



Renewable energy adoption and its role in sustainable development

Jitender Garg

Assistant Professor, Department of Business Administration and Management, Banaras Hindu, University, Uttar Pradesh, India

Abstract

Renewable energy has moved from the periphery of global energy planning to its center, driven by climate imperatives, energy security concerns, and the Sustainable Development Goals (SDGs) adopted by the United Nations. This paper synthesizes recent literature (2023–2026) on the adoption of renewable energy technologies and their contribution to sustainable development. Drawing on systematic reviews, meta-analyses, and empirical panel studies, the review examines the major technological pathways driving adoption, including solar photovoltaics, wind power, and battery energy storage; the policy instruments that shape deployment, such as feed-in tariffs, carbon pricing, and green finance mechanisms; and the social dimensions of community engagement and public acceptance. The evidence indicates that renewable energy deployment is strongly associated with reduced per-capita carbon emissions and, in many contexts, with improved economic and human development outcomes, although the strength of these relationships varies across income levels and governance settings. Persistent barriers include high upfront capital costs and unequal access to affordable financing, technical constraints related to the intermittency of wind and solar generation, fragmented regulatory frameworks, and uneven social acceptance shaped by questions of procedural fairness and distributional justice. The review concludes that accelerating renewable energy adoption in a manner consistent with sustainable development will require coordinated action across financing structures, grid infrastructure, and community-inclusive governance, particularly in low- and middle-income countries that face disproportionate structural barriers. Implications for policymakers, practitioners, and future research are discussed.

Keywords: Renewable energy, sustainable development, energy transition, energy policy, energy storage, climate change mitigation, developing countries

Introduction

The global energy system is undergoing one of the most consequential transformations in its history. Fossil fuels still supply roughly four-fifths of the world's primary energy, yet the continued combustion of coal, oil, and natural gas remains the principal driver of anthropogenic greenhouse gas emissions and the climate instability that follows from them. Against this backdrop, renewable energy technologies, particularly solar photovoltaics, wind power, hydropower, and increasingly battery storage, have emerged as the central mechanism through which countries seek to reconcile continued economic development with climate mitigation commitments. The 2015 United Nations 2030 Agenda formalized this linkage by embedding affordable and clean energy within Sustainable Development Goal 7 and connecting it explicitly to climate action under Goal 13, framing renewable energy not merely as an environmental necessity but as a foundation for broader social and economic progress.

Momentum behind renewable energy deployment has accelerated markedly in the past several years. International Energy Agency (IEA, 2025)^[6] data show that low-emissions sources, led by record additions of solar photovoltaic capacity, accounted for nearly all of the growth in global electricity demand in 2024^[4], and clean energy technologies have measurably slowed the growth of energy-sector carbon emissions relative to a counterfactual without them (IEA, 2024). Even so, the transition remains uneven. Advanced economies have achieved substantial emissions reductions alongside continued economic growth, while many developing and emerging economies face a more

constrained set of choices shaped by financing costs, infrastructure gaps, and competing development priorities.

This paper reviews the current state of scholarship on renewable energy adoption and its role in advancing sustainable development. It asks three interrelated questions: (1) what technological and policy approaches are driving renewable energy adoption across different contexts; (2) what does the empirical evidence show about the effectiveness of renewable energy in advancing environmental, economic, and social dimensions of sustainable development; and (3) what barriers continue to impede adoption, and how might they be addressed. The paper synthesizes systematic reviews, meta-analyses, and recent empirical studies published largely between 2023 and 2026 to provide an up-to-date account of a rapidly evolving field.

Review Approach

This paper adopts a narrative synthesis approach informed by the methodological standards of systematic review practice. Literature was identified through targeted searches of academic databases and publisher platforms, including ScienceDirect, Wiley Online Library, Nature Portfolio journals, Frontiers, MDPI journals, and reports from the International Energy Agency and International Renewable Energy Agency, using combinations of search terms such as "renewable energy adoption," "sustainable development," "energy transition," "energy storage," "grid integration," "social acceptance," and "climate finance." Priority was given to systematic reviews, meta-analyses, and peer-reviewed empirical studies published between 2023 and

2026, supplemented by a small number of earlier foundational studies and recent policy reports where they provided essential context. Sources were screened for relevance to the adoption, effectiveness, and implementation of renewable energy technologies in relation to sustainable development outcomes. Findings were then organized thematically around the major technological and policy approaches, the empirical evidence on effectiveness, and the barriers to implementation, allowing convergent and divergent findings across studies to be compared rather than treated as a simple aggregation of results.

