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Technical Report

Pathways for Scaling Solar-based Irrigation Technology Ownership in Nigeria: Suitability and Key Stakeholder Mapping in Kebbi, Kano, and Kaduna States

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Summary

Northern Nigeria's floodplains, particularly in Kebbi, Kano, and Kaduna States, hold immense potential for solar-powered irrigation systems (SPIS) due to abundant solar resources and accessible shallow groundwater. Despite this, adoption remains low, with farmers still reliant on costly and inefficient fuel-powered pumps. The recent removal of fuel subsidies has exacerbated financial pressures, leading to increased interest in solar alternatives. However, barriers such as high upfront costs, weak supply chains, and limited technical support hinder widespread adoption. This report, part of CGIAR's Scaling for Impact Science programme, focuses on co-designing scalable pathways for SPIS by engaging stakeholders and addressing systemic challenges.

The study employed a mixed-methods approach, combining 53 Key Informant Interviews (KIIs) and 12 Focus Group Discussions (FGDs), with farmers, government agency officials, private sector actors, and financial institutions. The findings reveal that while farmers are increasingly aware of the benefits of SPIS—such as reduced operational costs—skepticism persists due to concerns about affordability, inconsistent equipment quality, and a lack of reliable after-sales services. Successful models, such as the Dankwali Rice Cluster in Kebbi, underscore the importance of cooperative ownership, transparent governance, and multi-stakeholder collaboration in overcoming these barriers.

The study employed a mixed-methods approach, combining 53 Key Informant Interviews (KIIs) and 12 Focus Group Discussions (FGDs) with a diverse range of stakeholders, including farmers, government officials, private sector actors, and financial institutions. The findings reveal a complex landscape: while awareness of SPIS benefits is growing, adoption is highest in Kebbi due to significant state-led distribution and lowest in Kaduna, where support has been concentrated on formal irrigation schemes. Pervasive skepticism persists among farmers, driven by concerns over affordability, inconsistent equipment quality, and a critical lack of reliable after-sales services. Successful models, such as the Dankwali Rice Cluster in Kebbi, underscore the importance of cooperative ownership, transparent governance, and multi-stakeholder collaboration in overcoming these barriers.

Critical gaps in the SPIS ecosystem are systemic and interconnected. Financing constraints are paramount, with smallholder farmers unable to afford the high upfront cost and financial institutions hesitant to offer tailored credit. The supply chain is fragmented, characterized by the proliferation of substandard equipment in informal markets and a severe scarcity of skilled technicians and genuine spare parts, especially in rural areas. Additional barriers include risks of theft and vandalism, inconsistent policy frameworks, and weak extension services. The study also identifies significant disparities in intervention and support, with Kebbi benefiting from large-scale government and project distributions (e.g., ACReSAL, KASCO), while similar efforts in Kaduna have failed to reach farmers in informal, community-led schemes.

Addressing these challenges requires integrated solutions. The report outlines three comprehensive scaling pathways, each comprising specific activities and partnership models:

1. Enabled Collective and Individual Investment and Ownership: This pathway focuses on empowering farmers through tailored financing for individual ownership, Pay-As-You-Go (PAYG) models, and strengthened cooperative/cluster-based models, learning from the success of the Dankwali Cluster and the Kebbi Anchor Borrowers Programme (ABP).

2. Develop a Structure for Solar-Based Irrigation Services: This pathway promotes providing irrigation as a service through community-managed rental hubs, Public-Private

Partnerships (PPPs) for distribution, off-taker-backed schemes that link finance to market access, and grant-driven initiatives, while emphasizing robust community-level governance.

3. Foster the Self-Sustaining SPIS Ecosystem: This foundational pathway aims to build a resilient support system by investing in robust capacity training and after-sales networks, fostering strategic financial partnerships, strengthening the supply chain through PPPs, and leveraging traditional institutions to facilitate community ownership and governance.

The study highlights the pivotal role of "hidden" actors, such as off-takers who secure market linkages and traditional leaders who ensure community buy-in. The Kebbi ABP exemplifies how requiring farmer equity contributions (e.g., 30% upfront investment) enhances commitment and reduces default rates.

