

Creating an Enabling Environment for Solar Irrigation Ownership in Nigeria

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- Front cover photo: A solar irrigation installation in Senegal
- Back cover photo: Drip irrigation powered by solar pumping in Ghana

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Summary

Agriculture is central to Nigeria's economy, contributing nearly 25% of the national GDP and employing about 70% of the labour force (Taiwo, 2020). Most farmers are dependent on rainfed agriculture, making food production vulnerable to unpredictable rainfall and climate change. Although large-scale irrigation has dominated past investment, smallholder, farmer-led irrigation development holds significant potential, particularly in lowlands and inland valleys with ample groundwater. The potential for small-scale irrigation in Nigeria is significant, particularly the farmer-led irrigation approach where the farmers use the water resources available within their land area, determine and plan their irrigation investment, leverage the readily available technologies, and take the driver's seat in the entire irrigation practice. Solar-irrigation technologies are very well adaptable to supporting the energy needs in a farmer-led irrigation system. Advancing access to farmer-led irrigation technologies and solar irrigation has faced different challenges in Nigeria. This review examines the technical, economic, and systemic barriers to solar-powered irrigation adoption, assesses farmer willingness and capacity to invest, and draws lessons from successful models across sub-Saharan Africa. Insights from this synthesis inform pathways for scaling sustainable irrigation solutions to enhance climate resilience, agricultural productivity, and rural livelihoods in Nigeria.

The study's analytical framework examines the physical and institutional environment, intervention support mechanisms, financial institutions, systemic barriers, and opportunities, and the solar-powered irrigation supply chain to understand the enabling environment for catalyzing solar-powered irrigation in Nigeria, emphasizing the interplay between physical, institutional, and socio-economic factors. The physical environment assesses technical suitability by considering climatic conditions, solar radiation, water availability, and land use systems to ensure interventions align with local natural endowments. The institutional environment evaluates policies, governance structures, coordination mechanisms, and gender and social inclusion factors that influence adoption, alongside programs and initiatives—such as grants, subsidies, and training—designed to support scaling. The solar-powered irrigation supply chain is analyzed from global manufacturing and importation to local distribution, installation, and after-sales service. Farmers' investment behavior, including adoption willingness, payment preferences, and perceived costs versus benefits, is examined alongside systemic barriers and opportunities. Together, these elements inform ownership pathways—individual, cooperative, pay-as-you-go, or public-private partnerships—toward sustainable adoption, broader uptake, and enhanced agricultural productivity.

A comprehensive literature review was conducted to synthesize research on solar-powered irrigation systems (SPIS) in Nigeria and comparable sub-Saharan African contexts. The review employed searches across academic databases, institutional repositories, and key journals using relevant keywords, focusing primarily on studies from the last decade to ensure contextual relevance. Inclusion criteria prioritized peer-reviewed articles, technical reports, and working papers addressing SPIS, water management, agricultural policy, and rural development, while anecdotal or non-data-driven sources were excluded. The review examined the physical and climatic suitability for SPIS, assessed farmers' investment behavior and financing preferences, analyzed supply chain dynamics and institutional frameworks, and

identified systemic barriers and opportunities. This approach provided a holistic understanding of technical, socioeconomic, and policy dimensions necessary for scaling SPIS adoption and enhancing agricultural productivity in Nigeria.

1. Opportunities and potential for solar-powered irrigation in Nigeria

Nigeria has significant potential for solar-powered irrigation due to abundant solar radiation and vast shallow groundwater resources, particularly in the northern regions. SPIS offers a sustainable and cost-effective alternative to fuel-powered pumps, enhancing climate resilience, agricultural productivity, and food security. Adoption can reduce environmental degradation, enable year-round cultivation, improve water-use efficiency, and increase farmer incomes. Government initiatives, financial incentives, and emerging local policies can provide an enabling environment, while innovative financing models such as pay-as-you-go and lease-to-own approaches can further lower adoption barriers. Additionally, promoting local value chain development presents opportunities for job creation, skill development, and reduced import dependency.

2. Challenges and barriers to adoption

Despite its potential, SPIS adoption in Nigeria faces multiple constraints. High upfront costs, limited access to credit, fragmented supply chains, dependence on imports, and weak after-sales services undermine adoption among smallholder farmers. Institutional and infrastructural challenges, including policy inconsistencies, limited skilled labour, poor rural infrastructure, and inadequate extension services, further restrict deployment. Social barriers, particularly for women and youth, include limited access to land, finance, and training. Moreover, gaps in awareness, knowledge, and technical support exacerbate adoption challenges, while restrictive import policies may inadvertently increase costs and reduce affordability.

3. Knowledge gaps and pathways for scaling

Existing literature highlights critical potential and gaps for effective scaling of SPIS. Nigeria has strong potential for solar-powered irrigation systems (SPIS) due to abundant sunlight, shallow groundwater, and demand for climate-smart farming, but adoption is limited by high costs, weak supply chains, low awareness, and policy gaps. Two scaling pathways are proposed: private-led financial accessibility through flexible financing models, risk-sharing instruments, and targeted subsidies; and government-led enabling environment through awareness campaigns, extension services, subsidies, tariff reforms, and land tenure improvements. Co-designed, evidence-based approaches with farmers are essential to tailor solutions, attract investment, and ensure inclusivity. Together, these pathways can enhance climate resilience, increase productivity, and secure livelihoods for millions of farmers.

1. Introduction

Agriculture forms the bedrock of Nigeria's economy, contributing nearly 25% of the GDP and employing around 70% of the workforce (Taiwo, 2020). However, the sector is heavily reliant on rainfed agriculture, with over 70% of crop production dependent on erratic rainfall, making farmers highly vulnerable to seasonal fluctuations and climate change (Yahaya & Eyoma, 2024; Fagbemi et al., 2025). While irrigation has

gained attention as an adaptation strategy to climate change (Godspower, 2025; APN, 2020), historical investment has primarily focused on large and medium-scale formal schemes (Bashir & Kyung-Sook, 2018). Recently, there has been a growing interest in smallholder, farmer-led irrigation development (FLID) (Oke et al., 2024; Xie et al., 2023), particularly given the vast potential of non-formal lowlands and inland valleys. Nigeria boasts a profitable groundwater-irrigated area development potential of 5.04 million hectares, predominantly in the central and northern states (Xie et al., 2023). Regions such as Kebbi, Sokoto, Bauchi, Niger, and Zamfara have successfully utilized tube well technology for groundwater exploration in floodplains with sedimentary formations (Abubakar et al., 2020; Aremu & Ige, 2016).

Despite the immense potential for irrigation, the current reliance on fuel-powered pumps for small-scale FLID is problematic. The recent removal of fuel subsidies has further exacerbated the economic burden on farmers using these motorized pumps, highlighting an urgent need for sustainable alternatives (Xie et al., 2023). Solar-powered irrigation has emerged as a promising solution to address water access and energy challenges in agriculture, particularly in regions with abundant sunlight, such as Nigeria (Gebrezgabher et al., 2021). It offers a sustainable and cost-effective alternative to diesel and manual methods, providing year-round access to water and reducing environmental harm (Ofosu & Minh, 2021). Studies confirm the hydrogeological potential for shallow groundwater irrigation using tube well technology in areas such as Nasarawa State (Oke et al., 2024; Saadu et al., 2022; Adelana & Macdonald, 2008), further underscoring the technical suitability of solar-powered solutions.

However, despite these compelling benefits and the apparent suitability, the adoption rate of solar-powered irrigation systems in Nigeria remains remarkably low, especially among smallholder farmers who form most agricultural producers (Yahaya & Eyoma, 2024; Kefas et al., 2024). This low adoption stems from several critical barriers. The initial cost of solar-powered irrigation equipment is a significant deterrent, particularly for small-scale farmers who often lack access to credit or government subsidies (Durga et al., 2024). Beyond financial constraints, a lack of awareness and weak extension services further limit farmers' willingness and ability to invest in these systems. Furthermore, the solar supply chain in Nigeria is fragmented, with a scarcity of reliable equipment suppliers and limited access to affordable maintenance services (Osunmuyiwa et al., 2021). This contrasts with countries like Kenya and South Africa, which have made strides through local manufacturing, private sector engagement, and supportive policies (Burney et al., 2010; Mburugu & Gikonyo, 2019). The inconsistent quality standards and poor coordination within Nigeria's solar market erode farmer confidence and hinder the long-term sustainability of solar-powered irrigation technologies.

Policy and institutional constraints also play a significant role in the slow adoption of this approach. While some sub-Saharan African countries have successfully implemented supportive frameworks and financing schemes to accelerate solar-powered irrigation adoption, for example, Ethiopia's public-private partnerships and donor-supported programmes (Adamseged et al., 2025) and Ghana's pilot schemes integrating solar technologies (Minh & Ofosu, 2022) – Nigeria's approach remains fragmented and underfunded. To address these multifaceted challenges, this review seeks to gain insights into the suitability of solar-powered irrigation, assess farmers' willingness and ability to invest, examine the strengths and gaps within the solar and

agricultural value chains, and identify significant barriers hindering widespread adoption across Nigeria, with comparative insights from other sub-Saharan African contexts.

