Solar Energy Advancements and Deployment Strategies in Kwara State, Nigeria: A Comprehensive Review

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Abstract: Solar energy has emerged as a pivotal solution to Nigeria's chronic electricity supply challenges, particularly in underserved regions like Kwara State. This review examines the current state, technological advancements, policy frameworks, and socio-economic factors influencing solar energy deployment in Kwara State. Drawing on recent empirical and review-based literature, the paper highlights adoption barriers, including limited financing, regulatory gaps, and socio-cultural factors. Findings indicate an increasing interest in Solar Home Systems (SHS), particularly in off-grid communities, but underscore the need for policy alignment, technical capacity, and community engagement to scale up deployment. The paper concludes with actionable recommendations aimed at researchers, investors, and policymakers.

1 INTRODUCTION

Energy is the backbone of economic development, industrial growth, and social welfare in any nation. In developing countries like Nigeria, the scarcity and unreliability of electricity hinder progress in health, education, agriculture, and manufacturing sectors. Despite being endowed with vast renewable resources, including solar, wind, biomass, and hydropower, Nigeria continues to experience chronic energy deficits. Approximately 45–50% of Nigerians still lack access to reliable electricity, with rural areas being disproportionately affected (Bamisile et al, 2017).

Solar energy, a clean, sustainable, and increasingly cost-effective source of power, presents a promising opportunity to bridge Nigeria's energy access gap. The country receives annual solar radiation ranging from 3.5 to 7.0 kWh/m²/day, with an average of about 6 hours of sunlight daily across most regions (Agbo et al, 2021). This positions Nigeria—and by extension, Kwara State—as a potential hub for solar energy deployment.

Kwara State, situated in the North Central geopolitical zone of Nigeria, is a semi-urban region characterized by substantial agricultural activity and moderate industrialization. While the state benefits from moderate solar irradiance and a relatively stable geographical landscape, many of its communities remain off-grid. Electrification rates vary widely between Ilorin (urban capital) and remote LGAs such as Baruten or Kaiama (Kehinde et al, 2022).

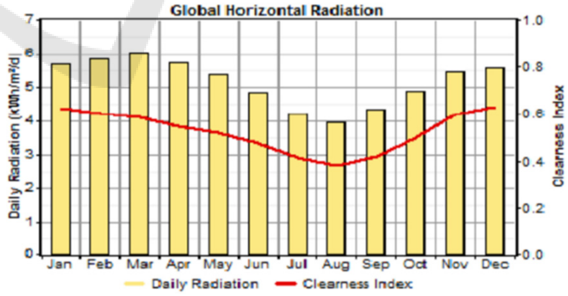

Figure 1. Solar radiation profile for Ilorin (Ajao et al, 2011).

Kwara has attracted interest from development partners and NGOs for solar-based rural electrification programs, but large-scale, government-driven solar initiatives remain limited. As such, Kwara represents both a microcosm of Nigeria's energy dilemma and a promising pilot region for scalable solar energy solutions.

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1.1 National and Global Renewable Energy Context

Globally, there has been a seismic shift toward renewables. The 2015 Paris Agreement and United Nations Sustainable Development Goals (SDG 7) have pushed countries to commit to universal access to affordable, reliable, sustainable, and modern energy by 2030. Solar photovoltaics (PV), with rapidly declining installation costs, have emerged as a leading technology in this transition.

Nigeria's energy policy, as outlined in the Renewable Energy Master Plan (REMP) and Electricity Vision 30:30:30, sets a goal to produce 30% of electricity from renewable sources by 2030. Solar is expected to contribute at least 15.27% of this target (Bamisile et al, 2017). Despite policy intentions, implementation challenges have hindered meaningful progress, especially at the state level.

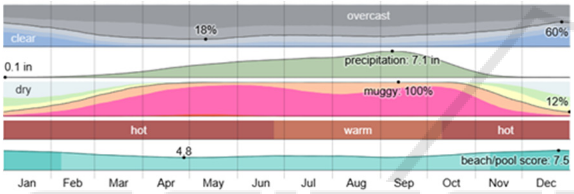

Figure 2. Monthly Solar Radiation in Ilorin, Kwara State (weatherspark.com).

1.2 Problem Statement

While Nigeria's solar potential is high, adoption remains limited due to a combination of technical, financial, socio-cultural, and regulatory barriers. In Kwara State, these issues manifest through high costs of solar systems, inadequate awareness among residents, and insufficient government-led initiatives. There is also limited data on how local socioeconomic factors such as education, income, and proximity to the national grid influence solar energy adoption (Ibrahim & Usman, 2019).

