# Green Technology Pathway for Pakistan's Energy Future

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Economic managers in Pakistan are dealing with a tough set of challenges: heavy reliance on imports and limited foreign exchange reserves are straining the economy; rising debt-to-GDP ratio caused by fiscal deficits, high interest payments, and currency fluctuations; the ongoing 25th IMF program and its conditions are adding pressure; and climate-related vulnerabilities are further complicating matters.

Energy-sector issues are central to these economic and environmental challenges. The country is dependent on imported fossil fuels. There are governance issues, technical and non-technical inefficiencies, and a surplus of installed capacity with a capacity payment burden. Above all, there is the long-standing issue of circular debt (PKR 1.7 trillion as of September 2025), which has led to higher tariffs that consumers ultimately have to shoulder.

Pakistan adds little to global greenhouse gas emissions, but it is highly susceptible to climate change. This year, the government submitted the third version of Nationally Determined Contributions (NDC 3.0), voluntarily promising to cut emissions by up to 50% by 2035. A window of great opportunity is available for Pakistan: adopting green energy technologies, such as solar, wind, biogas, green hydrogen, energy storage, and smart grids, can help the country meet its NDC 3.0 targets, provide reliable, affordable energy, and ease economic burdens. Therefore, charting a green technology pathway is highly imperative for Pakistan's energy future.

In the Green Future Index (2023) released by MIT Technology Review, which assesses countries across five areas: carbon emissions, energy transformation, a green society, clean innovation, and climate policies, Pakistan is at the 67th position out of 76 countries, down from 55th in 2022 (*Memon, 2023)*.

Countries like China and Denmark are investing in green innovations. They are creating new industries, increasing exports, improving energy security, and lowering their fossil fuel consumption *(EMBER, 2025; IRENA, 2025)*. These green technologies are helping them to achieve their set climate goals and transform their economies. The same approach should be adopted by Pakistan for energy security and to steer economic growth.

Moreover, the energy transition in Pakistan is rolling fast. Yet, it ranks 101 out of 118 in the World Economic Forum's 2025 Energy Transition Index. Its ranking is well below that of regional peers: Bangladesh is at 86, India at 71, Vietnam at 49, Cambodia at 73, and Indonesia at 58. Not to mention China, which is at 12. Against the global average of 56.9, Pakistan's score is 48.5.

Pakistan has vast potential for renewable energy sources, but what is missing is its readiness for the future, which we will discuss in this article.

## Renewable Energy Adoption–Current Status

Pakistan has rapidly become one of the world's top 10 solar markets, fueled mainly by market forces and some government policies. Solar photovoltaic (PV) provided about 25.3% of the country's utility-supplied electricity in FY2025. This has made Pakistan one of the few countries generating over a quarter of its energy from solar sources *(Maguire, 2025)*. An estimate from a study conducted by Renewable First suggests that Solar-PV attracted $17 to $19 billion in private investment from FY2017 to FY2025 *(Ayub, 2025)*.

As of September 2025, the government reported that renewable energy sources — hydro, wind, solar, and bagasse — accounted for over 46% of the energy mix, surpassing this year's target *(Energy Update, 2025)*. Now there are operational wind farms in Sindh and Baluchistan, and a growing capacity for net-metering (NM) (on-grid rooftop solar). NM capacity has reached 5.7 gigawatts (GW) as of June 2025, as households and businesses are increasingly opting for solar PV to minimize the impact of rising grid tariffs *(Malik, 2025)*.

In addition, there has been a significant increase in off-grid and behind-the-meter solar PV systems. In 2024, Pakistan imported about 17 GW of solar modules from China; almost 11–12 GW of these were off-grid and behind-the-meter *(Malik, 2025)*. From July 2024 to March 2025, another 12.7 GW of solar PV modules were imported. This is enormous given the country's existing total installed capacity of 46.6 GW *(ET, 2025)*. Solar PV has increased access and minimized the tariff burden for those who can afford it. Its influx and an increase in NM capacity have diversified the installed capacity mix. Moreover, increasing adoption of solar at the grassroots level (off-grid and behind-the-meter) is also a positive sign. In other words, green technology adoption has increased, but significant structural and institutional weaknesses remain, particularly in policy, infrastructure, innovation capacity, local production, and the investment environment. Grid challenges have also increased. These factors are responsible for lowering Pakistan's global ranking in transition readiness.

Localization of green energy technology is a worrying problem. The industry mostly assembles mounting structures, and depends on imports for solar panels, PV cells, wind turbines, inverters, and battery storage. This dependence has made green technology adoption expensive and susceptible to fluctuations in the rupee's value, weakening long-term sustainability and increasing the risk of disruptions in the supply chain. The local industry has been unable to compete with imports; insufficient advanced equipment and skilled labor are the major constraints. These deficiencies sometimes result in defective products. The key to improvement is the transfer of technology and expertise to Pakistan, which has remained limited *(Memon, 2025)*.

The current grid infrastructure is not ready for integrating renewables. As the number of NM consumers has increased, the reverse flow issues in Distribution companies (DISCOs) also increased. Hosting Capacity Analysis and a transformer monitoring system are absent in these DISCOs. Globally, investment in grid infrastructure touched $390 billion in CY2024 and is expected to exceed $400 billion in CY2025 (20% above the past decade). However, financial constraints have impeded utilities from investing in grid upgrades *(Malik, 2025)*.

Integrating intermittent renewable energy into Pakistan's grid requires improvements in grid management, energy storage, forecasting, regulatory frameworks, and human capacity development. For years, the grid has suffered from high system losses, reliance on inefficient thermal power, and inadequate financial discipline. All these factors are delaying the shift to greener energy. Moreover, installed renewable capacity often underperforms due to transmission bottlenecks and scheduling challenges.

