybrid Energy System

India has done remarkably well in its transition to low-carbon energy by developing renewable energy. However, to truly reap the benefits of renewable energy, a stable grid needs to be ensured. This calls for the adoption of a hybrid system, which combines two or more renewable energy sources with storage solutions to improve the balance and reliability of energy supply. [37] This system helps in elongating the time period of the energy supply. For example, in India, the solar output is highest in the afternoon, while the wind is highest in morning and evening time. Combining both will be beneficial since standing alone will not ensure the energy supply throughout the day. Moreover, India

[34] International Energy Agency. (n.d.). *Hydroelectricity*. Retrieved from https://www.iea.org/energy-system/renewables/hydroelectricity
[35] PIB India. (2024). *Government initiatives and hydropower potential in India*. Retrieved from https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2079832
[36] Puja Pal (2023). Present status and future outlooks of renewable energy in India for sustainable development. A Basic Overview of Environment and Sustainable Development [Volume: 2], pp. 408-433. ISBN: 978-81-962683-8-1. DOI: https://doi.org/10.52756/boesd.2023.e02.028
[37] *Economic Times EnergyWorld*. (2024). *The Rise of Hybrid Renewable Energy Solutions in India and Why It Matters for Energy Transition*. *The Economic Times*. Retrieved February 22, 2025, from https://energy.economictimes.indiatimes.com/news/renewable/the-rise-of-hybrid-renewable-energy-solutions-in-india-and-why-it-matters-for-energy-transition/101705569

lacks grid infrastructure, skilled labour, and energy storage, faces financial constraints and land acquisition constraints and undergoes seasonal variability.[38]

Hybrid systems can use different combinations of solar, wind, biomass, etc. This can also improve cost efficiency, as standalone projects cost more than combined projects with a combined storage facility.

As electricity generation from the hybridisation of renewables is a recent development, specific regulations on the subject are still scarce almost globally. India is one of the pioneering countries in this regard rolling out the National Wind-Solar Hybrid Policy in 2018.[39] This policy provides a robust framework for promoting large grid-connected wind-solar photovoltaic (PV) hybrid systems aiming to optimise wind and solar resources, transmission infrastructure, and land use. It also encourages innovative technologies and methodologies for the combined operation of wind and solar PV plants. Key features of the policy include flexibility in integration methods, conditional allowances for existing projects to adopt hybrid models, and provisions for battery storage to enhance power stability and availability.

Government agencies like SECI, NTPC, SJVN, and NHPC have issued tenders for hybrid projects, including those with assured peak-hour supply and round-the-clock renewable power.[40] In 2024, various agencies floated tenders for about 11 GW of wind-solar hybrid power (without storage), showcasing the government's interest in hybrid systems and the immense investment opportunities.

3 States Analysis

To understand the ground level implementation of national level policies on renewable energy as well to compare the regional production, opportunities and challenges, it becomes imperative to do a regional and states analysis.

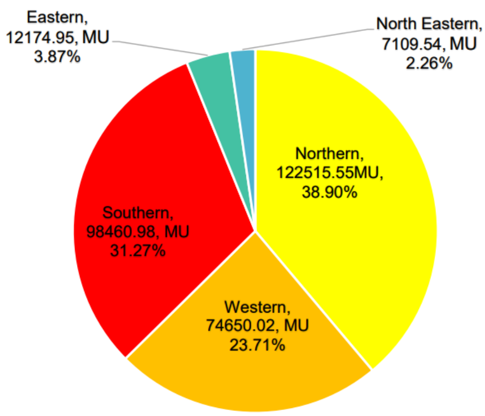

Figure 9.0 Region-wise Cumulative RE Generation from April to December 2024

Source: MNRE

[38] *Electrical India*. (n.d.). *Hybrid RE Systems in India*. Retrieved February 22, 2025, from https://www.electricalindia.in/hybrid-re-systems-in-india/

[39] Iberdrola. (n.d.). *Hybrid energy: combining renewable sources for greater efficiency*. Retrieved February 22, 2025, from https://www.iberdrola.com/innovation/hybrid-energy

[40] Press Information Bureau. (2023, July 5). *India achieves 50% non-fossil fuel installed capacity target ahead of 2030 timeline*. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2004187.