1.3 Research Aim and Objectives

The aim of this review is to analyse the current status, opportunities, and barriers to solar energy adoption in Kwara State. The paper seeks to:

- Examine the solar potential and technological advancements relevant to Kwara.
- Review the policy and institutional frameworks governing solar deployment.
- Analyse the socioeconomic determinants of Solar Home Systems (SHS) adoption.
- Identify barriers and enablers to sustainable solar energy scale-up.
- Offer evidence-based recommendations for policymakers, researchers, and investors.

1.4 Significance of the Study

This review contributes to both academic literature and policy discourse on decentralized renewable energy in Nigeria. By focusing on Kwara State—a region often underrepresented in energy studies—it provides localized insights with broader national implications. The findings could support:

- Targeted policy formulation and state-level energy planning.
- Informed investment in solar microgrids or SHS programs.
- Development of educational and technical capacity-building initiatives.

In Figure 3, a line plot shows relatively stable and high irradiance levels over three years, indicating consistent solar availability for PV systems. This confirms that Nigeria, including Kwara State, receives sufficient solar energy to support robust deployment of solar technologies.

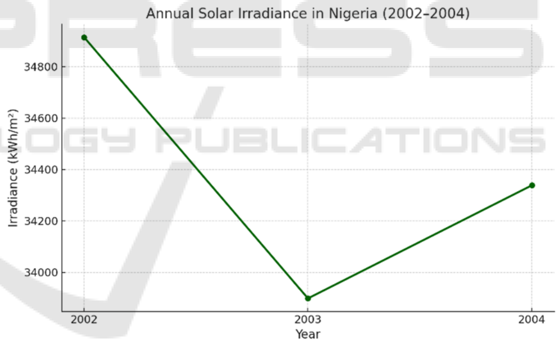

Figure 3. Annual Solar Irradiance in Nigeria (2002–2004) (Adapted from ERA5-Land Base Dataset (Idris et al, 2023).

1.5 Renewable Energy Goals and Solar Potential in Nigeria

Nigeria has one of the highest solar energy potentials in Sub-Saharan Africa due to its geographic location and climate. According to (Bamisile et al, 2017), the nation planned to generate 15.27% of its electricity from solar sources by 2030, a dramatic increase from just 1.26% in 2015 (Bamisile et al, 2017). Despite the robust availability of solar radiation (3.5–7.0 kWh/m²/day), the actual contribution of solar energy to Nigeria's energy mix remains limited due to infrastructural, policy, and financial barriers.

1.6 Status and Efficiency of Solar Energy Technologies

Technological advances in photovoltaic (PV) systems, including improved efficiency and durability, have made solar energy more accessible (Ojo et al, 2023). Note that innovations tailored to local climates, including off-grid and hybrid systems, are especially vital in Nigeria. The study stresses how crucial it is to develop solar solutions that suit each region's unique needs, with real-world examples taken from both Nigerian villages and colder regions like Canada (Ojo et al, 2023). Also, (Idris et al, 2023) looked at solar radiation data from 2002 to 2004, finding consistent readings above 33,000kWh/ m^2 per year across various areas. Their exploration of offshore solar power presents a novel opportunity for Nigeria's energy sector (Idris et al, 2023).

1.7 Socio-Economic Drivers and Constraints

In Nigeria, the uptake of solar technology is heavily influenced by socioeconomic conditions. A study involving 400 households in Kwara State used Tobit and Interval regression models to uncover key trends (Adamu & Oladipo, 2023).

It revealed that people with higher incomes and education levels were more likely to adopt Solar Home Systems (SHS). At the same time, those who were satisfied with their current energy supply were less motivated to switch (Adamu & Oladipo, 2023). Interestingly, rural communities far from the national grid were more drawn to SHS, valuing its dependable and self-sufficient nature over reliable grid power.

1.8 Policy and Regulatory Landscape

National initiatives, such as Nigeria's Renewable Energy Master Plan, provide a policy foundation; however, inconsistent regulations at the state level present significant barriers to the effective rollout of solar energy. As Agbo et al. (2021) highlight, despite growing recognition of solar energy as a practical option, progress is stalled by reliance on fossil fuels, a shortage of government incentives, and inadequate technical systems to support large-scale adoption (Agbo et al., 2021).