## Green Innovation Initiatives

Some efforts are in progress, for example, the establishment of the Green Tech Hub (G-TH) at the National University of Sciences and Technology (NUST) to support green technology startups and innovations *(NUST, 2024)*; completion of resource assessment, turbine siting, and design for a 200 MW hybrid project by SGS *(SGS, 2025)*; K-Electric successfully showcased market innovation in green energy by launching a hybrid project (solar and wind energy) *(Energy Update, 2024)*; and K-Electric's Energy Progress and Innovation Challenge 2025, which intends to promote localized innovation *(Rizvi, 2025)*. The Ministry of Science and Technology recently inaugurated a PV Modules Testing Laboratory in collaboration with Korea to ensure PV quality in line with international standards *(PID, 2025)*.

## Barriers to Green Technology

1) **Technological Constraints -** Expenditure on R&D has remained extremely low in Pakistan (0.3% of GDP) compared to its regional competitors *(Rizvi, 2025)*. Labs supporting research in battery storage, power electronics, smart grids, or renewable resource modeling are either absent or inadequate at universities. The industry-academia disconnect has led to research that hardly serves a commercial purpose.

   The Alternative and Renewable Energy Policy announced in 2019 did supported local manufacturing, but weaknesses on the implementation side, along with insufficient R&D expenditure by the government, have impeded progress. The shutdown of the Pakistan Council of Renewable Energy Technologies; the underutilization of SEZs under CPEC; ineffective technology transfer agreements, have all deterred innovation *(Memon, 2025)*.

2) **Limited Finance -** Green projects have high upfront costs and low and riskier returns; tight liquidity and the financial sector's preference for conventional thermal energy projects are the reasons behind the limited financing for innovation and technology. Venture capital investment in green technology is also low; the green bond market is underdeveloped and import restrictions have made it more expensive to adopt this technology.

3) **Inconsistent Policy and Governance -** Some recent developments on the regulatory and policy front, such as renegotiations and terminations of power purchase agreements, ambiguities about the NM policy, and fear of abrupt tariff adjustments, have discouraged investors. Inconsistencies in policy and regulations are a significant impediment to innovation in Pakistan. Bureaucratic procedures are delaying pilot projects and approvals for green technologies. The existing utility staff and other relevant personnel have little experience with green technologies.

The lack of a clear national innovation agenda has led to disjointed efforts by federal and provincial governments, ministries, regulators, universities, and private businesses.

4) **Structural and Market Challenges -** Financial problems persist in DISCOs and have been doing so for years. This is the reason they are showing reluctance in the way of the adoption of new technologies. The power system is centralized, with limited acceptance of distributed generation. Consumers currently show little demand for innovation, as there is less awareness about the value of energy efficiency and green technology; customers are embracing solar energy to escape higher costs from the energy grid. The absence of widespread certification labs and standards for solar equipment has further undermined quality and consumer confidence.

5) **Limited Skilled Professionals -** Lack of expertise in AI-enabled grid control systems, renewable energy engineering, energy storage solutions, EV infrastructure, and more has impacted innovation capability. Brain drain in engineering and research talent has diminished innovation. Regulatory hurdles, lack of mentorship, and limited incubation facilities have constrained entrepreneurship in the clean energy sector.

## Way Forward

The first prerequisite for green energy pathways is to invest in smart grids along with advanced metering infrastructure (AMI) and a state-of-the-art Supervisory Control and Data Acquisition (SCADA) system at the utility level. Pakistan's overall power system needs flexible transmission systems, real-time data analytics, and battery storage solutions to maximize the absorption of renewable energy and to minimize system losses. In parallel, the priority should be to address governance inefficiencies. The renewal and implementation of grid codes is also essential for grid modernization.

Second, we need to strengthen our industry. The government should design policies that incentivize industry to grow, produce high-quality products, and also compete globally. This is the only way to cut imports; it will also create jobs in the country. At the same time, setting and implementing robust quality standards is important for building trust in the products made in Pakistan. Only in this way can we provide better and cheaper options for our consumers and ensure sustainable economic growth.

Third, indigenization without innovation is not possible! Develop SEZs with incentives for collaboration between businesses and universities for technology transfer. It is equally important to increase government funding for research and skill development to encourage innovation in renewable energy, energy storage, smart grids, and clean energy services in universities. Initiatives such as green skills academies and national technical training programs should be established.

Fourth, the availability of finances is paramount for technology transfer and indigenous development. Global capital is rapidly shifting towards green projects; Pakistan needs to show readiness for innovation through a cogent strategy and a business plan to attract concessional finance. A green innovation fund can be a good option for supporting startups, universities, and research centers.

The financial industry, especially banks, is a key player in the market for green energy projects. However, they are reluctant to participate because of high risks and low returns associated with green lending. Experts have argued in favor of implementing efficient risk-sharing mechanisms and creating formal secondary markets for green energy products *(Jamal, 2024)*.

There are several other green financing options, e.g., green bonds, green sukuks, revolving funds, and specialized models to encourage private investors; they require regulatory support from SECP and SBP. There are successful examples of balanced public-private partnerships to learn from, such as the solar home system in Bangladesh and the Surya Shakti Scheme in India.

Pakistan needs more programs like G-TH, with support from both the government and the private sector; international donors should also be approached to help grow these initiatives. Pakistan is making progress, but achieving sustainability requires innovation in green technologies suited to domestic conditions; policies need to evolve to support research and capacity building for a green transition.

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