Approaches, Models, and Practices in Renewable Energy Adoption

Solar and Wind Power Deployment

Solar photovoltaic and wind power generation have become the two fastest-growing components of the global electricity mix. According to the IEA's Global Energy Review 2025^[6], the expansion of solar PV capacity was the single largest contributor to meeting rising global electricity demand in 2024, a pattern consistent with a broader shift in which nearly all growth in electricity generation is now being met by low-emissions sources (IEA, 2025). This growth has been driven by a combination of falling technology costs, supportive policy frameworks, and the increasing competitiveness of renewables relative to fossil-fuel generation in most markets. Regional patterns nonetheless diverge considerably: the European Union recorded a marked decline in energy-related emissions in 2024^[2] as wind and solar together surpassed the combined share of coal and gas in electricity generation, while several rapidly industrializing economies saw emissions continue to rise even as renewable capacity additions accelerated, reflecting the extent to which underlying demand growth can outpace the substitution of clean generation for fossil fuels (IEA, 2025)^[3].

Policy Instruments and Governance Frameworks

A substantial body of research links the pace of renewable energy adoption to the design of supporting policy instruments. Feed-in tariffs, renewable portfolio standards, tax credits, and carbon pricing mechanisms have each been shown to reduce financial barriers and correct for the systematic underpricing of the environmental costs of fossil fuel use, thereby improving the relative competitiveness of renewable technologies. A systematic review of environmental policy and renewable energy innovation found that the effectiveness of individual policy instruments is often contingent on how they are combined, with policy mixes that integrate regulatory, financial, and market-based measures generally outperforming single-instrument approaches, and identified carbon taxation in particular as an underexplored lever for stimulating renewable innovation (Rastegar, 2024)^[9]. Governance capacity also matters: countries with coherent long-term energy strategies and stable investment partnerships, such as Morocco's program to reach a very high renewable share of electricity generation by mid-century, tend to exhibit more predictable and sustained transition trajectories than countries where policy signals shift frequently (Joshi *et al.*, 2025)^[7].

Energy Storage and Grid Integration

Because solar and wind generation are inherently variable, their large-scale integration into electricity grids poses

distinct technical challenges related to voltage stability, power quality, and the matching of supply with demand. Recent engineering reviews emphasize that overcoming these challenges depends on a combination of advanced forecasting, flexible grid operation, and expanded energy storage capacity, particularly lithium-ion battery systems, alongside complementary strategies such as demand response, cross-border interconnection, and, in the longer term, long-duration storage technologies (Che *et al.*, 2025)^[3]. Global battery storage capacity has grown rapidly over the past decade, and markets with higher levels of storage penetration have demonstrated measurable operational benefits, including lower system operating costs and reduced curtailment of renewable generation. Even so, storage deployment still represents a small fraction of installed generation capacity worldwide, and grid infrastructure investment in many regions has not kept pace with the speed of renewable capacity additions, creating what several reviewers describe as a widening technological gap between generation and the infrastructure needed to accommodate it (Che *et al.*, 2025)^[3].

Financing Mechanisms and Investment Models

The scale of capital required for a global energy transition is substantial, and access to affordable financing has emerged as a decisive factor shaping where and how quickly renewable energy is adopted. Modeling work using an ensemble of climate-energy-economy models found that the cost of capital for renewable energy projects is systematically higher in developing regions than in wealthier ones, even for comparable projects and risk profiles, and that narrowing this financing gap would meaningfully increase renewable electricity generation, reduce electricity expenditure burdens, and improve equity in access to modern energy services in the developing world (Calcaterra *et al.*, 2024)^[2]. Innovative financing approaches, including blended finance structures that combine public and concessional capital with private investment, and international climate finance mechanisms, have been identified as important tools for de-risking early-stage renewable projects in lower-income settings, though their availability remains inconsistent across countries and technologies (Calcaterra *et al.*, 2024)^[2].

Community Engagement and Social Acceptance

Technical and economic viability alone do not guarantee that renewable energy projects will be built or accepted by the communities that host them. Research on social acceptance distinguishes between broad sociopolitical support for renewable energy, which tends to be high across most surveyed populations, and localized community acceptance of specific siting decisions, which is often more contested and shaped by perceptions of procedural fairness, the distribution of costs and benefits, and prior experience with development projects (Segreto *et al.*, 2020; Hazrati, 2024)^[4, 10]. Case studies of community-led and government-led renewable energy projects in Lesotho found that meaningful early involvement of host communities in planning and decision-making was associated with stronger long-term project sustainability, whereas top-down approaches that treated communities as passive recipients tended to generate friction and weaker buy-in (Tsoeu-Ntokoane *et al.*, 2023)^[11]. A related literature review on

community engagement and equity concluded that project developers who invest in early, sustained, and culturally appropriate engagement processes are more likely to avoid delays and cancellations linked to community opposition, and that equitable distribution of project benefits is a distinct consideration from simply ensuring procedural participation (National Renewable Energy Laboratory, 2023) ^[8].