Moreover, the absence of cohesive monitoring systems and unclear licensing protocols discourages private investments in the solar sector, particularly in less urbanized states like Kwara.

1.9 Environmental and Economic Implications

All reviewed studies underscore the dual role of solar energy in environmental protection and economic empowerment. By reducing carbon emissions, solar energy addresses climate challenges. Economically, the promotion of solar technologies fosters job creation in installation, maintenance, and manufacturing sectors. Long-term cost savings from solar use also benefit both households and enterprises.

2 METHODOLOGY

This review adopted a narrative synthesis methodology, integrating both qualitative and quantitative data to assess the state of solar energy adoption in Kwara State, Nigeria. The study methodology is divided into five interrelated phases: defining research objectives, executing a systematic literature search, screening and selecting relevant studies, extracting key data, and synthesizing findings for analysis. A block diagram below is designed to illustrate the phases.

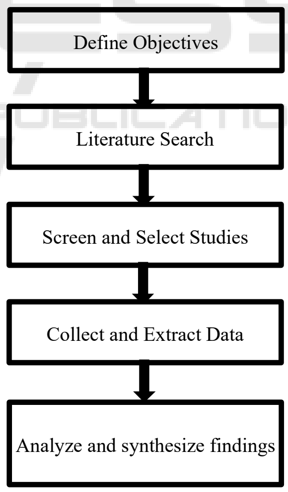

Figure 4. Block Diagram of Methodology Phases

Figure 5 offers a clear visual breakdown of the components (panel, controller, battery, inverter, load), enhancing the reader's understanding of the SHS architecture in the methodology and results discussion

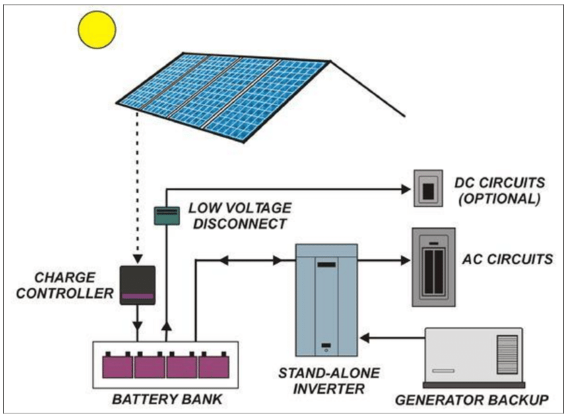

Figure 5: Off-Grid PV System Schematic

2.1 Defining Objectives

The first step in this review is to clearly establish the research objectives. The central aim of the study is to explore the status, advancements, and challenges of solar energy adoption in Kwara State. Specifically, the review investigates the region's solar potential, the technological and socioeconomic factors influencing adoption, existing policy frameworks, and the practical barriers to solar energy deployment. The objectives also encompass a review of interventions that can potentially scale up renewable energy penetration in rural and urban Kwara, making the study both academically relevant and policy informative.

2.2 Literature Search Strategy

A structured literature search was conducted to identify relevant peer-reviewed studies, reports, and datasets. Key databases, including Scopus, ScienceDirect, IEEE Xplore, and Google Scholar, were used, as well as the SciSpace AI database for enhanced coverage. Boolean logic and keyword combinations such as "solar energy AND Kwara State", "photovoltaic AND Nigeria", "solar barriers AND adoption", and "renewable energy AND policy Nigeria" were employed to filter search results.
The time frame for inclusion spanned from 2015 to 2024, ensuring the inclusion of the most recent and contextually relevant studies. Only English-language publications were considered. Emphasis was placed on empirical studies and review articles that analyzed solar technology deployment, policy frameworks, or behavioral adoption factors within Nigeria, with particular interest in regional contexts applicable to Kwara State.

2.3 Screening and Selection of Studies

An initial pool of 42 sources was identified. These were screened based on relevance to solar energy in Nigeria, especially at the state or community level. Inclusion criteria required that studies provide either data on solar irradiance, Solar Home System (SHS) adoption, or an assessment of policy and socioeconomic factors influencing solar uptake.
Studies focusing purely on other renewable energy types (e.g., wind or hydro) or those lacking methodological transparency were excluded. Following this process, five peer-reviewed articles were selected for detailed analysis, each offering a unique insight into the technical, behavioral, or institutional dimensions of solar energy adoption in Nigeria, and in some cases, specifically in Kwara.

