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Green energy as a catalyst for rural transformation: Assessing the role of renewable energy in livelihoods, financial inclusion and sustainable rural development in India

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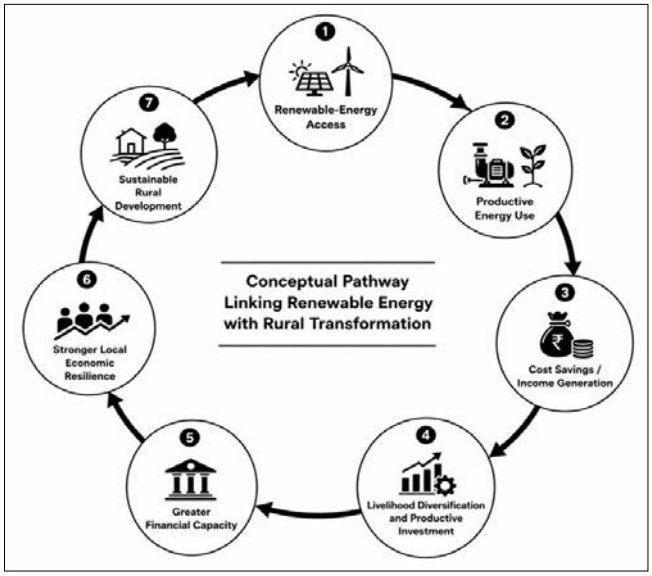
Abstract
India's rapid expansion of renewable energy has implications beyond electricity generation, particularly for rural livelihoods, agriculture and local economic activity. This paper examines the pathways through which renewable energy can contribute to rural livelihoods, productive economic activity, financial participation and sustainable rural development in India. An integrative secondary-research design was used, combining official 2024 energy indicators with policy documents, institutional reports and peer-reviewed studies. By December 2024, India's installed renewable-energy capacity reached 209.44 GW, including 97.86 GW of solar and 48.16 GW of wind. During 2024, 28.64 GW of renewable capacity was added, while rural power-supply availability reached 21.9 hours per day. PM-KUSUM had also facilitated the installation of more than 6.1 lakh standalone solar pumps by December 2024. The evidence identifies four major pathways: reducing dependence on conventional energy, enabling productive agricultural and non-farm activities, supporting livelihood diversification, and creating opportunities for formal finance and decentralized institutions. However, these benefits are neither automatic nor evenly distributed and depend on affordability, asset ownership, infrastructure, technical capacity, market access, groundwater conditions and institutional factors. The paper argues for a shift from a capacity-expansion approach towards a Green Rural Development perspective that integrates renewable energy with agriculture, livelihoods, rural finance, local governance, skills and environmental sustainability.

Keywords: Green energy, renewable energy, rural development, rural livelihoods, financial inclusion, solar irrigation, PM-KUSUM, sustainable development, India

Introduction

Energy is a critical input in rural economies, supporting agriculture, irrigation, livestock, food processing, small enterprises, transport, education and household activities. Thus, rural development depends not only on electricity access but also on the availability, reliability and affordability of energy for productive activities.India has made significant progress in renewable-energy deployment. By December 2024 [6], total installed renewable-energy capacity reached 209.44 GW, including 97.86 GW of solar and 48.16 GW of wind capacity. During 2024 alone, 28.64 GW of renewable capacity was added, with solar contributing 24.54 GW (Ministry of New and Renewable Energy [MNRE], 2025).

Rural electricity access has also improved substantially. Average rural power-supply availability increased from 12.5 hours per day in 2015 to 21.9 hours in 2024. Under SAUBHAGYA, 2.86 crore households received electricity connections during the programme period (Ministry of Power, 2024a, 2024b) [6]. However, these achievements also highlight the need to focus on the quality, affordability and productive use of energy.The PM-KUSUM scheme further links renewable energy with agriculture through solar pumps and decentralised energy generation. By December 2024[6], more than 6.1 lakh stand-alone solar pumps had been installed (MNRE, 2025a). Such interventions can reduce dependence on conventional energy and create opportunities for improved farm incomes and rural enterprises, although their outcomes depend on access to finance, technical skills, markets, institutions and sustainable resource management.