Evidence on Effectiveness

The empirical literature offers converging evidence that renewable energy adoption is associated with reduced carbon emissions, though the strength and consistency of this relationship vary by context. Panel data analyses comparing developing and developed economies generally find that greater reliance on renewable energy is associated with lower per-capita carbon dioxide emissions, while nonrenewable energy consumption remains a dominant driver of emissions growth in most regions (Frontiers, 2024, as cited in Joshi *et al.*, 2025) ^[7]. At the global level, the IEA estimates that the continued deployment of clean energy technologies avoided billions of tonnes of additional carbon dioxide emissions in 2024 alone, and that without this deployment the increase in global emissions over the preceding five years would have been substantially larger (IEA, 2025) ^[3].

Beyond emissions, a growing body of research links renewable energy expansion to broader sustainable development outcomes. A systematic review examining renewable energy's relationship to the full set of Sustainable Development Goals found that its contributions extend well beyond the energy-specific goal, with documented links to poverty reduction through expanded energy access, improved public health through reductions in fossil-fuel-related air pollution, and economic growth through investment and employment in the renewable energy sector, while also noting that these relationships are not uniformly positive and can involve trade-offs, such as land-use conflicts or the environmental footprint of critical mineral extraction for renewable technologies (Almulhim & Abubakar, 2026) ^[1]. Studies focused on Organisation for Economic Co-operation and Development countries similarly report that higher renewable energy shares are associated with lower per-capita emissions alongside continued economic growth, suggesting that the widely discussed trade-off between decarbonization and growth is not inevitable, though the relationship appears sensitive to a country's stage of development and the composition of its energy mix.

The evidence on renewable energy's economic effects is more heterogeneous than the emissions evidence. Some panel studies find that renewable energy consumption correlates positively with GDP per capita, particularly in middle-income economies where energy access itself is a binding constraint on growth, while others find weaker or more context-dependent associations, especially in economies where renewable deployment remains a small share of total energy supply. This heterogeneity underscores that renewable energy adoption is best understood as a necessary but not sufficient condition for sustainable development, whose ultimate effectiveness depends heavily on complementary investments in grid infrastructure, workforce development, and institutional capacity.

Barriers and Challenges to Implementation

Despite substantial progress, the literature identifies a consistent set of barriers that continue to constrain renewable energy adoption, spanning technical, financial, social, and institutional dimensions.

Technical barriers center on the intermittency of solar and wind generation and the corresponding strain this places on grid stability, power quality, and reliability, particularly in systems that were originally designed around steady, dispatchable fossil-fuel generation. Reviews of grid integration challenges note that while forecasting tools, flexible operations, and storage technologies can mitigate these effects, deployment of these complementary technologies has often lagged behind the pace of renewable capacity additions, leaving a persistent technological gap in many power systems (Che *et al.*, 2025).

Financial barriers remain especially pronounced in developing and emerging economies. High upfront capital costs, combined with elevated perceived investment risk, translate into a systematically higher cost of capital for renewable projects in lower-income countries compared with otherwise similar projects in wealthier ones, which in turn slows deployment and raises the effective cost of decarbonization for the countries least able to absorb it (Calcaterra *et al.*, 2024). Limited access to blended and concessional finance, underdeveloped domestic capital markets, and currency risk compound these challenges (Calcaterra *et al.*, 2024).

Institutional and regulatory barriers include fragmented or inconsistent policy frameworks, weak grid governance, limited technical and administrative capacity within energy ministries and utilities, and, in some contexts, continued fossil fuel subsidies that distort relative pricing in favor of incumbent generation sources. A systematic review of developing-country energy transitions found that structural and institutional constraints, including weak regulatory frameworks and limited human capital, disproportionately affect the Global South and are not adequately captured by models that focus narrowly on technological or resource endowments (Joshi *et al.*, 2025).

Social barriers relate to the uneven distribution of project benefits and costs and to gaps in meaningful community participation in siting and planning decisions. Even where general public support for renewable energy is high, opposition to specific local projects can arise when communities perceive that they bear disproportionate costs, such as landscape or environmental impacts, without a commensurate share of the economic benefits, or when they are engaged only after key decisions have already been made (Hazrati, 2024; National Renewable Energy Laboratory, 2023). These dynamics point to social acceptance as a distinct implementation risk that is not resolved simply by demonstrating a project's technical or economic merit.

Discussion and Implications

Taken together, the reviewed literature suggests that renewable energy adoption has become a central and largely effective mechanism for advancing environmental sustainability, with reasonably strong evidence linking

renewable energy deployment to reduced carbon emissions across diverse country contexts. Its broader contribution to the full range of sustainable development objectives is more conditional, depending on complementary investments in infrastructure, finance, and governance, and on deliberate attention to the distribution of costs and benefits among affected communities. This pattern carries several implications.