2.4 Data Collection and Extraction

The selected studies were examined for both quantitative and qualitative data. Quantitative data included metrics such as solar irradiance levels (in kWh/m^2), SHS adoption rates among households, and demographic predictors of energy behavior (e.g., income or education). One of the key parameters extracted was the annual average solar irradiance for Kwara State, which consistently exceeds 33,000 kWh/m^2, reinforcing the state's viability for solar PV installations. To understand energy output from a typical solar panel, the following formula was employed:

$$E = A * r * H * P_R \tag{1}$$

Where:
E is the energy output (kWh/day)
A is the area of the solar panel (m^2)
r is the panel efficiency (e.g., 0.18 for 18%)
H is the average solar radiation ($kWh/m^2/day$)
P_R is the performance ratio, accounting for losses (~0.75)

For example, a 10 m^2 panel with 18% efficiency in Kwara, which receives 5.5 $kWh/m^2/day$ of sunlight, would generate:

$$E = 10 * 0.18 * 5.5 * 0.75 = 7.425 kWh / day \tag{2}$$

This calculation demonstrates that small-scale solar panels are capable of meeting basic household electricity needs in the region.

Qualitative data focused on institutional barriers, local perceptions, and the impact of education and policy initiatives on solar adoption. This dualpronged data collection ensured a holistic understanding of the landscape.

2.5 Data Synthesis and Analysis

The final step involved synthesizing the data to identify patterns, contradictions, and evidence-backed insights. The findings were grouped into three primary dimensions: technical feasibility (solar potential, PV calculations), socioeconomic influences (education, income, grid distance), and policy or institutional barriers (regulations, subsidies, governance). Cross-study comparisons enabled the extraction of recurring themes, such as the role of donor programs in SHS diffusion and the persistent gap in public awareness. This systematic approach enabled the generation of evidence-based recommendations and contextual insights into how solar energy can be more effectively deployed in Kwara State.

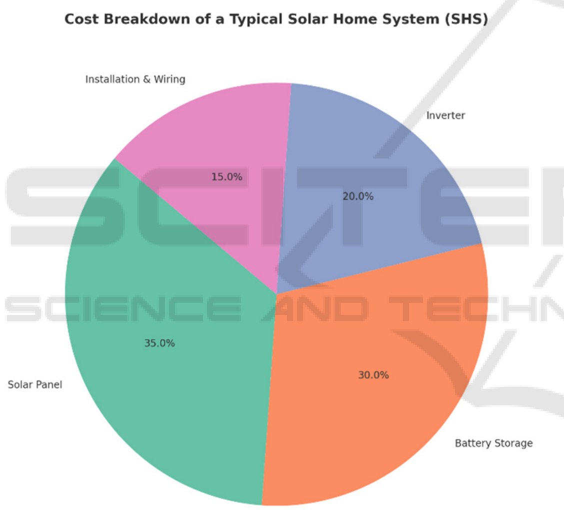

Figure 6. Cost Breakdown of a Typical Solar Home System (SHS).

This pie chart of Figure 6 illustrates the distribution of costs in a standard Solar Home System (SHS), highlighting that solar panels and battery storage account for the majority of expenses, contributing significantly to high upfront costs—one of the primary adoption barriers in rural Nigeria (Adamu & Oladipo, 2023).

3 RESULTS AND DISCUSSION

The findings highlight three major themes: the current adoption status of solar technologies, the determinants of adoption behavior, and the prevailing challenges inhibiting scale-up.

3.1 Adoption Trends of Solar Technologies in Kwara State

Solar Home Systems (SHS) remain the most common form of solar technology adopted in Kwara, especially in rural and peri-urban communities. The uptake is largely driven by necessity, particularly in off-grid regions where the national electricity grid is absent or unreliable. According to Adamu and Oladipo (2023), approximately 72% of off-grid households surveyed expressed willingness to adopt SHS, citing reliability and independence from the grid as key motivators (Ojo et al, 2023).

While donor-funded and NGO-supported projects (e.g., solar micro-grids) have had some success, they often lack sustainability mechanisms. Maintenance lapses and inadequate technical support frequently lead to project failures once donor funding ceases.