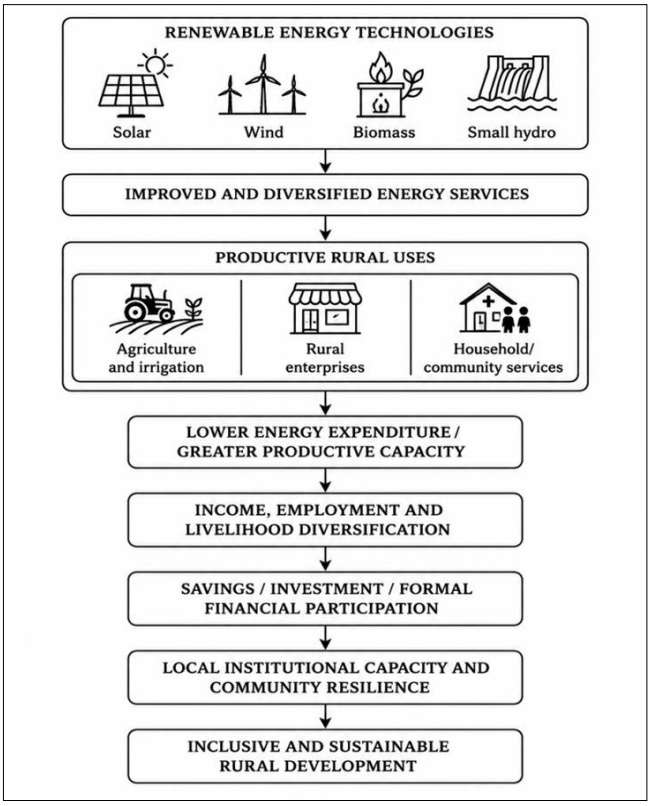


Accordingly, this paper examines the role of renewable energy in rural livelihoods and productive activities, financial inclusion, and sustainable rural development, with particular attention to the institutional and economic conditions that determine whether renewable-energy interventions can contribute to inclusive rural transformation in India.

Conceptual Perspective: Renewable Energy as Productive Rural Infrastructure

The study adopts a rural-development perspective in which energy is viewed as an enabling asset rather than an end in itself. The place-based approach established by the Organization for Economic Co-operation and Development (OECD) has alsoemphasized that renewable-energy investment contributes more strongly to regional development when it is connected to existing local economic activities, institutions and value chains rather than treated as an isolated technological intervention (OECD, 2012).

This pathway is conditional rather than automatic. Its outcomes are influenced by access to finance, technology, infrastructure, skills, markets, water resources, local institutions and public policy. The framework therefore distinguishes between energy deployment and developmental conversion. The first refers to the installation of renewable-energy capacity; the second refers to the ability of households and institutions to convert that capacity into sustained economic and social benefits.



Flowchart: Conceptual framework linking renewable energy with rural transformation.

The framework also highlights the importance of equitable ownership, control and distribution of benefits from renewable-energy assets. It considers who owns and manages the energy asset, who benefits from the income generated, and who bears the associated environmental and financial risks. These aspects are essential for ensuring that the green transition supports inclusive and sustainable rural development.

Review of Literature

The literature establishes that renewable energy can have economic, environmental and social effects, but these effects depend substantially on place and institutional context.

OECD (2012) provides a particularly relevant rural-development framework. Its analysis argues that renewable-energy investment can strengthen rural economies when it is embedded in local economic structures, governance systems, industries and value chains. The place-based approach is important because rural regions differ widely in natural resources, infrastructure, institutional capacity and access to markets.

The World Intellectual Property Organization's Green Technology Book: Energy Solutions for Climate Change further demonstrates the relevance of decentralised energy technologies to rural households, agriculture, water systems and community services. The report discusses solar-powered water systems, small hydro, solar appliances, decentralised systems and other technologies that can contribute to rural energy access and productivity (WIPO, 2024) [6].