Based on Figure 9.0, a region-wise analysis shows that the Northern region leads with 38.90% (122515.55 MU) of total RE generation, followed by the Southern region at 31.27% (98460.98 MU). The Western region contributes 23.71%, while the Eastern (3.87%) and North Eastern (2.26%) regions have significantly lower shares. This distribution suggests that RE generation is concentrated in the Northern and Southern regions, likely due to higher solar and wind capacities, while the Eastern and North Eastern regions lag in RE adoption.

The following Benchmarking table provides a comprehensive overview of renewable energy policies across all Indian states and union territories. It evaluates the presence of policies for solar, wind, hydro, and hybrid energy, along with specific policy names. The table also indicates the implementation level and assesses whether the policy initiatives align with the built capacity and the region's renewable energy potential. The analysis is based on data from government sources, including the CEA.[41], MNRE[42], and NITI Aayog[43].

Index:

Checkmarks (☑) indicate full implementation of policies/initiatives.

Circular dots (◯) suggest partial or in-progress implementation/framing of policies.

Crosses (✗) signify no policy implementation in that sector.

State/UT	Solar Policy	Wind Policy	Hydro Policy	Hybrid Policy	Policy Name(s)	Implementation Level	Capacity vs Potential Match
Andhra Pradesh	☑	☑	◯	✗	AP Solar Power Policy 2018	☑	☑
Arunachal Pradesh	✗	✗	☑	✗	Small Hydro Policy 2022	◯	◯
Assam	☑	✗	☑	✗	Assam Solar Energy Policy 2019	☑	☑
Bihar	☑	✗	✗	✗	Bihar RE Policy 2021	◯	✗
Chandigarh	☑	✗	✗	✗	Chandigarh Solar Policy 2022	◯	◯
Chhattisgarh	☑	✗	☑	☑	Chhattisgarh Renewable Energy Policy	✗	◯
Delhi	☑	✗	✗	✗	Delhi Solar Policy 2022	☑	☑

[41] Central Electricity Authority. (2024). *Broad Overview of RE Generation*. Ministry of Power, Government of India. Retrieved from https://cea.nic.in

[42] Ministry of New and Renewable Energy. (2024). *State Renewable Energy Policies*. Government of India. Retrieved from https://mnre.gov.in

[43] Ministry of New and Renewable Energy. (2024). *State Renewable Energy Policies*. Government of India. Retrieved from https://mnre.gov.in

Goa	☑	✗	✗	✗	Goa Solar Policy 2021	○	✗
Gujarat	☑	☑	☑	☑	Gujarat RE Policy 2020	☑	☑
Haryana	☑	✗	✗	✗	Haryana Solar Policy 2021	○	○
Himachal Pradesh	✗	✗	☑	✗	HP Hydro Policy 2019	○	○
Jammu & Kashmir	✗	✗	☑	✗	J&K Hydro Policy 2022	○	✗
Jharkhand	☑	✗	✗	✗	Jharkhand Solar Policy 2021	☑	☑
Karnataka	☑	☑	☑	☑	Karnataka Renewable Energy Policy	☑	☑
Kerala	☑	✗	☑	✗	Kerala Solar Policy 2019	○	○
Ladakh	✗	✗	☑	✗	Ladakh Hydro Policy 2023	✗	✗
Lakshadweep	✗	✗	✗	✗	No Policy Available	✗	✗
Madhya Pradesh	☑	☑	☑	☑	MP RE Policy 2022	☑	☑
Maharashtra	☑	☑	☑	☑	Maharashtra RE Policy 2020	☑	☑
Manipur	☑	✗	☑	✗	Manipur Solar Policy 2022	○	○
Meghalaya	✗	✗	☑	✗	Meghalaya Hydro Policy 2021	○	○
Mizoram	✗	✗	☑	✗	Mizoram Small Hydro Policy 2021	✗	✗
Nagaland	✗	✗	☑	✗	Nagaland Hydro Policy 2020	✗	✗
Odisha	☑	✗	☑	✗	Odisha RE Policy 2022	○	○
Puducherry	☑	✗	✗	✗	Puducherry Solar Policy 2021	○	○
Punjab	☑	✗	☑	✗	Punjab Solar Policy 2022	☑	☑
Rajasthan	☑	☑	☑	☑	Rajasthan RE Policy 2020	☑	☑