Addressing these barriers requires co-creation approaches, as proposed by initiatives like CGIAR's *Scaling for Impact Science*, to foster ownership and improve access. Understanding these elements is crucial for co-designing scaling pathways and adopting a co-creation approach to stimulate ownership, thereby enhancing access to sustainable solar pumping solutions, particularly in Northern Nigeria. By synthesizing evidence on technical suitability, economic viability, and systemic bottlenecks, this review aims to identify pathways for scaling sustainable solar-powered irrigation in Nigeria. Lessons from successful models in other African countries underscore the importance of integrated policies, private-sector engagement, and targeted financing in unlocking the technology's potential for smallholder farmers, thereby enhancing climate resilience and rural livelihoods.

2. Analytical framework

Figure 1 presents analytical elements to analyze the enabling environment for the ownership pathway to catalyze solar-based irrigation in Nigeria.

Physical environment: The analytical framework for catalyzing solar-based irrigation in Nigeria focuses on the physical environment to assess the suitability of the technology across different regions. This includes evaluating climatic conditions such as rainfall and temperature, identifying available water sources like shallow groundwater and runoff, and analyzing the solar radiation potential and land use systems. This foundational analysis is crucial for ensuring that all proposed interventions are both technically viable and well-aligned with the natural endowments of the area. *The institutional environment* for scaling the SPIS analyzes matters that are shaped by both the policy and regulatory framework and issues with gender and social inclusion. It encompasses the policies, governance structures, and coordination mechanisms among federal, state, and local governments, as well as NGOs and private sector actors, that either facilitate or impede SPIS adoption. *Intervention and support* refer to the various programmes and initiatives, such as grants, subsidies, and training, provided by these stakeholders to promote SPIS. The solar-powered irrigation supply chain details the entire process, from the global manufacturing and international importation of components to their national and regional distribution, local installation, and crucial after-sales service and maintenance.

Farmers' investments in solar-powered irrigation focus on the adoption, willingness and ability to invest, investment preference, the viability of different payment models, and their perception of costs versus benefits. This interacts with *systemic barriers and opportunities*, which identify overarching challenges like high upfront costs, limited technical expertise, and policy gaps, alongside leverage points such as financial innovation and robust community governance. Ultimately, *the ownership pathway for scaling solar-powered irrigation* represents the diverse models—individual, cooperative, pay-as-you-go, or public-private partnerships—through which farmers can acquire and sustainably utilize SPIS, leading to widespread adoption and enhanced agricultural productivity.

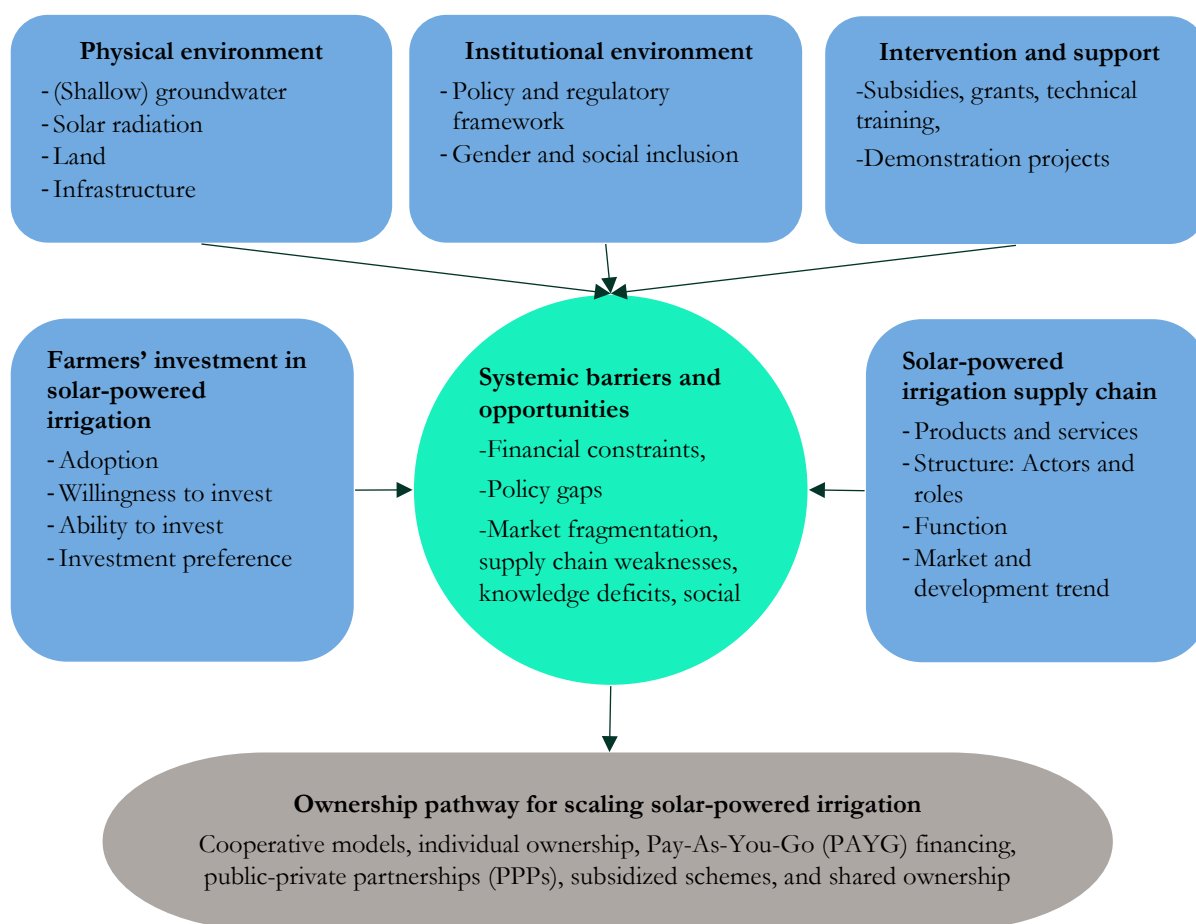


Figure 1. Analytical Framework

3. Methodology

3.1. Review process

A comprehensive literature review was conducted to synthesize existing research and reports on SPIS in Nigeria and other sub-Saharan African contexts. The review process included a (1) search strategy, (2) exclusion and inclusion criteria, and (3) a literature review.

1. Search Strategy

The search for relevant literature was primarily conducted on academic and institutional search engines, including Google Scholar, and the digital repositories of international development organizations such as the CGAIR, World Bank Group and the International Food Policy Research Institute IFPRI. Certain journal publishers like the *Hydrospatial Analysis*, *Physical Geography Series*, *Renewable and Sustainable Energy Reviews*, *Climate Policy*, *Renewable Energy*, *RSC Sustainability*, *Environmental Research Letters*, *Energy Research & Social Science*, *Renewable and Sustainable Energy Reviews*, *Sustainability*, *Agricultural Water*

Management, to mention a few, were also looked at. The search utilized a combination of keywords, including but not limited to: "solar-powered irrigation Nigeria," "SPIS Nigeria," "farmer-led irrigation," "water management Nigeria," "climate resilience agriculture Nigeria," "solar irrigation adoption sub-Saharan Africa," and "agricultural financing Nigeria."

2. Exclusion and Inclusion Criteria

The review focused on literature published primarily within the last decade to ensure relevance to the current socioeconomic and climatic context of Nigeria, but allowed older foundational or long-term trend papers to be included where their substantive, data-driven analysis was essential for historical context or methodological grounding, thus avoiding the arbitrary exclusion of highly pertinent, albeit older, literature. Inclusion criteria mandated the selection of peer-reviewed journal articles, technical reports, and working papers from reputable institutions that directly addressed SPIS, water management, agricultural policy, or rural development in Nigeria. For comparative insights, relevant studies from other sub-Saharan African countries with similar agro-ecological and socioeconomic conditions were also included. Exclusion criteria applied to all non-peer-reviewed sources, anecdotal blog posts, and literature that did not provide a substantive, data-driven analysis on the topic.

3. Literature Reviewed

The scope of the literature review was designed to build a foundational understanding of the SPIS ecosystem. It began by analyzing the Physical and Climatic Suitability of Nigeria for SPIS, examining factors such as solar radiation potential, water resources, and agro-ecological zones to determine the technical viability. The review then shifted to the Socioeconomic and Investment Context, where it explored farmers' willingness and ability to invest, their preferred financing models, and the viability of different ownership pathways. A critical assessment of the Supply Chain and Institutional Environment was also undertaken to understand the roles of key actors and the effectiveness of existing policy and regulatory frameworks. Finally, the scope concluded with an identification of Systemic Barriers and Opportunities, pinpointing overarching challenges and potential leverage points for scaling SPIS adoption across the country.

