



Renewable energy technologies for sustainable power generation: A review

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Abstract

The global electricity sector is moving away from fossil fuels at a pace that was hard to imagine a decade ago, and renewable energy technologies sit at the centre of that shift. This review examines the main renewable options for sustainable power generation, namely solar photovoltaics, wind, hydropower, bioenergy and geothermal energy, together with the storage and grid measures that allow them to supply dependable electricity. Drawing on peer-reviewed review articles and official capacity statistics published between 2022 and 2026, the paper summarises technology status, evidence on deployment effectiveness and the barriers that slow implementation, with particular attention to India. The evidence shows that solar and wind now account for almost all net renewable additions worldwide and that India has passed 300 GW of non-fossil capacity. However, installed capacity alone does not guarantee clean generation. Grid congestion, curtailment, storage costs and uneven regional access remain the main constraints. The review concludes that sustainable power generation depends less on any single technology than on coordinated investment in generation, storage, transmission and policy. Implications for Indian planners and directions for future research are discussed.

Keywords: Renewable energy, sustainable power generation, solar photovoltaics, wind energy, energy storage, grid integration, India

Introduction

Electricity generation is one of the largest sources of greenhouse gas emissions, which is why decarbonising it is treated as the first step in most climate strategies. Renewable energy technologies offer a way to cut those emissions while improving energy security and, in many markets, reducing generation costs. Østergaard *et al.* (2022) describe the research field as broad, spanning resource assessment, conversion technologies, integrated energy systems and the contribution of renewables to the Sustainable Development Goals. Ang *et al.* (2022) add that, according to International Energy Agency reporting, fossil-fuel use for electricity began to fall from 2019 while renewable use grew to meet rising demand.

The scale of change since then is striking. The International Renewable Energy Agency (IRENA, 2025) recorded 585 GW of new renewable capacity in 2024, and its 2026 statistics show a further 692 GW in 2025, taking the global total to roughly 5,150 GW (IRENA, 2026). For a fast-growing economy such as India, the stakes are especially high, because demand is rising quickly and the country has committed to 500 GW of non-fossil capacity by 2030 (Outlook Business, 2026). This paper has four aims: to outline the principal renewable technologies, to assess the evidence on how effective they have been, to identify the barriers to implementation, and to draw implications for India.

Review Approach

This paper is a targeted narrative review rather than a formal systematic review. Searches were run in October 2026 using combinations of terms such as renewable energy technologies, sustainable power generation, grid integration, energy storage and India renewable capacity. Publications from 2022 to 2026 were preferred. Two kinds of source were retained: peer-reviewed review articles that map

technologies and challenges, and official or institutional statistics that report deployment. Where journal literature had not yet caught up with very recent developments, credible trade and news reports of official announcements were used and flagged as such. Sources without identifiable authorship or a clear basis for their figures were excluded. The main limitation is the modest number of sources, so the review should be read as a structured overview rather than an exhaustive census of the literature.

Major Renewable Technologies

Ang *et al.* (2022) surveyed solar, hydro, wind, bioenergy, geothermal and hydrogen technologies, along with several hybrid configurations, and concluded that each faces its own mix of economic, technical and efficiency limits. The subsections below follow that technology-by-technology logic and update it with recent deployment data.

1. Solar Photovoltaics

Solar photovoltaics (PV) are now the dominant renewable technology. IRENA (2026) reports that PV supplied 510.3 GW of the 511.2 GW of solar capacity added in 2025, and industry reporting based on the same data puts total solar capacity at about 2,397 GW, or 46.5% of all renewable capacity (Mercom India, 2026). Research effort is moving beyond conventional silicon. A recently announced two-terminal perovskite-silicon tandem cell reached a certified efficiency of 35.5%, although it remains a laboratory result and its developer has no active mass-production plan for it (pv magazine, 2026). Tandem designs therefore look promising for the next generation of modules, but they are not yet a deployed solution.

India's solar expansion has been especially rapid. Installed solar capacity rose from 2.82 GW in 2014 to 150.26 GW by March 2026 (IANS, 2026) and to 164.59 GW by the end of July 2026 (Outlook Business, 2026).

2. Wind Energy

Wind power added a record 158.7 GW worldwide in 2025, 14% more than in 2024 (IRENA, 2026). In India, wind installations reached a record 6.05 GW in the 2025-26 financial year, taking cumulative capacity beyond 56 GW (Enerdata, 2026). The same report links this growth to policy instruments, including concessional customs duty on turbine components, competitive bidding, a separate wind renewable consumption obligation and a graded waiver of inter-state transmission charges until June 2028. The Indian case suggests that wind growth responds strongly to policy design as well as to resource quality.

3. Hydropower, Bioenergy and Geothermal Energy

These technologies grow more slowly but supply different system services. IRENA (2026) reports that renewable hydropower grew by 18.4 GW in 2025, mostly in China, while bioenergy added 3.4 GW and geothermal only 0.3 GW. Their value lies less in volume than in firmness: hydropower reservoirs and biomass plants can be scheduled, which helps balance variable solar and wind output. India's hydropower stood at 57.24 GW and bio-power at 11.75 GW in July 2026 (Outlook Business, 2026), so both contribute meaningfully to a diverse non-fossil portfolio.