3.2 Socioeconomic Determinants of SHS Adoption

Data from a study of 400 households in Kwara State provides insight into the key adoption drivers:

- Income Level: Households with higher disposable income are significantly more likely to adopt SHS. The cost of full-system installation is a major barrier for low-income earners (Ojo et al, 2023).
- Educational Attainment: Literacy and awareness about energy options are strongly correlated with adoption. Educated households understand the long-term cost-benefit advantage of solar over diesel generators (Ojo et al, 2023).
- Proximity to Grid: Households located farther from the grid exhibit greater interest and willingness to pay for solar technologies due to a lack of alternatives.
- Satisfaction with Existing Supply: Interestingly, those who reported being "satisfied" with their current energy sources (e.g., fuel generators or partial grid access) were less likely to consider solar transitions (Ojo et al, 2023).

These findings suggest the need for targeted incentive programs, particularly those designed for rural and lower-income groups. Figure 7, shown below, describes a bar chart comparing the influence scores of factors such as income, education, and grid distance. It emphasizes that socio-economic characteristics significantly shape willingness to invest in SHS. Tailored interventions are needed for different community profiles.

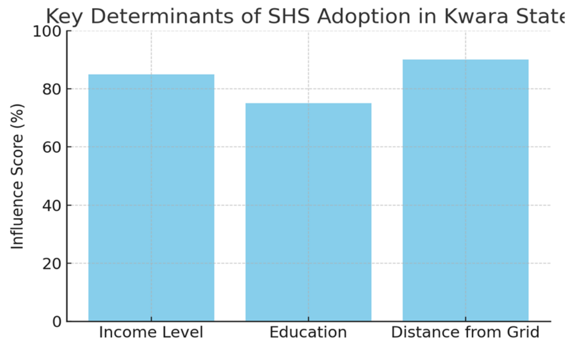

Figure 7: Key Determinants of SHS Adoption in Kwara State.

3.3 Evaluation of Solar Resource Availability

As seen in Table 1, solar irradiance in Nigeria has remained consistently high, with annual averages exceeding 33,000 kWh/m². Kwara, situated in the central belt, receives reliable sunlight year-round, positioning it as a strategic location for PV deployment (Adamu & Oladipo 2023).

Table 1. Annual solar irradiance in Nigeria (2002–2004).

Year	Irradiance (kWh/m²)
2002	34,914.73
2003	33,898.32
2004	34,338.32

Source: Adapted from Idris et al., 2023 (Adamu & Oladipo, 2023).

3.4 Barriers to Solar Energy Deployment

Despite the promising solar profile and growing interest, several obstacles persist. The top barriers identified from literature and local field studies are summarized in Table 2.

Table 2: Key barriers to solar energy in Kwara State.

Barrier	Severity (%)	Description
High Initial Cost	90%	Upfront cost deters low-income households
Technical Expertise	70%	Shortage of trained technicians for installation & repair
Policy Uncertainty	65%	Regulatory ambiguity discourages private investment
Low Awareness	60%	Misconceptions and a lack of information limit adoption

Source: Synthesized from (Agbo et al, 2021), (Ojo et al 2023)., and (Idris et al, 2023).

These findings emphasize the importance of financial subsidies, capacity-building programs, and clear policy frameworks to foster solar market expansion.

Figure 8 describes a severity ranking chart that shows high installation cost and technical limitations are the most pressing challenges. It suggests a clear roadmap for intervention—subsidies, local technician training, and awareness campaigns can directly reduce these high-impact barriers.

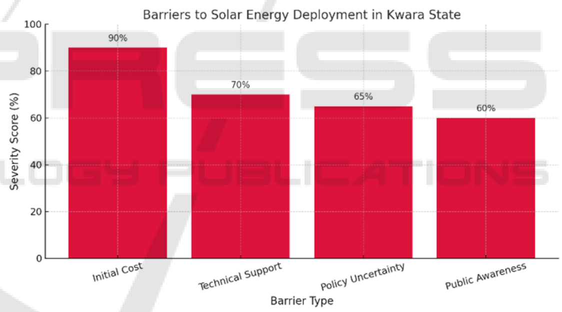

Figure 8. Barriers to Solar Energy Deployment in Kwara State.

3.5 Comparative Insight: Kwara vs. Other Nigerian States

Compared to states in Northern Nigeria (e.g., Kano or Katsina), Kwara has slightly lower irradiance but shows higher behavioral receptiveness to SHS due to stronger education indicators and NGO presence. However, states like Lagos benefit from more supportive policies and infrastructure, highlighting the impact of regional governance and institutional support. The chart below (Figure 9) compares the perceived severity of key barriers to solar energy adoption in Kwara, Lagos, and Kano States. Kwara shows consistently high ratings across all factors, especially in cost and technical support, emphasizing the need for localized interventions (ECN & REEEP 2022), (REEEP and NESP 2022).