3.2. Data analysis

This review synthesizes existing literature to gain insights into the suitability of solar-powered irrigation, assess farmers' willingness and ability to invest, examine strengths and gaps within the solar and agricultural value chains, and identify significant barriers hindering widespread adoption across Nigeria, drawing comparative insights from other sub-Saharan African contexts. The approach involves synthesizing evidence on technical suitability, economic viability, and systemic bottlenecks to identify pathways for scaling sustainable solar-powered irrigation in Nigeria. It emphasizes the need for co-creation approaches, such as those proposed by CGIAR's Scaling for Impact Science, to foster ownership and improve access to sustainable solar pumping solutions, particularly in Northern Nigeria. The review also incorporates lessons from successful models in other African countries, underscoring the importance of integrated policies, private-sector

engagement, and targeted financing to unlock the technology's potential for smallholder farmers, ultimately enhancing climate resilience and rural livelihoods.

4. Physical environment

4.1. Water resources

Water source in formal irrigation systems is usually distributed via a network of canals and field channels from a dam reservoir. However, in non-formal irrigation systems, the farmer-led water source could be from either rivers, streams, groundwater, or water ponds. Nigeria has a total internal runoff generation of 244 billion cubic meters (BCM) per year and a surface water resources potential of approximately 333 BCM per year (National Water Resources Policy, 2016). The total water resources potential, including inflows from neighboring countries, is estimated at 375 BCM/year. The total groundwater resource potential is estimated at 156 BCM/year as a renewable source, based on the estimated groundwater recharge (National Water Resources Policy, 2016). This indicates that there are water resources available to support current irrigation development (Goni & Adams, 2019).

The Northern regions (East, Central, and West) have extensive shallow aquifers, mostly unconfined, and are recharged through flash flooding events, which make them hold great groundwater resources for dry-season farming (Xia et al., 2023; Hamidu et al., 2017; Eduvie & Garba, 2012). These irrigated floodplains – commonly referred to as Fadama in Northern Nigeria – are formed by the deposition of transported, weathered, exogenic terrigenous materials derived from the surrounding basement rocks. Goni and Adams (2019) also confirmed the Alluvial sedimentary formation in floodplains and Rivers, including major rivers that drain the Sokoto Basin, such as the part of the Niger, Gulbin Ka, Zamfara, Gagare, and other tributaries. Several of these floodplains have been identified with the potential to accommodate tubewells, support irrigation, and other agricultural water uses. Figure 2 shows the map of groundwater suitability for irrigation across Nigeria (Xia et al., 2023). Hamidu et al., (2017) and Eduvie & Garbal (2012) reported the ranges and averages of hydraulic parameters for the shallow alluvial aquifers as follows: hydraulic conductivity (6.66 - 1316 m/day), and transmissivity (214,044 m/day).

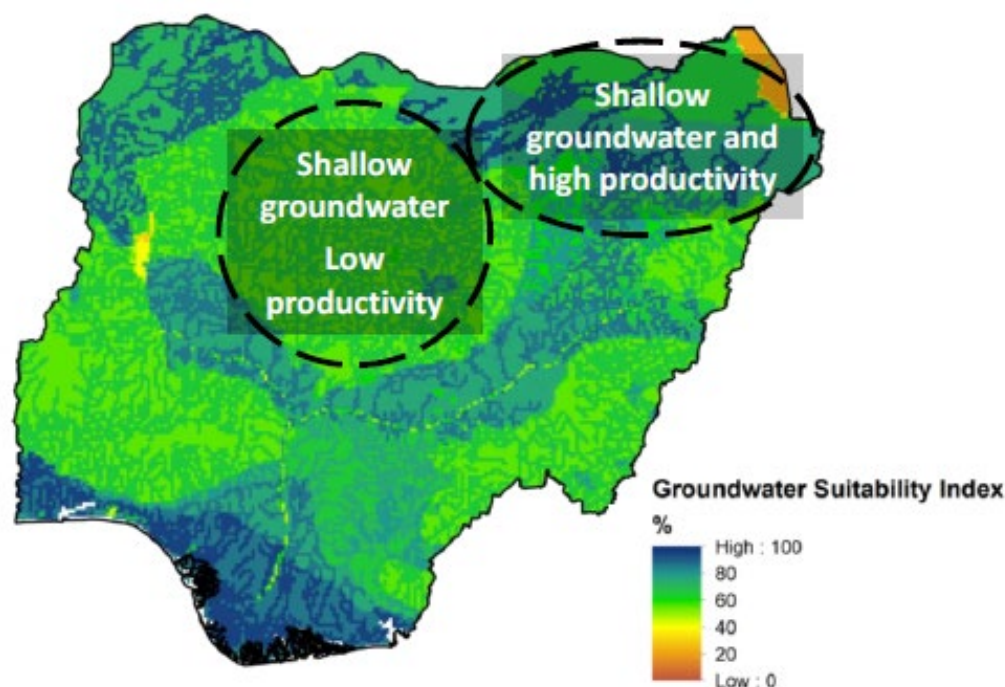


Figure 2: Groundwater irrigation suitability, Nigeria (Source: Xia et al., 2023).

4.2. Solar Radiation

Nigeria has significant potential for solar-powered irrigation due to its high solar radiation, averaging 5.25 to 5.44 kWh/m²/day, with some regions reaching up to 7.0 kWh/m²/day (Okakwu et al., 2022). These observations are in tandem with Ogunjuyigbe et al. (2017) and Oji et al. (2012), who reported that the average total radiation received per day at the northern cities of Kano, Zaria, and Kaduna is more than that of the southern cities of Ibadan, Lagos, and Nsukka. Furthermore, at each of these cities, the total radiation varies significantly with the period of the year; however, the annual average daily solar radiation is about 5.25 kWh/m²/day, varying between 3.5 kWh/m²/day at the coastal areas and 9.0 kWh/m²/day at the northern boundary. This abundant solar resource enables efficient use of photovoltaic (PV) technology for water pumping, particularly in rural and off-grid areas where access to electricity is limited (Adewumi & Akinola, 2021).

In a comprehensive study of a 26-year (1984–2009) daily global solar irradiance data measured from satellite over 25 locations in Nigeria, Osinowo et al. (2015) analyzed satellite-derived global solar irradiance across Nigeria's five major climatic zones: Tropical Rainforest (TRF), Guinea Savannah (GS), Sahel Savannah (SHS), Sudan Savannah (SUS), and Mangrove Swamp Forest (MSF). Their frequency distribution showed that 46.88% and 40.6% of days (out of 9,794) in TRF and MSF, respectively, had daily irradiation between 15.01 and 20.01 MJ/m²/day. In contrast, 46.19%, 55.84%, and 58.53% of days in GS, SHS, and SUS, respectively, fell within the range of 20.01–25.01 MJ/m²/day. The coefficient of variation of solar irradiance peaked in July and August and was lowest in January and December. Mean irradiance values were lowest in July and August, and highest in February and December for TRF, GS, and MSF, and in March and April for SHS and SUS. The average daily clearness index ranged from 0.43 to 0.63, exhibiting a zonal pattern with the highest values in northern Nigeria (e.g., Sokoto, Kano) and decreasing southward to coastal areas,

such as Port Harcourt and Calabar gives an impression that implementing a solar energy strategy is an excellent opportunity for Nigeria to get renewable energy at low cost, as well as minimize dependence on fossil fuels. Ogunyuyigbe et al. (2017) put Nigeria's solar energy potential clearly: "If solar collectors/modules were used to cover 1% of Nigeria's land area, it would be possible to generate 1850×10^3 GWh of solar electricity per year. This is over 100 times the current grid electricity consumption level in the country".