Indian evidence provides a stronger empirical basis for the agricultural livelihood pathway. Gupta (2019) [1] studied 414 farmers across six districts of Rajasthan using a difference-in-differences approach and found that solar-water-pump adoption affected energy use, water consumption, crop patterns and farm profitability. The study is particularly valuable because it also demonstrates the complexity of the energy-water-food relationship: lower marginal energy costs can increase irrigation and agricultural returns while simultaneously creating risks of additional groundwater extraction.

Kumar, Darshna and Ranjan (2023) [4], through a bibliometric review of 2,640 publications between 2002 and 2023[4], demonstrate the rapid expansion of scholarship connecting green energy, resource efficiency and sustainable development. Their analysis indicates that renewable energy is increasingly examined as part of broader transitions involving environmental sustainability, resource management and circularity.

The financial dimension is comparatively less developed. The institutional importance of renewable-energy finance has nevertheless increased. The Reserve Bank of India's Priority Sector Lending framework recognizes renewable energy as an eligible priority-sector category. The 2025[10] Directions, effective from 1 April 2025[10], specifically retain renewable energy within the priority-sector framework (RBI, 2025) [10]. This provides a formal institutional route through which renewable-energy investments can interact with rural credit.

The literature therefore points towards a multidimensional relationship and also suggests that renewable energy contributes to rural development through several interconnected factors. Simply providing energy is not enough; its development impact depends on how it is used productively, how effectively local institutions support it, and how fairly its benefits are shared. In this way, energy can become an important foundation for sustainable and inclusive rural development.

Methodology

1. Research design

The study uses an integrative secondary-research design combining descriptive quantitative analysis with qualitative thematic synthesis. This formulation is preferred to a conventional primary-data mixed-method design because the study does not generate household-level survey data or conduct an econometric estimation using a nationally representative sample.The quantitative component examines

official indicators of renewable-energy capacity, rural electricity availability and selected programme implementation data. The qualitative component synthesizes government policy documents, institutional reports and peer-reviewed empirical studies dealing with renewable energy, rural livelihoods, agriculture, finance and sustainable development.The two streams are brought together during interpretation rather than being treated as independent causal estimates.

2. Sources and evidence selection

Priority was given to primary government sources, particularly MNRE, the Ministry of Power and RBI;international institutional sources, including OECD, IRENA and WIPO; andpeer-reviewed studies providing direct empirical evidence on rural energy and agricultural outcomes.The principal empirical case used in the paper is Gupta (2019) [1], because it provides India-specific household/farm evidence rather than relying exclusively on aggregate capacity statistics.Sources released during early 2025 are used only where they report the completed 2024 position. No post-2024 outcome data are used to construct the substantive results.

3. Analytical approach

The analysis is organized around five interconnected themes: (i) renewable-energy scale and composition; (ii) rural energy access and productive use; (iii) agriculture and livelihood transformation; (iv) financial participation and rural finance; and (v) institutional and environmental sustainability. The approach is interpretive rather than causal at the national level. The paper does not claim that renewable-energy expansion directly caused specific changes in rural income or financial inclusion across India. Instead, it examines the mechanisms through which renewable energy can influence rural development, drawing on empirical evidence, policy design and credible institutional analysis.

Results and Discussion

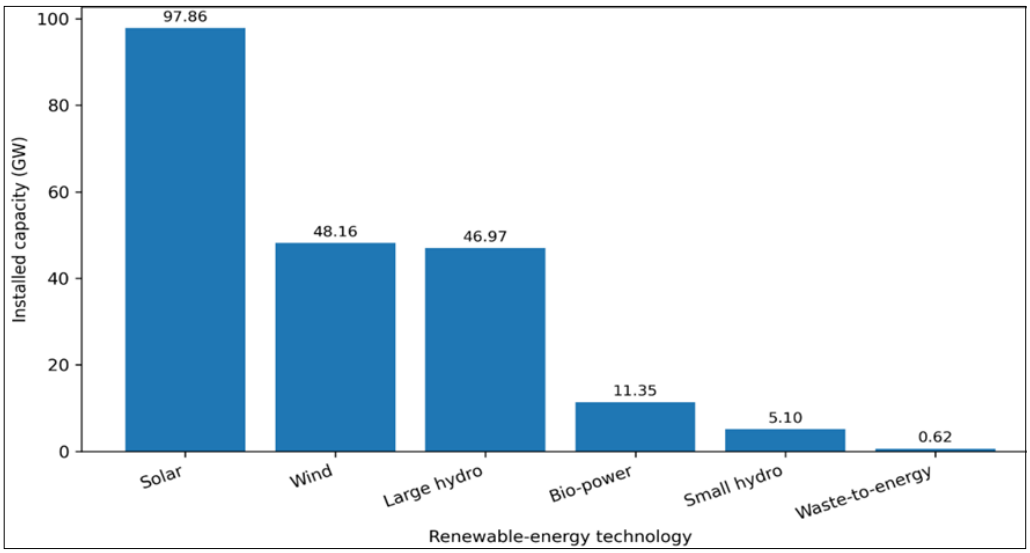
1. Scale and structure of India's renewable-energy transition