Sikkim	✗	✗	☑	✗	Sikkim Hydro Policy 2021	○	○
Tamil Nadu	☑	☑	☑	☑	Tamil Nadu RE Policy 2021	☑	☑
Telangana	☑	☑	✗	☑	Telangana RE Policy 2022	☑	☑
Tripura	☑	✗	☑	✗	Tripura Solar Policy 2021	○	○
Uttar Pradesh	☑	☑	☑	☑	UP RE Policy 2022	☑	☑
Uttarakhand	✗	✗	☑	✗	Uttarakhand Hydro Policy 2020	○	○
West Bengal	☑	✗	☑	✗	West Bengal RE Policy 2021	○	○

Based on the data provided in the table in Annexure 1 and the benchmarking table, the performance of Indian states in renewable energy potential varies significantly across different sectors such as wind, solar, biomass, and hydropower. The top five performing states shown in Figure 10.0 include Rajasthan, Gujarat, Tamil Nadu, Maharashtra, and Karnataka. Among the top-performing states, Rajasthan leads with 20.30% of India's total renewable energy potential, driven primarily by its exceptional solar capacity of 142.310 GW. The state's vast land availability, high solar irradiance, and strong policy incentives make it a key player in India's renewable energy transition. Gujarat follows (9.58%), strongly emphasising wind power (1,56,222 MW) and a robust solar energy capacity.

Maharashtra (11.76%) and Tamil Nadu (5.56%) also exhibit substantial wind power potential, with Maharashtra diversifying into biomass and solar sectors, while Andhra Pradesh (7.92%) showcases balanced growth across wind and solar energy.

Moderate-performing states include Karnataka (6.10%), Madhya Pradesh (5.84%), Telangana (3.71%), and Himachal Pradesh (2.59%), each contributing to different segments of renewable energy. Karnataka demonstrates a balanced potential across wind and solar energy, whereas Madhya Pradesh focuses mainly on solar and wind projects. Despite its smaller size, Telangana performs well in solar energy, and Himachal Pradesh excels in hydropower generation, benefiting from its mountainous terrain. Additionally, northern states continue to dominate hydroelectric energy production, although many of these regions paradoxically face water scarcity challenges.

States that lag behind in renewable energy development include Goa, Nagaland, Mizoram, and Tripura, each contributing less than 1% to the national renewable energy mix. These states face multiple barriers, including limited land availability, lower solar irradiance, inadequate investment, and difficult topographies that restrict large-scale projects. Additionally, policy and infrastructure gaps and lower industrial demand further hinder their ability to expand renewable energy capacities.

Overall, the analysis highlights a stark regional disparity in renewable energy potential, with western and southern states leading the transition while northeastern and smaller states struggle to keep pace. Key factors influencing this imbalance include geographical advantages, supportive policy frameworks, industrial demand, and infrastructure readiness. Addressing these disparities through targeted investments, regional policy interventions, and improved infrastructure will be crucial in ensuring a more balanced and sustainable renewable energy expansion across India.

4 Conclusion

India's renewable energy sector stands at a critical juncture, with significant progress made in solar, wind, hydro, hybrid systems, and green hydrogen. However, realising the full potential of these energy sources requires a multifaceted approach. Strengthening grid infrastructure, addressing transmission bottlenecks, and enhancing energy storage solutions are imperative to ensure seamless integration of renewables into the national power grid. The adoption of hybrid energy systems can further optimise resource utilisation and improve grid stability by balancing generation variability across different sources.

The expansion of domestic manufacturing, particularly in the solar sector, is crucial to reducing dependence on imports and mitigating supply chain vulnerabilities. While initiatives like the imposition of basic customs duties on solar modules and cells have been implemented, further support is needed to enhance indigenous production capacity across the entire photovoltaic supply chain. Similarly, investments in offshore wind energy, particularly through viability gap funding, can unlock new avenues for power generation and strengthen India's position as a global leader in wind energy.

State-level initiatives in Rajasthan, Gujarat, and Tamil Nadu highlight the importance of regional policy frameworks in accelerating renewable adoption. Rajasthan's aggressive solar expansion, Gujarat's leadership in solar module manufacturing, and Tamil Nadu's wind repowering efforts demonstrate that a tailored, state-driven approach is key to meeting national targets. Addressing land acquisition challenges, regulatory delays, and curtailment issues will be essential for scaling up these efforts.