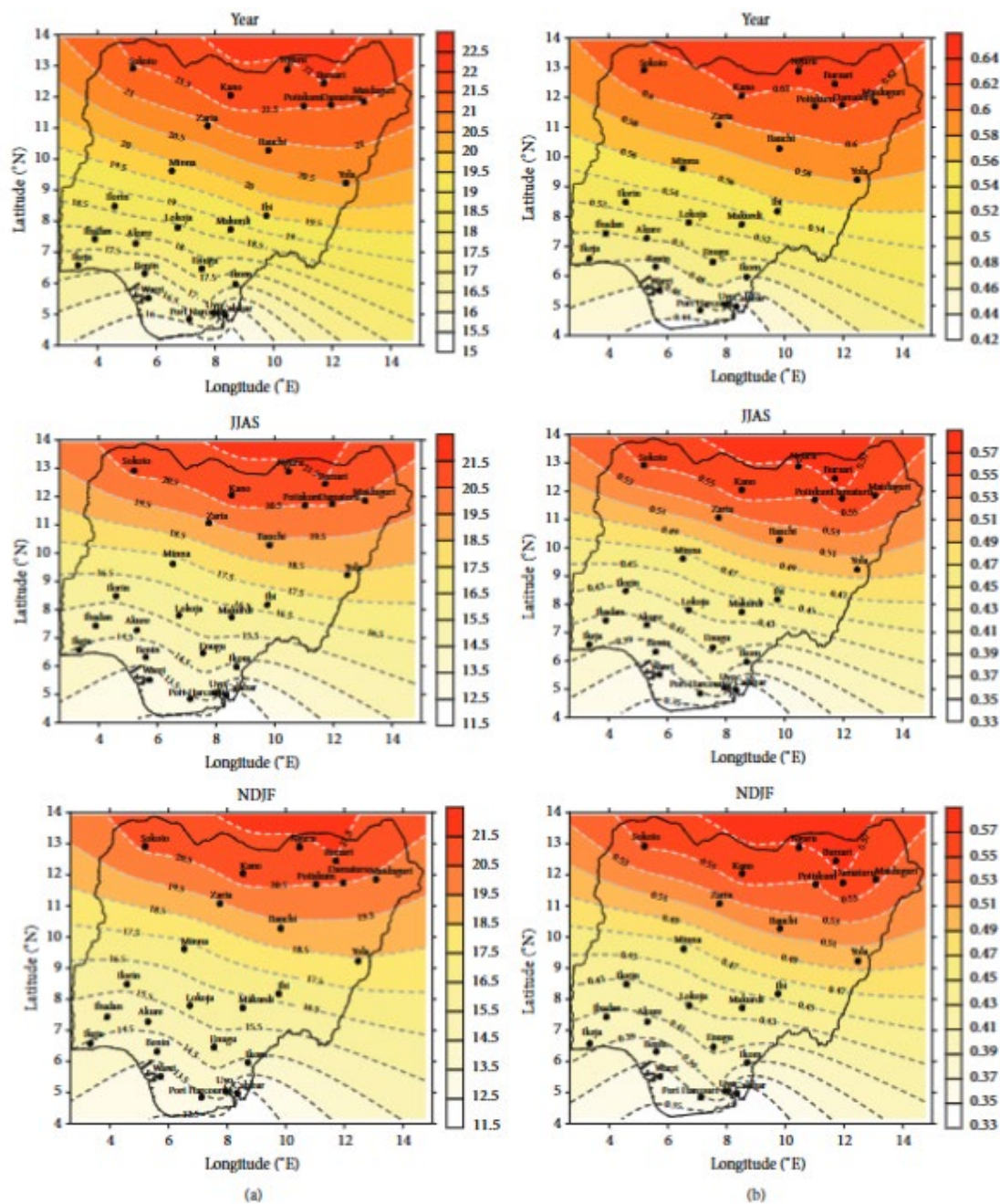


Figure 3: Contour maps of the (a) averaged daily global solar irradiance (MJ/m²/day), (b) clearness index for the year, and wet season (JJAS) and dry season (NDJF) for the locations across Nigeria. (Source: Osinowo et al., 2015).

4.3. Land

Estimates for the amount of land with irrigation potential in Nigeria vary, with figures from FAO (2014) and others ranging from 1.5 to 3.14 million hectares. A significant portion of this potential, approximately 2.1 million ha, is considered irrigable. The majority of this, about 1.6 million ha, can be irrigated from surface water, while 0.5 million ha is suitable for groundwater irrigation. Despite this potential, there is an issue with underutilization. World Bank (2014a) reports that while areas equipped for irrigation in the FADAMA and private small-scale schemes are fully utilized, schemes managed by River Basin Development Authorities (RBDAs), sugar estates, and state development are often underutilized.

Land suitability is a critical factor for irrigation, particularly in northern Nigeria. Recent studies using Geographic Information Systems (GIS) techniques confirm that a large percentage of land is highly or moderately suitable for agriculture. These analyses consider multiple factors, including topography (slope and drainage are key considerations), soil properties (soil texture, organic carbon, and pH are used to determine suitability). For example, studies on the Lapai-Agaie irrigation scheme in Niger State found that large areas meet the necessary biophysical conditions for irrigated farming (Jankaro et al., 2023). Northern Nigerian soils are often sandy-textured, with low water-holding capacity and low organic matter content, which means they require frequent irrigation (Sani et al., 2022). An exception is the "fadama" soils found in floodplains, which are rich in organic matter and have a higher water content, making them particularly suitable for irrigation. While there is great potential, irrigation in northern Nigeria faces significant environmental challenges, including salinity and waterlogging, as many schemes suffer from these issues, which can severely reduce crop yields and contribute to land degradation, declining groundwater; over-extraction of groundwater resources poses a threat to the long-term sustainability of irrigation, as noted by Sobowale et al. (2014). Also is the issue of soil degradation, as studies have shown that continuous irrigation can alter soil properties, affect the clay content and lead to changes in the soil's physical and chemical composition.

4.4. Nigeria's irrigation and water infrastructure

The irrigation and water infrastructure in Nigeria presents a complex picture, marked by both substantial development efforts and notable challenges. While there has been significant investment in dams and irrigation projects, these initiatives have been met with hurdles related to funding, maintenance, and strategic planning.

Nigeria has developed a network of about 250 medium and large dams, which have a combined storage capacity of around 30 billion cubic meters (Federal Ministry of Water Resources, 2017). This infrastructure includes completed projects such as Kashimbila Multipurpose Dam (500 thousand cubic meters) in Taraba; Ogwashi-Uku Multipurpose Dam (4 million cubic meters) in Delta; and Adada Dam (1.4 million cubic meters) in Enugu. Some others are Sulma Earth Dam (4 million cubic meters); Gimi Earth Dam (4.5 million cubic meters); Kampe Omi Dam (250 million cubic meters); Amla-Otukpo Dam (1.5 million cubic meters), located in Katsina, Kaduna, Kogi and Benue states respectively; Amauzari Earth Dam (25 million cubic meters) in Imo; Ibiono-Ibom Earth Dam (0.3 million cubic meters) in Akwa-Ibom, and Kargo Dam (2.3 million cubic meters) in Kaduna. Moreso, the irrigation land projects in Nigeria include Ejule-Ejebe (50 hectares) in Kogi; Azara-Jere (1,880ha) in Kaduna;

Sabke (879ha) in Katsina, and Sepeteri (280ha) in Oyo. All these had been completed. The ongoing irrigation schemes include Bakalori (13,557ha) in Zamfara; Hadejia Valley (6,000ha) in Jigawa; and Kano River (15,000ha) in Kano. Others are Dadin Kowa (2,000ha) in Gombe; Middle Rima (4,333ha) in Kano, and Gari (2,114ha) in Jigawa (Adeyolanu and Okelola, 2024).

Despite these efforts, the functionality and sustainability of many projects have been a concern. A significant number of water schemes are not fully operational, with research indicating that about 46% of schemes are non-functional (Andres et al., 2018a). The Federal Ministry of Water Resources reported that 116 projects, including dams and irrigation schemes, have been ongoing for an average of 15 years (Adamu, 2017). These delays and failures are often linked to issues of governance and the politicization of infrastructure projects, as noted by the Global Water Partnership-Nigeria (GWP-N, 2014). Moreover, the existing infrastructure is struggling to keep pace with population growth, largely due to rapid deterioration and insufficient investment in maintenance (Macheve, 2015). While there are plans to construct an additional 370 dams, critics have suggested that this approach may not be sustainable if the underlying issues of infrastructure decay are not addressed (Adetola, 2019; GWP-N, 2014). Besides, an analysis of dam construction reveals a disproportionate allocation of resources. While Nigeria has extensive inland waterways that could be leveraged for economic growth (CIA, 2011), approximately 75% of dam construction has been directed toward agriculture and water supply. In contrast, the energy sector, which is a key driver of economic development, has received only about 6% of this investment. This imbalance highlights an opportunity to diversify future infrastructure development to support a broader range of economic sectors and ensure more holistic national growth.

5. Institutional environment

5.1. Policy and regulatory framework

Nigeria's increasing commitment to solar energy adoption signifies a pivotal shift in its national energy priorities, aiming to achieve energy security, rural development, and environmental sustainability (Abdullahi et al., 2017). The government has established ambitious targets, including increasing solar power's share to 30% of total electricity generation by 2030, which translates to approximately 20,000 megawatts (Dakhling, 2024). Furthermore, the Federal Government aims for utility-scale solar capacity to reach 8 gigawatts (GW) by 2030 and an impressive 197 GW by 2050, with solar energy projected to contribute over 76% of the country's total installed power generation capacity by mid-century (Africa Renewable Energy Manufacturing Initiative [AREMI], 2024). This strategic transition moves away from heavy reliance on fossil fuels towards renewable, decentralized solutions that are better suited to the geographic and infrastructural realities of rural Nigeria.

A significant policy thrust involves promoting local manufacturing capacity within the solar energy sector, including a call for a ban on solar panel importation (Ogunsona, 2025). The government's strategy extends beyond mere technology acquisition to fostering industrial development, requiring companies securing solar energy contracts to establish manufacturing or assembly facilities in Nigeria, typically within a year of contract signing (AREMI, 2024). This policy aims to reduce dependency on imported components, stimulate local job creation, facilitate skill development, and

encourage technology transfer, ensuring that the economic benefits of the energy transition are broadly shared across Nigerian society.