Table 1: India's renewable-energy installed capacity, December 2023 and December 2024 [2, 6]

Renewable-energy source	Dec. 2023 (GW)	Dec. 2024 (GW)	Change (GW)	Growth (approx.)
Solar	73.32	97.86	24.54	33.47%
Wind	44.74*	48.16	3.42	7.64%
Bioenergy	10.84	11.35	0.51	4.70%
Small Hydro	4.99	5.10	0.11	2.20%
Total renewable energy**	180.80	209.44	28.64	15.84%

Source: Ministry of New and Renewable Energy, Government of India; PIB, 13 January 2025[10].
*Wind value is derived from the reported 2024 total and official year-on-year growth rate.
**The total renewable-energy figure reported by MNRE includes large hydropower and the renewable components reported by the Ministry.

Table 1 show that India's renewable-energy transition accelerated strongly during 2024[6]. The most important change was the expansion of solar capacity, which increased by 24.54 GW in one year and accounted for the overwhelming majority of the reported renewable-capacity addition. Solar's rapid growth is particularly significant for rural development because many solar applications, including pumps, decentralized generation and rooftop systems, can be deployed close to productive users. At the same time, the concentration of growth in solar should not be interpreted as evidence that all rural areas benefit equally; infrastructure, finance, technical services and local resource conditions remain decisive.



Note: Values in GW: solar 97.86; wind 48.16; large hydropower 46.97; bio-power approximately 11.35; small hydropower 5.10; waste-to-energy approximately 0.62. Source: MNRE, Government of India.

Fig 1: India's renewable-energy installed capacity by technology, December 2024[6]

2. Rural electrification: from connection to productive energy access

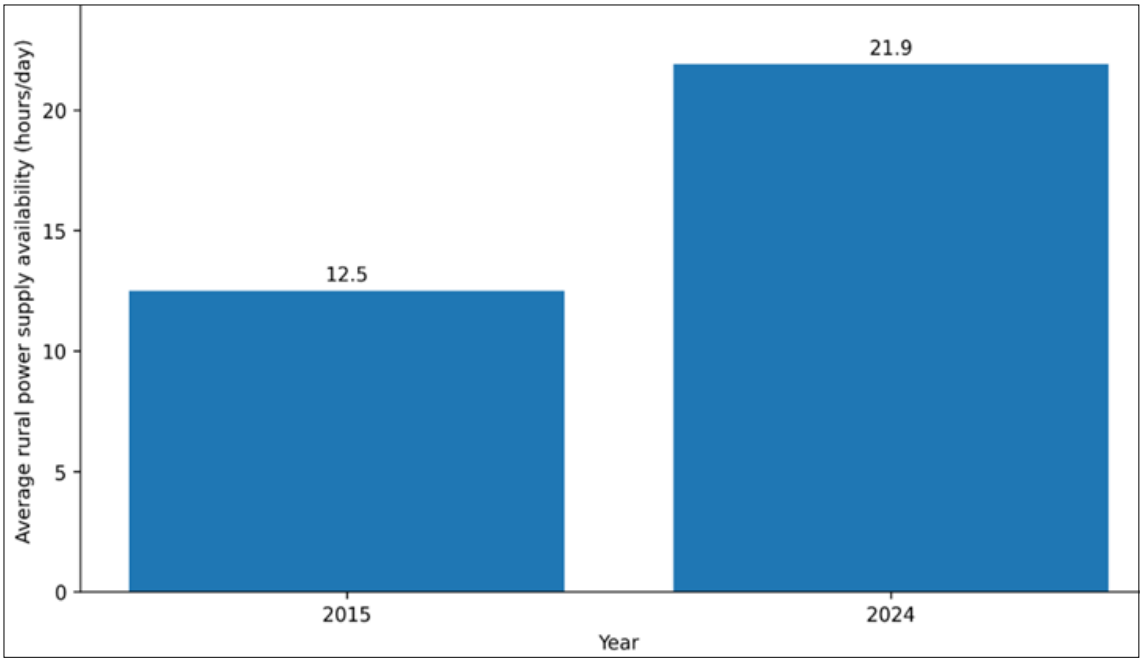
India's rural energy situation has improved substantially over the last decade. The reported increase in average rural electricity availability from 12.5 hours per day in 2015 to 21.9 hours in 2024 indicates a major change in the quantity of electricity available to rural areas. The achievement of household electrification under SAUBHAGYA also demonstrates progress in basic access.