India's push towards green hydrogen presents a transformative opportunity for decarbonising hard-to-abate sectors such as steel, chemicals, and transport. Strategic policy support, including demand aggregation and incentives for electrolyser manufacturing, will be instrumental in making green hydrogen commercially viable. Simultaneously, continued policy refinements, such as optimising Renewable Purchase Obligations (RPOs) and streamlining open access policies, will foster investment confidence and ensure long-term sectoral growth.

As India advances towards its goal of 500 GW of non-fossil fuel capacity by 2030 and net-zero emissions by 2070, proactive measures are required to address financial, technical, and regulatory barriers. Encouraging public-private partnerships, expanding funding mechanisms, and ensuring transparent policy implementation will be crucial to sustaining momentum. By building on the progress achieved and strategically overcoming existing challenges, India can not only secure its energy future but also emerge as a global leader in the transition towards sustainable, low-carbon growth.

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5 Annexure 1.

This table presents the estimated potential of renewable energy generation in India as of March 31, 2023, categorised by state/UT and energy sources, including wind, solar, hydro, biomass and total production.

Sl. No.	State/UTs	Wind Power @150m	Small Hydro Power	Biomass Power	Cogeneration-bagasse	Solar Energy	Large Hydro	Total	Distribution (%)
1	Andhra Pradesh	123336	409	1999	280	38440	2596	167060	7.92%
2	Arunachal Pradesh	246	2065	18	0	8650	50394	61373	2.91%
3	Assam	459	202	322	0	13760	643	15386	0.73%
4	Bihar	4023	527	964	3.47	11200	130	17191	0.81%
5	Chhattisgarh	2749	1098	354	0	18270	1311	23728	1.13%
6	Goa	14	33	0	0	880	0	932	0.04%
7	Gujarat	180790	202	2638	555	35770	550	220505	10.45%
8	Haryana	593	107	1353	362	4560	0	6980	0.33%
9	Himachal Pradesh	239	3460	70	0	33840	18305	55914	2.65%
10	Jammu & Kashmir	1(Ladakh)	1707	83	0	111050	12972	125812	5.96%
11	Jharkhand	16	228	113	0	18180	300	18870	0.89%
12	Karnataka	169251	3756	1794	1762	24710	40414	205648	9.74%
13	Kerala	2621	647	778	0	6110	2473	12629	0.60%
14	Madhya Pradesh	55423	862	2516	0	61660	1145	132239	5.84%
15	Maharashtra	173868	786	2630	3917	64320	3148	248665	11.79%
16	Manipur	5	260	0	0	9900	1927	11889	0.56%
17	Meghalaya	55	169	54	0	9600	2028	11806	0.53%
18	Mizoram	0	182	54	0	7290	325	7851	0.37%
19	Nagaland	0	286	39	0	25780	325	41318	1.96%
20	Odisha	12129	288	329	414	25780	325	41318	1.96%
21	Punjab	428	578	3022	414	2810	1301	8554	0.41%
22	Rajasthan	284250	567	1500	0	142310	411	482332	22.30%
23	Sikkim	0	267	5	0	4940	6051	11262	0.53%
24	Tamil Nadu	95107	656	1560	639	4610	1785	117366	5.56%
25	Telangana	54717	102	1678	117	20410	1302	78327	3.71%
26	Tripura	0	47	34	0	2080	0	2161	0.10%
27	Uttar Pradesh	510	461	2800	4926	22830	500	31627	1.52%
28	Uttarakhand	49	1664	93	215	16800	13481	32303	1.53%
29	West Bengal	0	291	1742	0	6260	809	10484	0.50%
30	Andaman & Nicobar	1245	7	18	0	0	0	1270	0.06%
31	Chandigarh	0	0	0	0	0	0	0	0.00%
32	Dadra & Nagar Haveli, Daman & Diu	17	0	2	0	0	0	19	0.00%

33	Delhi	0	0	0	0	2050	0	2050	0.10%
34	Lakshadweep	31	0	1	0	0	0	32	0.00%
35	Puducherry	408	0	5	0	0	0	413	0.02%
36	Others	0	0	0	0	284	790	1074	0.05%
All India Total	11,63,836	21,134	28,447	13,818	7,48,990	1,33,410	21,09,654	100.00%	

Source: Ministry of Statistics and Programme Implementation. (2024). Energy Statistics India 2024. Government of India. https://www.mospi.gov.in/sites/default/files/publication_reports/EnergyStatistics_India_publication_2024N.pdf

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