Insights from this qualitative survey have directly informed the design of a subsequent Discrete Choice Experiment (DCE). The DCE is structured around key attributes—including ownership model, financing option, and the use of mobile solar panel carts—to quantitatively capture farmers' trade-offs between cost, autonomy, and flexibility. The results will provide robust, evidence-based guidance for policymakers and partners to tailor interventions that reflect farmers' realities, enabling SPIS to transition from a niche technology to a mainstream solution for enhancing food security, climate resilience, and rural livelihoods in Nigeria.

1.0 Introduction

Northern Nigeria's floodplains have long been a cornerstone for lowland irrigation, leveraging their abundant shallow groundwater resources. Regions characterized by sedimentary formations and reliable aquifers, such as Kebbi, Sokoto, Bauchi, Niger, and Zamfara, have successfully harnessed tube well technology for groundwater exploration. This approach is a proven method for accessing shallow groundwater in these areas, particularly in states like Kano, Kebbi, Niger, and Sokoto, among others (Aremu & Ige, 2016; Adelana & MacDonald, 2008). Historically, farmers in these regions have predominantly relied on fuel-powered pumps for their smallholder irrigation needs. However, the landscape of irrigation is rapidly evolving, driven by both innovation and economic pressures. While fuel-powered pumps remain the most common in farmer-led irrigation systems, their limitations have become increasingly apparent. Through innovative piloting, a successful demonstration of the compelling potential of solar-powered irrigation pumps (SPIPs) to spark interest in solar-based irrigation was conducted within the Doma Rutu landscape in Nasarawa.

The adoption of SPIPs in Nigeria is currently very low (Xie et al., 2023). The recent removal of fuel subsidies, leading to a significant increase in fuel prices, has exacerbated the challenges faced by farmers using motorized, fuel-powered pumps. This escalating cost of fuel has, in turn, substantially heightened smallholder farmers' interest in solar irrigation. Recognizing this pivotal shift and the urgent need for sustainable solutions, the CGIAR's Scaling for Impact Science programme is embarking on a critical initiative. There is a pressing need to thoroughly understand the optimal scaling pathways and to adopt a co-creation approach to cultivate ownership and enhance access to these vital solar irrigation technologies across Nigeria. This ambitious initiative is structured around a comprehensive four-phased process designed to scale solar-based irrigation for dry-season crop production throughout Northern Nigeria, ensuring a holistic and sustainable approach.

The first phase, which is to analyze and identify areas with strong potential for solar irrigation, is foundational. It involves a meticulous identification of geographical areas exhibiting strong potential for solar irrigation, characterized by the availability of shallow groundwater and robust market connectivity. This stage extensively leverages existing literature reviews and engages in critical stakeholder consultations to gather diverse perspectives and validate assumptions. This foundational analysis has been done. The review established that solar-powered irrigation is gaining traction as a promising and sustainable alternative to traditional fuel-dependent methods, especially in Nigeria's sun-rich regions. Technical assessments confirm the excellent suitability of shallow groundwater in states like Kebbi, Kano, and Kaduna for solar-powered tube wells, highlighting a significant untapped resource for agricultural development. This presents a clear path toward enhanced crop yields and reduced operational costs for smallholder farmers. While the widespread adoption of this beneficial technology is still in its early stages among smallholder farmers, the path forward involves a strategic focus on collaboration and innovation.

This report specifically focuses on the second phase of our initiative, which emphasizes dynamic interaction and alignment among various stakeholders. It builds directly on the insights gained from the initial review, delving into irrigation suitability and systemic barriers of farmers' willingness to invest in solar irrigation technologies and providing a thorough analysis of existing supply chains for solar equipment, as well as the prevailing policy environment that could either support or hinder adoption. A crucial element of this phase involves contacts with relevant stakeholders for possible collaborations, where we meticulously mapped all key actors across irrigation agriculture, from government agencies and private sector actors to farmer cooperatives and community leaders. These identified stakeholders were actively engaged through a series of Key Informant Interviews and Focus Group Discussions. The primary objective of these engagements is to ensure a strong

alignment of interests among all parties and to collaboratively co-create robust and mutually beneficial scaling pathways that are acceptable and sustainable for all. The specific objectives are:

- Map key stakeholders across public, private, financial, service provider, NGO, and community sectors in the states, including government ministries, solar technology providers, banks, and farmer organizations.
- Identify systemic barriers hindering the widespread adoption of solar irrigation, drawing insights from current practices, perceptions, and supply chain challenges,
- Explore leverage points for effective scaling pathways, pinpointing opportunities for interventions and collaborations that can accelerate the sustainable ownership and use of solar irrigation technologies, and
- Inform the co-design of effective scaling pathways, ensuring solutions are context-specific, farmer-centric, and address identified challenges for sustainable impact in Kebbi, Kano, and Kaduna States.