Table 2: Selected indicators of rural electricity access and availability

Indicator	Reported position	Year/reference point
Average rural power-supply availability	12.5 hours/day	2015
Average rural power-supply availability	21.9 hours/day	2024
Households provided electricity connections under SAUBHAGYA	2.86 crore	Programme period up to closure
Villages electrified under DDUGJY	18,374	Programme period

Source: Ministry of Power, Government of India (2024a, 2024b) [6].

The figures of Table 2 indicate that India's rural energy challenge has moved beyond the absence of electricity connections towards questions of reliability, quality and productive use. A connection is necessary but not sufficient for rural transformation. Agriculture may require electricity for irrigation; small enterprises may need dependable power for machinery; food businesses may require refrigeration; and rural households increasingly require electricity for digital services. The development value of renewable energy therefore depends partly on whether it improves the reliability and productive usefulness of energy services.



Source: Ministry of Power, Government of India. Rural availability increased from 12.5 hours/day in 2015 to 21.9 hours/day in 2024.

Fig 2: Rural power-supply availability in India, 2015 and 2024

3. Renewable energy, agriculture and rural livelihoods

Agriculture provides one of the clearest pathways through which renewable energy can influence rural livelihoods. Irrigation, in particular, is energy intensive, and the cost and reliability of energy influence farmers' production choices. PM-KUSUM is important because it attempts to connect renewable-energy deployment with agricultural production. Its components cover decentralised solar generation, stand-alone solar agricultural Pumps and solarisation of grid-connected agricultural pumps. By December 2024, the programme had installed 616,210 stand-alone solar pumps, while 396.98 MW of solar capacity had been installed under Component A. Under Component C, 5,272 pumps had been solarised under individual-pump solarisation and 107,184 pumps under feeder-level solarisation, according to government-reported programme achievements as of 31 December 2024 (MNRE, 2025a).

Table 3: Selected PM-KUSUM Achievements

PM-KUSUM component/activity	Sanctioned	Installed/Solarised	Reported Outcome
Component A: decentralized solar capacity	9,962 MW	396.98 MW	Decentralised solar generation
Component B: stand-alone solar pumps	12,32,327 pumps	6,16,210 pumps	Solar irrigation
Component C:Individual Pump Solarisation	1,31,640 pumps	5,272 pumps	Grid-connected pump solarisation
Component C:Feeder Level Solarisation	34,35,874 pumps	1,07,184 pumps	Feeder-level solarisation

Source: Ministry of New and Renewable Energy/Press Information Bureau, Government of India; programme achievements as of 31 December 2024 [6].

Table 3 shows substantial implementation under PM-KUSUM, particularly in stand-alone solar pumps. However, implementation does not automatically translate into improved rural welfare. Its impact depends on productive use, sustainable water management, maintenance support and equitable access, particularly for small and marginal farmers.