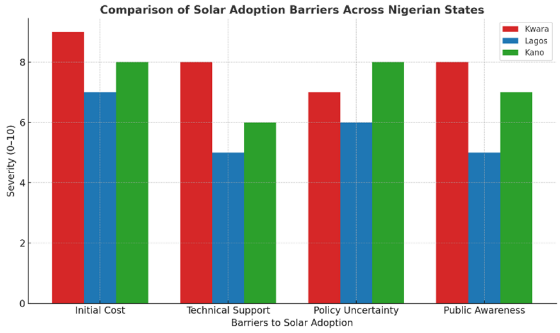

Figure 9: Comparison of Solar Adoption Barriers Across Nigerian States.

3.6 Interpretation and Implications

The interplay between technical feasibility, socioeconomic realities, and policy infrastructure defines the success of solar energy programs. In Kwara State, the latent potential remains high, but systematic issues must be addressed. The state can emerge as a model for decentralized solar adoption if localized strategies are aligned with national goals, especially in rural electrification, job creation, and climate action.

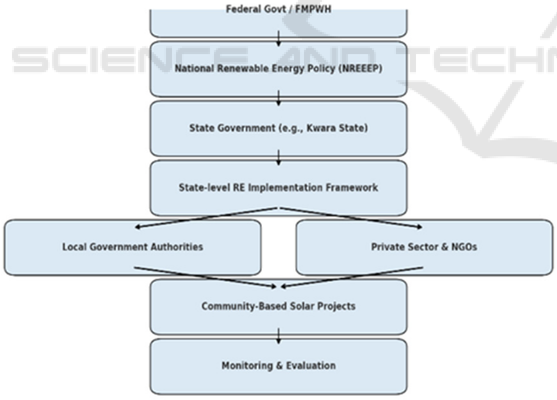

Figure 10. Flowchart of Solar Energy Policy and Implementation Framework in Nigeria.

4 CONCLUSIONS

This review demonstrates that solar energy holds immense potential for addressing Kwara State's persistent electricity access gaps, particularly in rural and peri-urban communities. The steady availability of over 33,000 kWh/m² of solar energy each year, combined with falling prices of solar panels, confirms that solar power is technically ready for large-scale use.

Even with solar energy's potential, its rollout in Nigeria faces several roadblocks, including steep initial costs, scarce technical know-how, poor policy enforcement, and low public engagement. Household data from Kwara reveal that factors such as income, education, and how far people live from the grid significantly affect whether they adopt SHS. These findings point to the need for policies that address specific social and economic realities. Additionally, inconsistent regulations and the lack of unified state-level renewable strategies only make matters worse.

Kwara holds significant promise as a model for decentralized solar energy solutions in Nigeria- provided that key challenges are effectively addressed – in line with both domestic priorities and global climate commitments.

To scale up solar adoption in Kwara, a thoughtful and locally informed strategy is essential. This begins with drafting a detailed state-specific renewable energy policy that aligns with national plans but reflects Kwara's unique context. The policy should specify clear steps for implementation, offer financial incentives, and set realistic, trackable goals to encourage private investment and infrastructure expansion.

Breaking down financial barriers is just as important, especially for households with limited income. This could involve government-supported subsidies, grants from donor agencies, and flexible microfinance options that spread out the cost of Solar Home Systems. It is vital that these financial solutions are accessible and aligned with the everyday economic realities of rural communities.

At the same time, building local capacity through technical training is vital for the long-term success of solar energy deployment. Investments should focus on equipping residents with hands-on skills in installation and maintenance, using platforms like vocational centers, technical schools, and community-led initiatives to train a competent solar workforce.

Boosting public understanding and energy knowledge is also a key step towards wider solar adoption. Education campaigns, hands-on demonstration projects within communities, and including renewable energy in school lessons can play a major role in making solar technology familiar and trusted- particularly in regions where uptake remains low.

Public-private collaboration should be actively pursued as a strategic approach to unite funding and technical know-how. When governments, NGOs, and private firms work together, they can introduce creative solutions, reach more communities, and keep solar energy efforts going strong for the long term.

In the end, successful implementation depends on having clear systems to monitor progress, evaluate results, and listen to community voices. Relying on real-time data and feedback will improve solar programs over time and make policies more responsive and effective.

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