Financial incentives are crucial for attracting investment and lowering barriers for both local and foreign investors in the solar energy market. These include tax holidays, duty exemptions for specific solar equipment, and feed-in tariffs (FITs) that guarantee premium rates for solar-generated electricity fed into the grid. The Green Manufacturing Policy and Investment Guide (2024) provides a comprehensive suite of fiscal and tax incentives, including a corporate income tax holiday of up to five years under the Pioneer Status Incentive, zero import duties on capital goods and raw materials, and VAT exemptions on key inputs. Additionally, manufacturers benefit from accelerated capital allowances, investment tax relief, and access to the Export Expansion Grant (EEG), as well as concessionary loans from institutions such as the Bank of Industry (AREMI, 2024). These incentives enhance the bankability of solar projects, particularly for rural deployment, where economic returns can be uncertain due to low purchasing power and limited infrastructure. This, in turn, attracts broader private sector participation in rural electrification and solar-powered irrigation systems.

Off-grid solutions are receiving particular attention in national policy, addressing the logistical challenges of extending the grid to many rural and underserved areas. The government prioritizes the deployment of solar mini-grids and standalone systems to bridge the energy access gap, with initiatives like the Energizing Economies Initiative supporting investments in these solutions (Agu & Onasoga, 2024). This focus is highly relevant for agricultural households and rural enterprises, often located far from centralized electricity infrastructure. Off-grid solar systems offer a reliable and cost-effective alternative, enabling crucial activities such as irrigation, post-harvest processing, storage, and cold chain development—key enablers of improved agricultural productivity and income diversification (Garcia et al., 2024).

The regulatory environment has also evolved to support the scaling of renewable energy, particularly solar power. Foundational documents, such as the Renewable Energy Master Plan (REMP) 2005, the National Renewable Energy and Energy Efficiency Policy (NREEEP 2015), and the Green Manufacturing Policy and Investment Guide 2024, provide a comprehensive framework for planning, investment, and implementation. The NREEEP, for instance, aims to expand energy access by promoting coordinated use of renewable energy, especially for off-grid rural areas, while improving energy efficiency (Federal Ministry of Power, 2015). These policies integrate energy access with broader goals of poverty reduction, sustainable livelihoods, and rural development, emphasizing coordination between government, private investors, NGOs, and international development agencies. Furthermore, the new Electricity Act introduces a more liberalized and decentralized electricity market, encouraging more players in the generation, distribution, and retail sectors. Initiatives like the Energising Economies Initiative aim to improve energy access in markets, rural communities, and agricultural clusters through mini-grids and tailored solar solutions. These efforts align with the goals of agricultural economics and rural sociology by reducing energy poverty, enhancing agricultural productivity, and promoting inclusive rural development, ultimately building a more resilient and equitable energy system with far-reaching implications for food security, environmental sustainability, and rural transformation.

5.2. Gender and social inclusion

In Nigeria's agricultural sector, the transformative potential of adopting solar energy technologies is significantly constrained by persistent gender and youth disparities, which limit equitable access to and benefits from these technologies. Women and young farmers often face systemic obstacles stemming from their limited access to essential productive resources, including land, credit, and extension services (Msangi, 2024; World Bank, 2014b). These resources are crucial for adopting innovations such as solar-powered irrigation systems or solar dryers (Ijoma, 2021; Boye et al., 2024). Furthermore, deeply entrenched social and cultural norms reinforce gender inequality by restricting women's decision-making power, mobility, and access to vital information. These norms also contribute to an unequal burden of household responsibilities, such as fuelwood collection and caregiving, which significantly diminishes women's available time and energy for engaging in agricultural activities (Perelli et al., 2024). Similarly, young farmers face a unique set of socio-economic barriers, including insecure land tenure, lack of experience, and underdeveloped networks, all of which reduce their capacity to invest in and benefit from solar innovations (Boye et al., 2024).

Moreover, significant education and training gaps exacerbate the digital and technical divide, disproportionately affecting rural women and youth. Women, particularly in northern and remote regions, are less likely to have received formal education or vocational training, which in turn reduces their ability to engage with emerging technologies (Akeju et al., 2024). Their access to training is often further hindered by mobility restrictions and sociocultural expectations that prioritize male participation in formal economic activities (Ibrahim & Nnaji, 2022). For youth, the constraints are often more economic, characterized by scarce capital and the reluctance of formal financial institutions to provide credit to young or first-time farmers without sufficient collateral (FAO, 2014). Consequently, despite their potential to drive innovation and sustainability in agriculture, young people are frequently marginalized in solar energy programmes. This marginalization not only curtails overall adoption rates but also risks perpetuating generational cycles of poverty and underemployment within agricultural communities.

To effectively address these pervasive disparities, gender- and youth-inclusive approaches must be thoroughly mainstreamed into Nigeria's agricultural and energy policy frameworks. This requires deliberate efforts to expand access to financing through targeted low-interest loans, credit guarantees, and pay-as-you-go models specifically designed for women and youth. Additionally, community-level sensitization programmes and participatory development initiatives are crucial for dismantling restrictive gender norms and empowering underrepresented groups. Capacity-building efforts must focus on delivering tailored training and extension services that are both culturally appropriate and physically accessible to marginalized populations. Integrating these critical considerations into national strategies will not only enhance the adoption of solar energy but also promote equitable participation, significantly improve livelihoods, and strengthen the overall resilience of Nigeria's agricultural sector in the face of ongoing climate and energy challenges (Toyin et al., 2023).

6. Interventions and supports for solar-powered irrigation development

Various government entities, NGOs and development partners in Nigeria are actively promoting solar-powered irrigation as a pivotal strategy for enhancing agricultural productivity and ensuring food security. At the state level, governments are launching targeted schemes to drive the adoption of this technology. For instance, the Jigawa State Government initiated a summer farming programme for youths, utilizing solar-powered borehole irrigation systems with dedicated funds from its annual budget to boost production in desert-prone areas (The Punch Newspaper, 2025). Similarly, the Benue State government has distributed solar-powered irrigation pumps among other inputs, urging farmers to leverage these resources to increase food production and alleviate poverty, which underscores the recognition of this technology as a key tool for economic development (Media Plus Nigeria, 2024).

Large-scale development projects, often supported by international partners, are also central to the intervention landscape. The Niger State Special Agro-Industrial Processing Zone (SAPZ) is facilitating access to solar-powered pumps to provide a reliable water supply, particularly in areas with limited electricity, thereby improving crop yields sustainably¹. This approach is similar to the Agro-Climatic Resilience in Semi-Arid Landscapes (ACReSAL) project, which promotes Farmer-Led Irrigation Development (FLID) by connecting farmers with private sector suppliers for technology, affordable finance, and market access (ACReSAL, 2024). Furthermore, the Horti-Nigeria programme, funded by the Embassy of the Kingdom of the Netherlands, has directly supported farmers in Kano, Ogun, Kaduna, and Oyo states by providing high-capacity solar irrigation pumps and training over 50,000 farmers in sustainable practices (The Guardian, 2024).

The push towards solar-powered irrigation is largely a response to the significant economic and environmental drawbacks of conventional fuel-powered pumps. These pumps are not only subject to rising fuel costs but are also prone to frequent breakdowns, increasing maintenance burdens, and leading to poor crop yields, especially during the dry season. Moreover, their carbon emissions contribute to environmental degradation (IFDC, 2025). In contrast, interventions by programs like Horti-Nigeria highlight solar technology as a clean, cost-effective, and reliable alternative. By harnessing solar energy, these irrigation systems significantly reduce the carbon footprint of farming activities, offering a sustainable pathway to boosting agricultural productivity and building resilience among Nigerian farmers (The Guardian, 2024; IFDC, 2025). Complementing these efforts is the crucial work of the National Agency for Science and Engineering Infrastructure (NASENI), which focuses on the local production of cost-effective solar irrigation pumps, aiming to build indigenous industrial capacity and ensure a sustainable domestic supply chain for the technology (NASENI, 2025). Together, these multifaceted interventions, spanning government subsidies, donor support, market linkages, and local manufacturing, are creating a framework to advance solar-powered irrigation development in Nigeria.

¹ <https://nigersapz.com/solar-powered-irrigation-systems/>

Table 1: Summary of interventions and supports for SPIS development in Nigeria

Initiative / Programme	Description	Location(s)
FLID – ACRoSAL (Farmer-led)	Small-scale solar irrigation, finance, and market linkages	North & Central Nigeria
Niger SAPZ	Solar pumps, training, subsidies for farmers	Niger State
Jigawa Summer Farming	Youth-focused solar irrigation scheme	Jigawa State
Edo State Solar Pump Distribution	53 pumps via FADAMA III and REA	Edo State
HortiNigeria Pilot	Solar pumps + training	Oyo & Ogun States
HortiNigeria Pump Distribution	10 pumps, farmer training	Kano, Ogun, Kaduna, Oyo
Heifer Nigeria Leasing Scheme	Lease-to-own model for solar pump access	Ogun State
NASENI Solar Pump	Locally produced sustainable irrigation pump	Nigeria-wide

7. Solar-powered irrigation equipment supply chain

The technology supply chain for solar-powered irrigation in Nigeria is currently heavily import-dependent, with most solar systems, pumps, and irrigation equipment produced outside the country (Figure 4). Centralized importers manage the flow of these products but face significant challenges, including high import tariffs, currency instability, and logistical delays (Adewole, 2023). These factors inflate the cost of solar-powered irrigation technologies, making them largely unaffordable for many farmers. The near absence of local manufacturing (represented by "red-coded sections" in typical supply chain diagrams in Figure 3) leaves Nigeria vulnerable to global market shocks and supply disruptions. While solar PV distributors and financial institutions are relatively established and offer credit schemes and installment payment options, their effectiveness is limited by weak linkages with service providers and end-users. The sparse availability of solar pump distributors and service providers means farmers in rural areas struggle to access spare parts, installation support, or repairs (Ajayi et al., 2024). This lack of widespread technical capacity, coupled with poor after-sales services, contributes to system failures, erodes farmer trust, and often leads to the abandonment of the technology. Operation and maintenance challenges are further exacerbated by the absence of

quality control mechanisms, resulting in the proliferation of substandard products that erode farmer confidence (Akingbesote & Ewetumo, 2025).