Gupta (2019) [1], based on 414 farmers in Rajasthan, found that solar-water-pump adoption was associated with changes in diesel use, electricity consumption, cropping intensity, crop choices and agricultural profits, highlighting the livelihood potential of renewable energy. However, lower energy costs may also encourage groundwater extraction, making effective water management essential.

Decentralised renewable energy can reduce energy costs, improve irrigation reliability, diversify livelihoods and support rural enterprises such as food processing and cold storage. These benefits, however, depend on asset ownership, market access, technical skills, finance and access to land and water.

4. Renewable energy and financial inclusion

The relationship between renewable energy and financial inclusion requires cautious interpretation. Financial inclusion involves access to affordable and appropriate services such as credit, savings, insurance and payment systems. Renewable-energy adoption does not automatically ensure these outcomes, but productive energy assets can create greater opportunities for engagement with formal finance. The RBI's Priority Sector Lending Directions, 2025[10], continue to include Renewable Energy as a priority-sector category, supporting financing for eligible renewable-energy activities (RBI, 2025) [10]. Renewable-energy adoption can facilitate productive energy use, generate cost savings and additional income, improve household cash flows, and consequently enhance opportunities for savings, investment and access to formal credit. This pathway is particularly relevant to solar pumps, decentralized energy systems, energy-efficient equipment and community energy enterprises. However, high initial costs, limited access to credit, collateral and documentation requirements, and concerns regarding technology, maintenance and insurance may restrict participation, especially among small and marginal farmers, women and tenants. Renewable energy should therefore be viewed as a potential gateway to financial inclusion, complementing rather than replacing broader financial-inclusion policies.

5. Institutional, gender and distributional dimensions

The benefits of the green transition are likely to be uneven where access to land, capital, information, institutions and decision-making remains unequal. Women are important users of rural energy, particularly in household production, water collection, food processing and care-related activities. WIPO (2024) highlights that decentralised energy technologies can reduce household and water-related burdens while creating opportunities for productive activities. Therefore, women should be recognised not only as beneficiaries but also as users, entrepreneurs, technicians, owners and decision-makers.Community institutions such as PRIs, FPOs, SHGs, cooperatives and other collective organisations can play an important role in providing information, facilitating finance, supporting maintenance and ensuring accountability. The OECD (2012) also emphasises the importance of local institutions and place-based governance in enabling rural communities to gain greater economic benefits from renewable-energy investments.

The distribution of ownership, control, income and risks is therefore central to inclusive rural development. An increase in renewable-energy capacity alone cannot be considered inclusive rural transformation unless its economic and social benefits are fairly distributed and environmental and financial risks are appropriately managed.

6. Environmental sustainability and the energy-water-food nexus

Renewable energy is frequently associated with environmental sustainability because it can reduce dependence on fossil fuels. Yet renewable-energy technologies are not environmentally neutral in every local context.Solar irrigation provides a particularly important example. A diesel pump imposes an energy cost that constrains irrigation intensity. A solar pump, once installed, can substantially reduce the marginal energy cost of pumping. This can improve farm profitability and energy security, but in groundwater-dependent areas it may also encourage increased extraction if electricity generation is no longer the limiting factor.This illustrates the importance of an energy-water-food nexus perspective. Rural energy policy should therefore be coordinated with groundwater regulation, crop planning and water-efficient irrigation technologies. Similarly, large renewable-energy projects can generate land-use concerns, transmission constraints and local conflicts if communities do not perceive that benefits and costs are being fairly distributed.Sustainable rural transformation consequently requires more than replacing fossil-energy technologies with renewable ones. It requires environmentally appropriate siting, resource management, community participation and long-term maintenance.

7. Falling technology costs and rural opportunity

The economic attractiveness of renewable energy has improved over time. IRENA's 2024[6] report on renewable power generation costs documents the continued global decline in the costs of major renewable technologies and shows that solar photovoltaic and onshore wind have become highly competitive sources of new electricity generation (IRENA, 2024) [6].For rural India, declining technology costs can reduce one of the principal barriers to decentralised adoption. However, equipment cost is only one component of the actual cost faced by rural users. Financing costs, installation, maintenance, storage, replacement, insurance and after-sales service can determine whether a system is economically viable over its operating life.A rural-development framework should therefore use a whole-life-cost perspective rather than focusing exclusively on equipment purchase prices.