This report continues with an analytical framework (Section 2), followed by a methodology section detailing the study areas, stakeholders involved, data collection instrument, and dataset and data analysis (Section 3). The findings are presented in Section 4, followed by Sections 5 and 6, which outline pathways for scaling SPIS in Kebbi, Kano, and Kaduna States, and conclude the report, respectively.

1.1 Analytical Framework

The analytical framework for catalyzing solar-based irrigation in Nigeria considers interconnected elements crucial for successful scaling (Figure 1). The physical environment assesses the suitability of solar-powered irrigation across diverse geographical zones by examining climatic conditions (rainfall, temperature variations), available water resources (shallow groundwater, runoff), solar radiation potential, and land use systems (agro-ecological zones, soil types, agricultural potential). This foundational analysis ensures that interventions are technically viable and aligned with natural endowments and has been done and reported from the literature reviewed for the study area.

The institutional environment 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 outlines the entire process, from global manufacturing and international component importation to national and regional distribution, local installation, and essential 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, identifying overarching challenges such as high upfront costs, limited technical expertise, and policy gaps, alongside leverage points like 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.

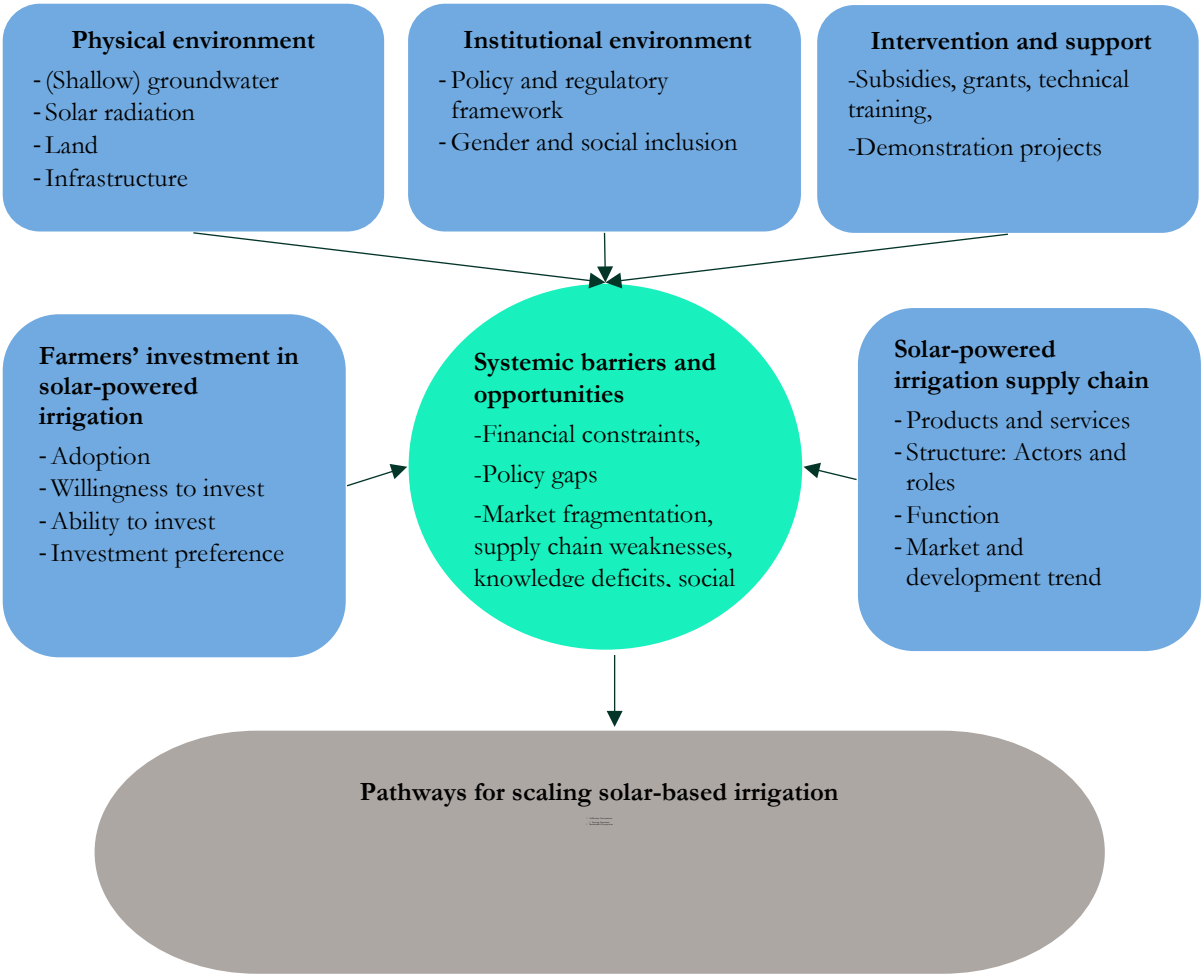


Figure 1. Analytical Framework

2.0 Methodology

2.1 Study Areas

Kebbi State

Kebbi State, located in northwestern Nigeria, is primarily characterized by a short-grass savanna drained south-westward by the Niger and Sokoto Rivers, with a significant portion of the Kainji Reservoir in its southern part. The state's geography provides fertile floodplains (*fadamas*) that are highly suitable for intensive agriculture. The population, primarily rural, is diverse, comprising significant numbers of Fulani, Hausa, Dakarki (also known as Dakarawa), and Kamberi ethnic groups, among others.[1]. Agriculture is the economic backbone of Kebbi, employing over 80% of the population. The state is a leading producer of rice, often referred to as Nigeria's "rice bowl," but also cultivates other cash crops, including groundnuts, cotton, and sugarcane, alongside subsistence crops such as sorghum, millet, cowpeas, and onions. Its extensive river network greatly favours irrigated farming, making agricultural production possible year-round and positioning Kebbi as a crucial food hub for Nigeria.[2].