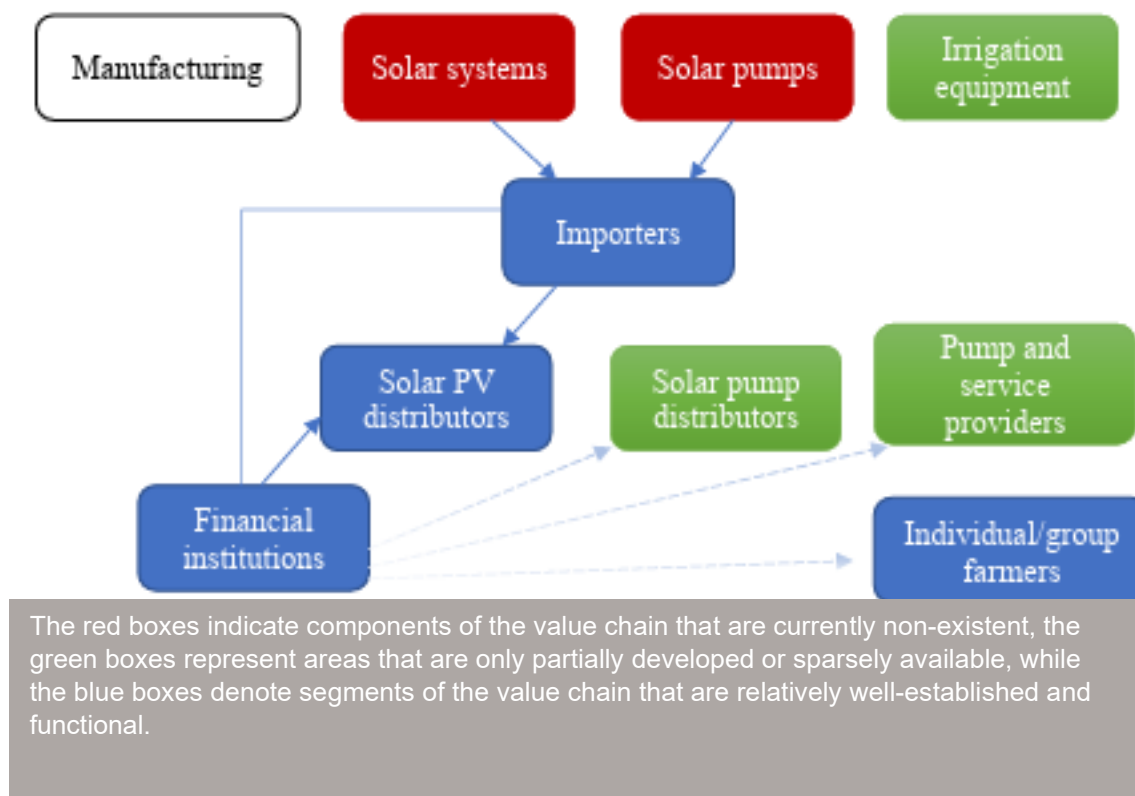


Figure 4: Solar-powered irrigation supply chain in Nigeria. (Adapted from Osunmuyiwa et al., 2021).

The actor roles and relationships within the solar-powered irrigation value chain also present significant bottlenecks. There is poor information flow and inadequate support structures (Diemuodeke et al., 2021). Agricultural extension services rarely include solar-powered irrigation training, and peer-to-peer learning is limited due to the low density of existing adopters. Key intermediaries, such as NGOs, cooperatives, and agricultural extension agents, play a minor role in creating awareness, offering technical advice, or building capacity (Yahaya & Eyoma, 2024). Retailers are often not well-integrated into the broader distribution chain, which limits their ability to provide accurate guidance and reliable after-sales service. Financial institutions, while present, frequently target formal cooperatives or urban markets, effectively excluding most rural and small-scale farmers from accessible financing. This disconnection between financial support and last-mile delivery weakens the overall impact of the supply chain, directly hindering the affordability of technologies and reinforcing the idea that this affordability "differs among farmer segments" as indicated in the diagram.

8. Farmer investment in solar-powered irrigation

8.1. Adoption of solar-powered irrigation

Despite these challenges, integrating the agricultural value chain holds immense potential for increased income. Farmers cultivating water-intensive and high-value

crops such as maize, vegetables, rice, tomatoes, and leafy greens have significantly benefited from increased yields and improved cropping cycles due to solar-powered irrigation (Panwar et al., 2014; Akintola et al., 2021). Solar-powered irrigation systems significantly enhance crop yield, water use efficiency, and overall farm productivity, particularly in water-scarce regions (Akintola, 2021; FAO, 2018). Ojo et al. (2022) reported yield increases of 30–50% for staple crops among farmers using solar-powered irrigation, attributing this to timely and reliable water delivery. In regions where adoption has occurred, it has led to better market access and higher income, as farmers are no longer constrained by erratic rainfall or high fuel prices for diesel pumps (Ojo et al., 2022). However, these gains are not widespread due to the fragmented nature of adoption and limited access to reliable irrigation systems, indicating that the goal of "economic returns require well-functioning markets, good agricultural practices and sustainable water use" is far from fully realized. Improving the solar-powered irrigation supply chain in Nigeria requires a holistic approach that establishes local manufacturing, enhances the availability of certified service providers, invests in technical training and quality assurance, and strengthens the roles of various actors in farmer education and system deployment. A resilient and farmer-centered supply chain, well-integrated with the agricultural value chain, is critical for unlocking the full benefits of solar-powered irrigation and achieving sustainable agricultural transformation in Nigeria.

The diagram in Figure 5 illustrates a crucial progression for successful irrigation technology adoption, starting with irrigation technology suitability and flexibility, then moving to irrigation technology affordability, and ultimately leading to increased income, which requires well-functioning markets, good agricultural practices, and sustainable water use. This framework directly aligns with the challenges and opportunities within Nigeria's solar-powered irrigation sector. While the suitability of solar-powered irrigation technologies is increasingly recognized, especially for enhancing agricultural productivity and climate resilience, their financial viability and widespread adoption are heavily dependent on addressing critical gaps in the supply chain and ensuring affordability across diverse farmer segments. The diagram emphasizes that even with increased income, sustained economic returns are contingent on broader systemic factors, including market access and sustainable water management, which are intrinsically linked to a robust supply and value chain.

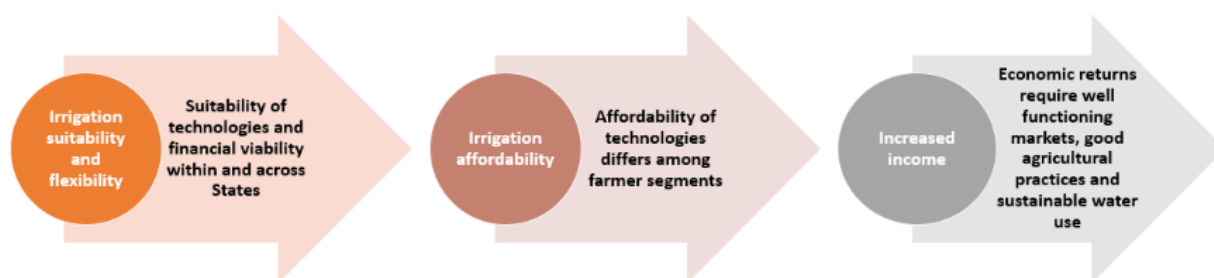


Figure 5: The Interplay of Irrigation Technology Suitability, Affordability, and Economic Returns (Source: Xia et al., 2023)

8.2. Willingness to Invest

While fuel-powered pumps (petrol and diesel) are currently widespread in Nigerian agriculture due to their availability, reliability, flexibility, and ease of operation (Aliyu et al., 2018; Sabo et al., 2023; Mohammed et al., 2022; Cloutier & Rowley, 2011),

their drawbacks are increasingly apparent. The removal of fuel subsidies in Nigeria has led to significant increases in fuel costs, directly impacting farmer-led irrigation systems (Reff). Furthermore, the environmental degradation and health risks associated with greenhouse gas emissions from fossil fuels necessitate a shift towards sustainable alternatives (Lorenzo et al., 2018; Falchetta et al., 2023). Despite the inherent advantages and potential of solar solutions as a sustainable replacement, investment in solar pumping has been low (Divine et al., 2024). However, with the rising cost of petroleum, there is an increasing willingness among farmers to consider solar solutions, driven by the perceived benefits of reduced operational costs and increased yield stability. Studies by Osunmuyiwa et al. (2024) indicate that Nigerian farmers' willingness to invest is influenced mainly by these perceived benefits, though high initial costs and limited awareness constrain it. Similarly, Osuafor and Ude (2021) and Anugwa et al. (2022) emphasize that while farmers value climate-smart technologies, such as efficient irrigation, their willingness to pay (WTP) is shaped substantially by socio-economic factors, including education, income, farm size, and access to credit and extension services.