4. Energy Storage and Hybrid Systems

Storage has become the technology that makes high shares of solar and wind workable. Deguenon *et al.* (2023) reviewed electrochemical battery storage and concluded that, depending on system characteristics, batteries could support variable renewable penetration of about 40-50%. They also proposed incentive approaches for weakly interconnected grids. In India, solar developers have begun adding batteries to PV projects to attract buyers and limit the curtailment that grids cannot absorb (Oilprice.com, 2026). Ang *et al.* (2022) similarly found that hybrid renewable configurations can improve overall generation performance compared with single-source plants.

Evidence on Effectiveness

Deployment data show that renewables are now the main source of new power capacity. They made up 92.5% of global capacity additions in 2024 (IRENA, 2025) and 85.6% in 2025, with solar and wind together responsible for 96.8% of net renewable additions (IRENA, 2026). Variable renewables had reached about 35.4% of installed capacity worldwide, and renewables as a whole about 49.5% (Mercom India, 2026).

India's results follow the same direction. The country added a record 55.3 GW of non-fossil capacity in 2025-26, compared with 29.5 GW the year before (IANS, 2026), and reached 50% non-fossil installed capacity in June 2025, five years ahead of its Paris Agreement target. By 31 July 2026, non-fossil capacity stood at 300.50 GW, more than 54% of an installed base of about 552 GW (Outlook Business, 2026). Listed domestic solar module manufacturing capacity has also passed 200 GW, which reduces dependence on imports (OpenGov Asia, 2026).

These figures should be read carefully. Capacity is not the same as generation, because solar and wind plants produce electricity only part of the time, so a 50% capacity share does not translate into a 50% share of electricity supplied. IRENA (2025) also warns that, despite record additions, the world is not on track to triple renewable capacity to about

11 TW by 2030, a goal that would need additions above 1,120 GW each year. Effectiveness is therefore strong in direction but still short of the pace required.

Barriers and Challenges to Implementation

The first barrier is the grid. Reporting on India notes that transmission expansion is moving more slowly than renewable installation, which has increased curtailment and could slow further growth (Oilprice.com, 2026). Variability is a related technical problem: Deguenon *et al.* (2023) stress that growing shares of intermittent solar and wind strain the stability and reliability of power systems, and that weak grids are particularly exposed.

The second barrier is uneven access. IRENA (2025) noted that small island developing states hold only 0.2% of global renewable capacity, and Asia delivered 74.2% of new capacity in 2025 (IRENA, 2026). Deployment is therefore concentrated in a few regions, leaving others behind.

The third group of barriers concerns technology readiness and economics. Ang *et al.* (2022) identify economic, technical and conversion-efficiency limitations across the technologies they reviewed, and the tandem solar example shows how a laboratory breakthrough can remain far from commercial supply (pv magazine, 2026). Battery storage, while promising, still has to be paired with suitable incentives and market rules to become widely adopted (Deguenon *et al.*, 2023). The sources reviewed here say comparatively little about financing and land acquisition, which practitioners often raise as obstacles, and this gap is itself worth noting for future work.

Discussion and Implications

Taken together, the evidence points to a shift in what counts as progress. The first phase of the transition was about adding generating capacity, and the figures above show that phase is succeeding. The next phase is about making that capacity useful, which requires transmission lines, storage, flexible demand and market rules that reward reliability. India's experience of curtailment alongside record installations illustrates why capacity targets alone are an incomplete measure.

Several implications follow for Indian planners. Transmission planning should be synchronised with renewable auctions so that new plants are not stranded. Co-locating storage with solar and wind, as developers are already starting to do, should be encouraged through clear tariff signals. Policy continuity matters, since the wind sector's recent growth followed a defined package of incentives (Enerdata, 2026). Domestic manufacturing strengthens supply security, but it needs to be matched by attention to module quality and end-of-life management.

For researchers, the main gaps are generation-based performance measures, lifecycle environmental impacts, and financing and land-use constraints, which the reviewed literature addresses only lightly. Future studies would also benefit from regional analyses of Indian states, since grid conditions and resource quality differ widely.

A further implication concerns how success is communicated. Headline capacity milestones are useful for tracking policy targets, but students, analysts and policymakers should pair them with indicators such as share of electricity generated, curtailment rates, storage capacity and transmission availability. Reporting a fuller set of indicators would give a more honest picture of whether the

transition is delivering reliable, low-carbon electricity to consumers across different states and income groups.

Conclusion

Renewable energy technologies have moved from being an alternative to being the default choice for new power capacity. Solar and wind lead this growth, hydropower and bioenergy provide firmness, and storage is increasingly the link that keeps the system reliable. India's rapid progress towards its 2030 non-fossil target shows what coordinated policy can achieve. Yet the evidence also shows that sustainable power generation is limited by grids, storage, uneven access and technology readiness rather than by the availability of resources. Future progress will depend on treating generation, storage, transmission and policy as a single system.

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