Argungu and Augie are two Local Government Areas (LGAs) in Kebbi State, strategically chosen as key communities for the scaling of Solar-Powered Irrigation Systems (SPIS). Argungu is renowned for its fertile floodplains (*fadamas*) along the Sokoto River, which are historically significant for intensive dry-season farming. The area is globally recognized for the Argungu Fishing Festival, underscoring its deep connection to water resources and traditional agricultural practices.[3]. Farmers in Argungu heavily rely on irrigation for cultivating staples like rice, maize, and various vegetables, making the efficient and sustainable use of water a critical concern. Similarly, Augie shares similar agro-ecological characteristics, featuring productive lowland areas that are highly conducive to irrigation-based agriculture. The communities in Augie LGA are actively engaged in crop production that benefits immensely from reliable water access during the dry season.

Both Argungu and Augie communities were selected due to their high agricultural potential, extensive existing irrigation activities (often relying on fuel-powered pumps), and the confirmed presence of shallow groundwater resources suitable for tube wells. Their established farming communities and reliance on dry-season cultivation make them ideal to demonstrate the economic and environmental benefits of transitioning to sustainable solar-powered irrigation, directly addressing the challenges posed by rising fuel costs and climate vulnerability.

Kano State

Kano State, situated in Nigeria's northwest region, is a sprawling, densely populated area known for its semi-arid tropical climate, characterized by distinct wet and dry seasons. Its geography, predominantly savannah, benefits from significant water resources for irrigation. As Nigeria's most populous state and a historical commercial hub, Kano's economy is vibrant and diverse, with agriculture playing a vital role alongside trade, commerce, and a growing manufacturing sector. The state is a major producer of various grains, including millet, sorghum, and maize, and is particularly renowned for its rice cultivation, which has seen increased focus on boosting local production. Dry-season irrigation is extensively practiced, supporting market garden crops like tomatoes,

[1] https://www.britannica.com/place/Kebbi-state-Nigeria
[2] https://kipa.kebbistate.gov.ng/quick-win-investment-sectors
[3] https://ich.unesco.org/en/RL/argungu-international-fishing-and-cultural-festival-00901#:~:text=Argungu%20international%20fishing%20and%20cultural,Periodic%20reporting

peppers, onions, and Irish potatoes[4]. Livestock farming, particularly cattle and goats, also significantly contributes to the state's agricultural economy.