8.3. Ability to Pay

Despite a growing willingness to invest in solar-powered irrigation, farmers' ability to pay (ATP) remains a persistent and significant barrier. The initial investment cost for solar-powered irrigation systems, encompassing solar panels, pumps, batteries, and technical setup, is substantial and often prohibitive for smallholder farmers who typically operate on small margins and lack access to formal credit (Abdullahi et al., 2017; Divine et al., 2024; Xia et al., 2023; Kefas et al., 2024). Microfinance institutions are frequently reluctant to fund such long-term ventures due to perceived risks. This mismatch between farmers' willingness and their financial capacity highlights the critical need for innovative financing mechanisms. Beyond cost, other limitations to adoption include dependence on weather conditions, intermittency in energy generation, land use requirements for panel installation, and limited energy storage capacity (Kefas et al., 2024; Okomba et al., 2023; Habib et al., 2023; Elkadeem et al., 2019). While Nigeria has implemented various subsidy programmes like the World Bank-backed Distributed Access through Renewable Energy Scale-up (DARES) programme and the Solar Power Naija initiative, which allocate significant funds for distributed solar solutions and incentivize local manufacturing (Environment Energy Leader, 2025; Rural Electrification Agency, 2020), large-scale direct subsidies specifically for solar-powered irrigation pumps are still emerging. Nevertheless, the federal government's plans to expand solar-powered irrigation to cover 750,000 hectares, along with initiatives by the Rural Electrification Agency (REA) in partnership with CESEL, signal a growing commitment to subsidizing and scaling this technology (REA, 2025; IFDC, 2025).

8.4. Preferred ownership and financing models

To bridge the gap between willingness and ability to invest, innovative financing and ownership models tailored to the realities of rural farmers are crucial. Models such as lease-to-own, pay-as-you-go (PAYGO), cooperative ownership, and seasonal payment structures have been proposed as viable solutions to lower adoption barriers. Comparative international evidence from Pakistan, Thailand, and Uganda supports this, showing that affordability, flexible repayment models, and context-specific regulatory support significantly influence willingness to adopt (Elahi et al.,

2022; Luangchosiri et al., 2025; Nabaweesei et al., 2024). The role of institutional and policy support is also a key enabling factor. Programmes that combine subsidies, targeted extension services, training, and demonstration projects can significantly increase adoption rates by reducing uncertainty and building trust in solar technology. Evidence suggests that peer demonstrations and community-based implementation strategies can overcome behavioral inertia and amplify social acceptance. Ultimately, accelerating solar-powered irrigation adoption requires an integrated approach that complements financial innovation with robust institutional frameworks, ongoing technical support, and effective regulatory oversight to ensure the availability of quality and affordable systems. Empowering farmers through education, cooperative networks, and supportive public-private partnerships is essential for building a resilient, climate-smart agricultural sector in Nigeria.

9. Barriers and opportunities for solar-powered irrigation

9.1. Physical and infrastructure

Nigeria's solar-powered irrigation development faces significant physical and infrastructural challenges. Many rural and peri-urban communities lack basic infrastructure such as reliable roads, storage facilities, and distribution networks, making it difficult to transport solar components, install systems, and provide timely maintenance services (Azi et al., 2021). The shortage of skilled technicians and engineers further compounds this problem, leading to substandard installations and reduced system reliability (Dinneya-Onuoha, 2025). Despite these constraints, Nigeria has considerable opportunities. The country receives abundant solar radiation, ranging from 3.5 to 7.0 kWh/m²/day, especially in the northern regions, which makes it exceptionally suitable for photovoltaic systems (Ojo et al., 2023; Olagunju, 2019). In addition, groundwater reserves, seasonal rivers, and surface water sources provide reliable opportunities for solar-powered irrigation. Pilot programmes in states such as Kano, Kebbi, Borno, and Jigawa have demonstrated that solar-powered drip and sprinkler systems can substantially increase productivity and align well with crop water needs, particularly for high-value horticultural crops (Adamu et al., 2025).

9.2. Solar-powered irrigation supply chain

A critical barrier to the solar irrigation supply chain is the recent policy proposal to ban solar panel imports. While intended to boost local manufacturing, this policy risks raising costs in the short term due to Nigeria's limited domestic production capacity and supply constraints (Jowett, 2025). The supply chain for spare parts and service components also remains weak, making repairs costly and maintenance delays common (Durga et al., 2024). These challenges discourage adoption and undermine farmers' confidence in long-term system viability. Yet, there are strong opportunities: solar-powered irrigation is already gaining traction across multiple states, including Kano, Adamawa, Ogun, Oyo, Bauchi, Benue, and Edo. Interventions by both the private sector and donors—such as the Horti-Nigeria programme, Heifer International, KN-CARES, and the Rural Electrification Agency—are driving adoption (IFDC, 2025; Shiaoondo, 2025; World Bank, 2022). Demonstrated successes with

drip and sprinkler systems show that solar irrigation can effectively support smallholder farmers and high-value crop production.

9.3. Farmers' investment

For most smallholder farmers, the primary barrier is the prohibitively high upfront cost of solar-powered irrigation systems, which includes panels, pumps, batteries, and technical setup (Abdullahi et al., 2017). These costs are insurmountable for many farmers operating on thin profit margins. Access to affordable financing is extremely limited, as microfinance institutions are reluctant to support such long-term ventures due to high risks (Oyefeso & Lawrence, 2024). Consequently, most farmers are excluded unless external subsidies or donor support are provided. However, the long-term benefits present clear opportunities. Compared to diesel-powered pumps, solar systems offer substantial cost savings by eliminating fuel expenses and reducing maintenance costs. They also enable year-round farming, particularly in the dry season, and allow for crop diversification in staples and high-value crops such as rice, vegetables, maize, and tomatoes (Yahaya & Eyoma, 2024).

9.4. Institutional environment

The institutional environment poses serious barriers. Policy inconsistency, market volatility, and high operational risks deter investors from committing to large-scale solar projects (Oyeyemi et al., 2025). Government extension agents, who are crucial for disseminating agricultural innovations, often lack adequate training in renewable energy applications, leading to poor farmer awareness and limited outreach (Ohunakin et al., 2014). In addition, weak coordination between government bodies, NGOs, and private sector actors undermines the scaling up of solar irrigation initiatives. On the other hand, opportunities lie in Nigeria's supportive renewable energy policies and tax incentives, which, if better implemented, could attract investment (Peter et al., 2024). Solar irrigation also aligns closely with Nigeria's renewable energy and food security strategies, while programmes such as youth-led agribusiness in Benue State show how solar irrigation can be integrated into broader climate-smart agriculture policies to foster employment and rural development (Shiaondo, 2025).

9.5. Intervention and support

Solar irrigation development suffers from inadequate institutional support and training opportunities. Many farmers are unaware of the benefits and proper use of solar irrigation systems, while structured training programmes remain rare and are often limited to pilot projects driven by NGOs or donor agencies (Teferi et al., 2024; Ohunakin et al., 2014). This knowledge gap means that systems often fail prematurely due to poor operation or minor faults that could have been avoided with basic technical know-how. Nevertheless, interventions and support mechanisms are expanding. The World Bank's KN-CARES programme distributed solar pumping machines to hundreds of farmers (World Bank, 2022), while REA has launched a major initiative to deploy solar-powered irrigation systems across 200,000 hectares of farmland (REA, 2025). Similarly, IFDC's Horti-Nigeria programme and Heifer International's support to smallholders through equipment subsidies and training demonstrate the effectiveness of multi-stakeholder partnerships (IFDC, 2025;

Shiaondo, 2025). These efforts not only boost agricultural productivity but also create opportunities for rural youth employment and broader economic development.