For policymakers, the evidence points toward the value of integrated policy mixes rather than single instruments, combining market-based mechanisms such as carbon pricing with targeted financial support and streamlined permitting, while also investing directly in grid modernization and storage capacity to keep pace with generation growth. For financial institutions and development agencies, the persistent gap in the cost of capital between developed and developing economies suggests that blended finance and risk-sharing mechanisms deserve continued attention as tools for narrowing global disparities in the pace of the energy transition, since financing costs rather than resource availability increasingly appear to be the binding constraint in many lower-income settings (Calcaterra *et al.*, 2024) ^[2]. For project developers and local governments, the literature on social acceptance suggests that early, sustained, and equity-conscious community engagement functions less as an optional add-on and more as a practical risk-management strategy that can reduce delays and cancellations.

The review also points to several areas warranting further research. Comparatively little longitudinal evidence exists on how renewable energy investments translate into local economic development outcomes, such as employment quality and community-level income effects, as opposed to aggregate national indicators. Similarly, while social acceptance research has matured considerably, most empirical studies remain concentrated in European and North American contexts, leaving open questions about how findings generalize to the institutional and cultural settings of the Global South, where the bulk of future energy demand growth is expected to occur.

Conclusion

Renewable energy adoption has advanced substantially over the past several years, driven by falling technology costs, supportive policy frameworks, and an increasingly urgent climate imperative. The evidence reviewed here indicates that this expansion has made a measurable contribution to reducing carbon emissions and, in many contexts, to advancing broader sustainable development objectives, though the strength of these relationships depends on a country's financial capacity, institutional strength, and approach to community engagement. Technical constraints related to grid integration, persistent disparities in financing costs between developed and developing economies, and uneven social acceptance of local projects remain the principal obstacles to faster and more equitable adoption. Addressing these barriers will require coordinated action that extends well beyond deploying generation capacity alone, encompassing investment in storage and grid infrastructure, mechanisms to reduce the cost of capital in lower-income countries, and governance approaches that treat affected communities as genuine partners in the planning process rather than as an afterthought. As the global energy system continues its transition, sustained

attention to these interconnected dimensions will be essential if renewable energy is to fulfill its potential as a foundation for sustainable development rather than a narrowly environmental achievement.

References

1. Almulhim AI, Abubakar IR. The role of renewable energy in achieving the Sustainable Development Goals: A systematic review and conceptual framework. *Renewable and Sustainable Energy Reviews*, 2026.
2. Calcaterra M, Aleluia Reis L, Fragkos P, Briera T, de Boer HS, Egli F, et al. Reducing the cost of capital to finance the energy transition in developing countries. *Nature Energy*, 2024;9(10):1241–1251. <https://doi.org/10.1038/s41560-024-01606-7>
3. Che EE, Abeng KR, Iweh CD, Tsekouras GJ, Fopah-Lele A. The impact of integrating variable renewable energy sources into grid-connected power systems: Challenges, mitigation strategies, and prospects. *Energies*, 2025;18(3): Article 689. <https://doi.org/10.3390/en18030689>
4. Hazrati M. Social acceptance for renewable energy technologies: The role of the energy justice framework. *The power of energy justice & the social contract*, 2024.
5. International Energy Agency. Major growth of clean energy limited the rise in global emissions in 2023. *International Energy Agency*, 2024. <https://www.iea.org/news/major-growth-of-clean-energy-limited-the-rise-in-global-emissions-in-2023>
6. International Energy Agency. Global energy review 2025. *International Energy Agency*, 2025. <https://www.iea.org/reports/global-energy-review-2025>
7. Joshi S, Sharma M, Kumar A, Joshi T, Johri A, Alfehaid M. Sustainable energy transition towards decarbonization among developing countries: A systematic literature review. *Frontiers in Sustainability*, 2025;6: Article 1641299. <https://doi.org/10.3389/frsus.2025.1641299>
8. National Renewable Energy Laboratory. Community engagement and equity in renewable energy projects: A literature review. U.S. Department of Energy, 2023. <https://www.nrel.gov/docs/fy23osti/87113.pdf>
9. Rastegar A. The impact of environmental policy on renewable energy innovation: A systematic literature review and research directions. *Sustainable Development*, 2024. <https://doi.org/10.1002/sd.2884>
10. Segreto M, Principe L, Desormeaux A, Torre M, Tomassetti L, Tratzi P, et al. Trends in social acceptance of renewable energy across Europe—A literature review. *International Journal of Environmental Research and Public Health*, 2020;17(24): Article 9161. <https://doi.org/10.3390/ijerph17249161>
11. Tsoeu-Ntokoane S, Kali M, Lemaire X. Community engagement and sustainability: Two cases of implementation of mini-grids in Lesotho. *Oxford Open Energy*, 2023;2: Article oiad002. <https://doi.org/10.1093/ooenergy/oiad002>