Bunkure LGA, located in the southern part of Kano State, is a predominantly agricultural area known for its fertile lands and significant involvement in both rainy and dry season farming.[5]. The LGA plays a crucial role in Kano's food production, with farmers cultivating a variety of crops, including grains like rice, millet, sorghum, and maize during the wet season, and high-value cereals and vegetables such as rice, wheat, tomatoes, onions, carrots, cucumbers, and cabbage during the dry season. The presence of the Kano River Irrigation Scheme (KRIS) within Bunkure further highlights its significance for irrigated agriculture, enabling year-round cultivation and contributing to the economic stability of its communities. Within Bunkure LGA, the Alkamawa communities, specifically Kumurya and Dunsusu, have been identified as prime locations for SPIS scaling. These communities are deeply entrenched in dry-season farming, a practice vital for their livelihoods and for ensuring food security in the region, especially during periods of scarce rainfall. Their reliance on irrigation for successful crop cycles makes them particularly vulnerable to the rising costs of fuel-powered pumps, which have historically been the norm.

The selection of Kumurya and Dunsusu for SPIS scaling is based on their demonstrated need for sustainable irrigation solutions, their active engagement in agriculture, and the confirmed potential for shallow groundwater resources in the area. By introducing solar-powered irrigation, the initiative aims to reduce operational costs for farmers, enhance the reliability of water access, and ultimately boost agricultural productivity and income for these communities, aligning with the broader goals of promoting sustainable and resilient farming practices in Kano State.

Kaduna State

Kaduna State, located in Nigeria's Northwest region, boasts a diverse geography that encompasses both savanna and forest zones, providing vast arable and well-watered land, which is crucial for its robust agricultural sector. It is one of Nigeria's most economically significant states in the North. Agriculture is a cornerstone of Kaduna's economy, contributing substantially to the state's GDP and employing a significant portion of its population. The state is a leading producer of maize, ginger, and tomatoes in Nigeria, and a major contributor to national production of rice, soybeans, and sorghum[6]. Irrigation farming is widely adopted to enhance year-round crop production, leveraging rivers such as the Kaduna, Galma, and Karama, along with numerous dams (Kaduna State Government, 2021). Beyond crop production, livestock farming, including cattle, sheep, and goats, is a significant agricultural activity that complements the state's thriving agro-processing industry.

Kagarko LGA, situated in the southern part of Kaduna State, bordering Abuja, FCT, is a significant agricultural hub within Nigeria's North-West region, being one of the LGAs where the Gurara Irrigation Scheme is situated. The LGA boasts diverse landforms and water resources that support extensive farming activities, including both rainfed and irrigated crop production. Farmers in Kagarko cultivate a wide range of crops, including ginger, turmeric, maize, millet, and vegetables, with a strong emphasis on dry-season cultivation made possible through various irrigation methods. The area's agricultural potential, combined with the active involvement of its

[4] https://azmanuniversity.edu.ng/about-kano-city
[5] https://propertypro.ng/guide/axes/Bunkure-Kano/#:~:text=The%20area%20thrives%20on%20agriculture,contributing%20to%20the%20local%20economy.
[6] https://oxfordbusinessgroup.com/reports/nigeria/2022-report/economy/diverse-assets-economic-growth-bolstered-by-agriculture-and-technology#:~:text=Kaduna's%20economy%20bolstered%20by%20agriculture,Africa%202022%20-%20Oxford%20Business%20Group

communities in farming, makes it an ideal setting for agricultural development initiatives.[7] Within Kagarko LGA, the communities of Koro, Kagarko (the LGA headquarters), and Jere have explicitly been selected for the scaling of Solar-Powered Irrigation Systems (SPIS). These communities are deeply reliant on agriculture for their livelihoods, engaging in intensive dry-season farming that requires reliable and affordable access to water. While traditional irrigation methods, including fuel-powered pumps, are currently in use, farmers face increasing challenges due to escalating fuel costs and the need for more sustainable practices.