Table 2: Summary of barriers and opportunities for SPIS in Nigeria

Category	Barriers	Opportunities
Physical and Infrastructure	- Poor rural infrastructure (roads, storage, distribution networks) limits transportation, installation, and maintenance of solar systems. - Shortage of skilled technicians reduces installation quality and system reliability.	- Nigeria has high solar radiation (3.5–7.0 kWh/m²/day), especially in northern regions. - Groundwater and seasonal rivers provide reliable water sources for solar irrigation. - Suitability confirmed by geospatial mapping and pilot programmes (Kano, Kebbi, Jigawa).
Solar-powered irrigation supply chain	- Ban on solar panel imports risks raising costs due to weak domestic manufacturing. - Weak supply chain for spare parts and service components. - Limited trained service providers, high repair costs, and delayed maintenance.	- Growing adoption across states (Kano, Adamawa, Ogun, Oyo, Bauchi, Benue, Edo). - Private sector and donor programmes (HortiNigeria, Heifer, KN-CARES, REA). - Demonstrated success with drip and sprinkler systems for high-value crops.
Farmers' investment	- High upfront cost of panels, pumps, and batteries. - Limited access to affordable finance; microfinance institutions are hesitant due to risks. - Thin margins make it hard for smallholders to commit long-term.	- Long-term cost savings vs. diesel pumps. - Reduces production costs and ensures year-round farming. - Increases yields and crop diversification (rice, vegetables, maize, tomatoes).
Institutional environment	- Policy inconsistency and market volatility deter investors. - Limited training of extension agents in renewable energy applications. - Weak coordination between the government, NGOs, and the private sector.	- Supportive policies and tax incentives (though unevenly implemented). - Solar irrigation aligns with national renewable energy and food security targets. - Extension of climate-smart agriculture strategies (e.g., Edo youth-led agribusiness).
Intervention and support	- Limited structured training for farmers on solar technology use and maintenance. - Pilot projects often lack scale-up or long-term sustainability. - Knowledge gaps and poor awareness among rural farmers.	- Multiple interventions: World Bank (KN-CARES, FADAMA), REA's 200,000-hectare solar irrigation initiative, IFDC's HortiNigeria, Heifer International's pump distribution. - NGOs, donors, and state governments providing equipment, training, and subsidies. - Opportunities for youth employment and rural

10. Summary of the literature: delineated gaps and opportunities for solar irrigation in Nigeria

The existing literature highlights Nigeria's significant potential for solar-powered irrigation, driven by abundant solar radiation and vast shallow groundwater resources, particularly in the northern regions. This technology provides a sustainable and cost-effective alternative to traditional fuel-powered pumps, thereby contributing to climate resilience, food security, and reduced environmental degradation.

However, despite apparent suitability and growing farmer willingness to invest due to rising fuel costs and perceived benefits, several barriers impede widespread adoption. The primary challenge is the prohibitively high initial cost of solar-powered irrigation systems, often insurmountable for smallholder farmers with limited access to formal credit. The technology supply chain is heavily import-dependent, resulting in high costs, logistical delays, and vulnerability to global market fluctuations. Local manufacturing is virtually non-existent, and distribution networks for spare parts and services are fragile, leading to poor after-sales support, quality control issues, and diminished farmer confidence.

Institutional and infrastructure barriers include slow capital inflow into large-scale solar projects, despite government incentives, policy inconsistencies, inadequate rural infrastructure (such as roads and transmission lines), and a shortage of skilled human capital for installation and maintenance. Furthermore, there is a significant lack of awareness and knowledge among farmers regarding the benefits of solar-powered irrigation, which is compounded by insufficient training and institutional support from extension services. Gender and youth disparities also constrain access, with women and young farmers facing systemic obstacles like limited access to land, credit, information, and training due to socio-cultural norms and economic barriers.

The Nigerian government has demonstrated its commitment through ambitious solar energy targets, policies promoting local manufacturing, financial incentives (including tax holidays and duty exemptions), and the prioritization of off-grid solutions. Specific initiatives aim to expand energy access and support solar deployment. However, the ban on solar panel imports, while intended to boost local production, may inadvertently increase short-term costs and reduce the affordability of solar energy.

Solar-powered irrigation presents a significant opportunity for Nigeria, primarily by leveraging the country's abundant solar radiation and vast shallow groundwater resources, particularly in the arid northern regions. This shift is economically compelling as it mitigates the burden of rising fuel costs for farmers, offering long-term savings compared to traditional fuel-powered pumps. Crucially, solar-powered irrigation enhances agricultural productivity and food security by enabling year-round

farming, boosting crop yields (for crops like maize, vegetables, rice, and tomatoes), improving water use efficiency, and reducing post-harvest losses, thereby increasing farmer income.

Furthermore, a supportive enabling environment is emerging through strengthened government policies, ambitious solar targets, and financial incentives designed to attract investment and accelerate deployment. There is also an opportunity to promote local value chain development, with policies encouraging in-country manufacturing of solar components, which can reduce import dependency, create jobs, and foster skill development. The adoption of innovative financing models like lease-to-own and pay-as-you-go (PAYGO) can significantly lower upfront cost barriers for smallholder farmers. Finally, targeted programmes aimed at gender and youth empowerment can expand access to financing, training, and resources for women and young farmers, not only boosting solar adoption but also promoting equitable participation, improving livelihoods, and strengthening agricultural resilience.

The current literature on solar-irrigation in Nigeria, while highlighting key challenges, exhibits several significant gaps that impede a comprehensive understanding and effective scaling. There is a notable lack of granular, quantitative cost-benefit analyses at the household level, failing to account for varying farmer segments, income levels, and crop types, and omitting a clear breakdown of operational savings versus upfront investment. Furthermore, while government subsidies and incentives are mentioned, their actual effectiveness, reach, and impact on adoption rates among target farmer groups remain unevaluated.

Beyond economic aspects, the literature is deficient in in-depth research on specific demand-side drivers, detailed farmer preferences for different solar-powered irrigation system types, and comprehensive behavioral insights including the influence of peer networks and trust. Quantifying supply chain bottlenecks, such as the precise impact of import tariffs, currency instability, logistical delays, and regional gaps in spare parts and service provision, is also missing. There's a particular absence of empirical studies assessing the current progress and challenges of local manufacturing policies and their actual effect on reducing technology costs. Finally, while technical capacity gaps and challenges faced by women and youth are identified, the literature lacks detailed assessments of specific skill deficits, the capacity of existing training institutions, the effectiveness of current training programmes, and the empirical impact of gender- and youth-inclusive interventions on adoption and livelihoods.

Household-level survey data can provide critical insights to address the identified gaps and inform effective scaling pathways for solar-powered irrigation in Nigeria. Such surveys offer quantitative insights into cost-benefit dynamics and affordability across diverse farmer segments by capturing data on income, irrigation costs, credit access, willingness to pay and best-fit procurement model(s), thus informing optimal pricing and subsidy mechanisms. They are also instrumental in pinpointing awareness and knowledge deficiencies, allowing for the design of targeted extension campaigns, and revealing demand-side preferences regarding pump capacities, payment models, and after-sales service expectations to guide product and financing development. Furthermore, these surveys will help map supply chain accessibility and service requirements, pinpoint geographical gaps, and, critically, enable the evaluation of existing policies and programs by assessing the impact of subsidies,

training, and financing on adoption and agricultural outcomes. Ultimately, disaggregated survey data are vital for identifying gender- and youth-specific barriers and informing capacity-building initiatives, ensuring the development of inclusive and practical programs for all stakeholders.

10.1 Conclusion and key recommendations for Scaling pathways for SPIS in Nigeria

Nigeria holds significant potential for solar-powered irrigation systems (SPIS) thanks to its abundant solar radiation, shallow groundwater resources, and increasing demand for climate-smart agriculture. However, adoption remains constrained by high upfront costs, fragmented supply chains, limited technical support, low awareness, and inadequate institutional backing. These challenges are further compounded by gender and youth disparities, insecure land tenure, and policy inconsistencies.

To address these barriers, two complementary scaling pathways are proposed:

Path 1: Private-led scaling through expanded financial accessibility.

The private sector, comprising suppliers, financial institutions, cooperatives, and service providers, should play a leading role in making SPIS affordable and commercially viable. Expanding access to flexible financing models such as pay-as-you-go, lease-to-own, seasonal repayment, and cooperative schemes can ease adoption for smallholders. These models should be supported by innovative financial instruments, including risk-sharing guarantees, revolving funds, results-based financing, and targeted subsidies, to lower entry costs and attract impact-oriented investment.

Path 2: Government-led scaling through awareness and enabling environment.

The government's role is to create an enabling environment and expand awareness of SPIS adoption. This includes launching nationwide sensitization campaigns, strengthening extension services, and embedding SPIS within agricultural development programs. At the policy level, coherent subsidies, tariff reforms, and quality assurance standards are essential to reduce costs and curb the spread of substandard imports. In addition, reforms in land tenure, water governance, and institutional coordination will encourage long-term investment and ensure equitable participation, particularly for women and youth.

Unlocking Nigeria's SPIS potential requires strategic, inclusive, and evidence-based approaches co-designed with farmers and other stakeholders. Further qualitative and quantitative research can help tailor solutions to farmers' needs, financial capacities, and preferences, thereby refining policy frameworks, guiding investment flows, and strengthening capacity-building programs for equitable and sustainable adoption.

Taken individually or in combination, these pathways offer a roadmap to scale SPIS in Nigeria, enhancing climate resilience, boosting agricultural productivity, and securing sustainable livelihoods for millions of farmers.

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Scaling for Impact



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