Policy Implications: Towards A Green Rural Development Model

1. **Shift from electricity access to productive energy access:** Programme monitoring should move beyond electricity connections and installed capacity and incorporate indicators such as irrigation supported, enterprises enabled, agricultural processing capacity, energy expenditure, productive working hours and local employment.

2. **Link renewable energy with rural livelihoods:** Renewable-energy technologies, including solar pumps, decentralised solar systems, biomass and small hydro, should be integrated with agriculture, dairy, food processing, cold storage, fisheries, handicrafts and other rural services to strengthen livelihood opportunities and local economic activity.

3. **Expand green rural finance:** Banks, Regional Rural Banks, cooperatives and other financial institutions should develop appropriate financing products for decentralised renewable-energy systems, including solar pumps, energy-efficient equipment and community energy enterprises. The recognition of renewable energy under the Priority Sector Lending (PSL) framework provides an institutional foundation, but financing opportunities should be made more accessible to small, marginal and underserved rural borrowers.

4. **Strengthen community institutions:** PRIs, Farmer Producer Organisations (FPOs), cooperatives and Self-Help Groups (SHGs) should be actively involved in collective procurement, information dissemination, local accountability, and maintenance and market linkages. Greater institutional participation can strengthen local ownership and improve the sustainability of renewable-energy interventions.

5. **Integrate gender into the green transition:** Women should be recognized as beneficiaries, entrepreneurs, technicians, owners and decision-makers in rural renewable-energy programmes. Programme design and monitoring should also consider women's time use, livelihood opportunities and participation in local economic decision-making.

6. **Develop rural green-skills ecosystems:** The renewable-energy transition requires technicians, installers, repair and maintenance workers, digital monitoring personnel and financial-management skills. Rural skill-development programmes should therefore be aligned with emerging renewable-energy markets and local employment opportunities rather than focusing exclusively on conventional training.

Together, these six priorities support a Green Rural Development Model in which renewable energy, agriculture, livelihoods, rural finance, local governance, skill development and environmental sustainability are integrated to ensure that renewable-energy expansion contributes to inclusive, resilient and sustainable rural transformation.

Limitations and Future Research

The study is limited by its reliance on secondary evidence and therefore does not estimate household-level causal effects of renewable-energy adoption. National capacity data also do not show the share directly serving rural communities. In addition, evidence linking renewable energy with formal financial inclusion remains comparatively limited, and findings from Rajasthan may not be generalizable to India's diverse rural regions.

Future research should use village- and household-level longitudinal studies comparing adopters and non-adopters, with particular attention to small and marginal farmers, women, SHGs, FPOs and geographically disadvantaged communities. Greater focus is also needed on the relationship between solar irrigation, groundwater use, cropping patterns and rural livelihoods, examining not only whether renewable energy works, but for whom, under what conditions, at what cost and with what environmental consequences.

Conclusion

India’s renewable-energy transition has grown to a scale that is increasingly shaping rural development. By December 2024[6], renewable capacity had reached 209.44 GW, while initiatives such as PM-KUSUM were linking clean energy with agriculture and rural livelihoods.The evidence suggests that renewable energy can support rural transformation by reducing dependence on conventional energy, improving agricultural and business productivity, diversifying livelihoods, and creating opportunities for investment and access to formal finance. However, its benefits depend on factors such as affordability, asset ownership, technical skills, market access, finance, local institutions and gender relations.Renewable energy is therefore not a stand-alone solution to rural poverty. For example, solar irrigation can reduce farming costs but may also increase groundwater pressure where regulation is weak.

India’s next phase of the green transition should focus not only on expanding renewable capacity but on building an integrated Green Rural Development Model that connects energy with agriculture, livelihoods, finance, skills, local governance, gender inclusion and environmental sustainability. Ultimately, the success of the transition should be measured by how far it improves rural incomes, resilience, opportunities and quality of life.

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