The communities of Koro, Kagarko, and Jere within Kagarko LGA were strategically selected for SPIS scaling due to their high agricultural productivity and the presence of both formal and informal irrigation schemes. By introducing solar-powered irrigation in these areas, the project aims to significantly reduce farmers' operational expenses, enhance water availability and reliability, and ultimately boost crop yields and incomes. This strategic selection also capitalizes on their proximity to the Federal Capital Territory (FCT), providing crucial market connectivity to the bustling Abuja markets.

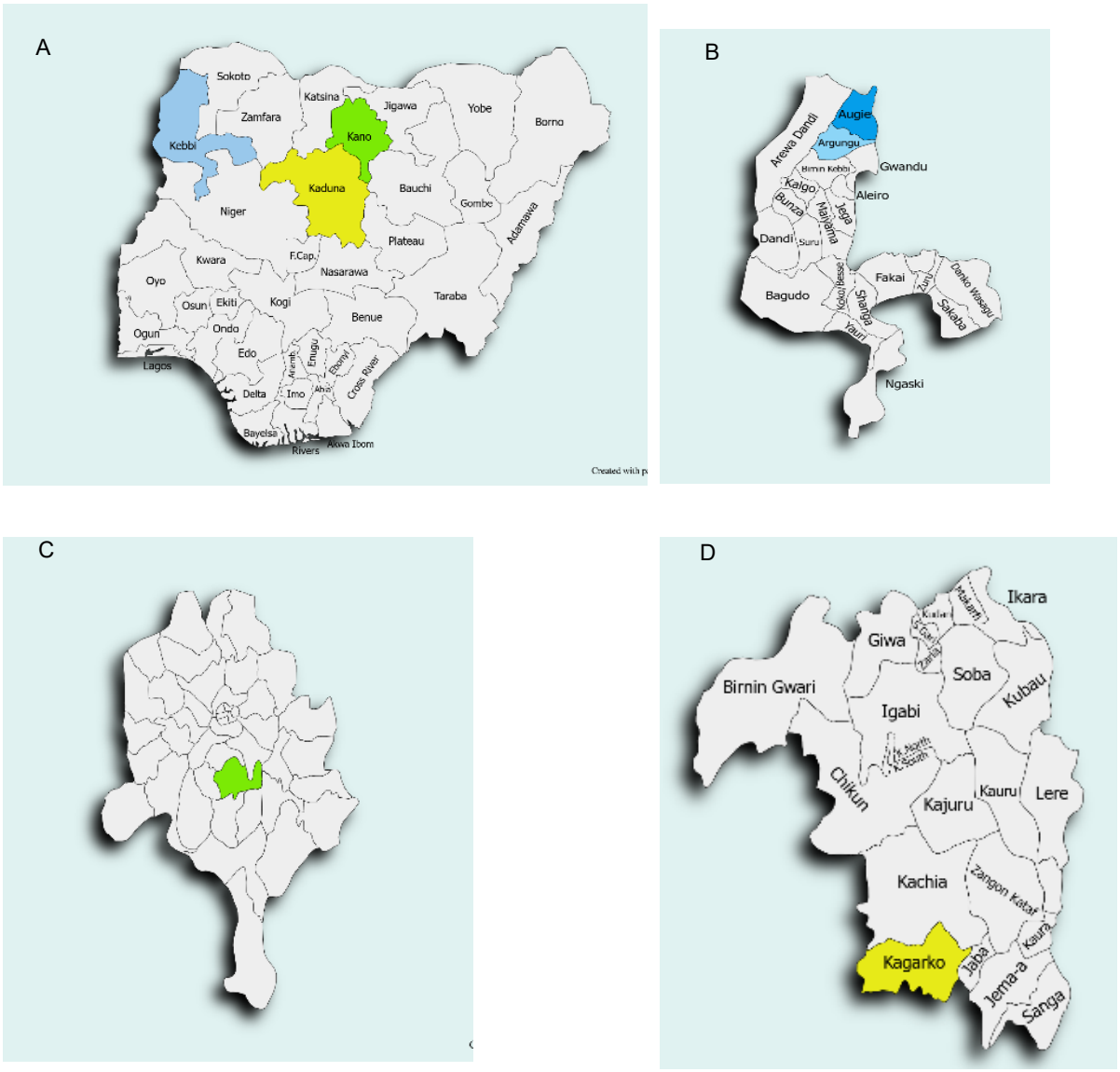


Figure 1: Maps showing the study area (A) Map of Nigeria showing Kebbi, Kano, and Kaduna States, (B) Map of Kebbi State showing Augie and Argungu LGAs, (C) Map of Kano State showing Bunkure LGA, (D) Map of Kaduna State showing Kagarko LGA

[7] https://icermediation.org/groups/kagarko-local-government-area

2.2 Stakeholder identification and categorization

The initial phase of our methodology involved refining a broad list of stakeholders to ensure effective engagement for scaling Solar-Based Irrigation Systems (SBIS). This process began by categorizing stakeholders, including public sector institutions, private companies, financial institutions, NGOs, and community groups, and then moving from general titles to specific individuals and organizations. We also identified their roles, interests, and potential contributions across the SBIS value chain, which helped us determine who was best suited for Key Informant Interviews (KIIs) for strategic insights and who was more appropriate for Focus Group Discussions (FGDs) for community-level perspectives. This rigorous refinement ensured that our data collection was precise and directly informed the co-design of scalable and sustainable SPIS solutions in Kebbi, Kano, and Kaduna States.

To systematically understand the diverse landscape influencing solar irrigation, identified stakeholders were carefully categorized. Public sector institutions represent government bodies crucial for creating an enabling environment. This category includes entities like States' Ministries of Agriculture (MoAs) and Agricultural Development Agencies (ADPs), that set policy and manage resources, along with Local Government Agricultural Departments (LGAs) that provide essential extension services and local governance. Complementing this, private sector actors encompass the commercial entities driving the market. This group includes solar technology providers (manufacturers, distributors, and vendors of solar pumps and equipment) and agribusinesses (off-taker companies), whose innovations and market mechanisms are vital for the supply, adoption, and economic viability of solar irrigation systems.

Beyond government and private businesses, other key categories of stakeholders are crucial for the success of solar irrigation. Financial institutions, such as commercial banks and microfinance institutions, the Bank of Agriculture, and states' enterprise development agencies, are vital for providing the necessary capital, loans, and flexible payment models that can enable farmers to invest in these new technologies. Equally important are service providers, including irrigation equipment maintenance firms and solar installers; these entities ensure the proper setup, functionality, and longevity of SPIS, offering essential technical support and after-sales services. Also, local NGOs play a significant role on the ground, often leading climate-smart agriculture initiatives and farmer training organizations (e.g., ACReSAL, Sasakawa, FADAMA-AF) that build capacity, raise awareness, and facilitate community-level adoption of sustainable irrigation practices.

Completing the comprehensive stakeholder categorization is vital for community-level actors. Community structures, such as traditional rulers and religious institutions, hold significant influence and play a crucial role in mobilizing communities, fostering trust, and facilitating the adoption of new technologies. Farmer organizations, including smallholder farmer cooperatives, are essential for collective action, knowledge sharing, and providing a unified voice for farmers' needs and preferences. Finally, the farming communities themselves are at the heart of all efforts, representing the end-users whose direct experiences and insights are fundamental to co-designing truly effective and sustainable solar irrigation solutions.

The selection of participants for both Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs) was guided by specific criteria designed to ensure comprehensive insights and a balanced representation of the solar irrigation ecosystem in Kebbi, Kano, and Kaduna States, using the framework provided by Patton (2015) in Qualitative Research and Evaluation Methods: Integrating Theory and Practice

2.3 Data Collection Instruments and the Data Set

Generating this report relied on two primary data collection instruments to gather comprehensive insights: Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs). Ethical considerations formed a cornerstone of the data collection methodology. Informed consent was obtained from all participants in both Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs), with clear explanations provided regarding the study's purpose, voluntary participation, and data use procedures. Ensuring confidentiality was prioritized, with all participant identities protected and data anonymized to guarantee that contributions were used exclusively for research purposes. These measures were instrumental in fostering trust and creating an environment conducive to open and reliable dialogue

Key Informant Interviews (KIIs)

KIIs were strategically employed to gain high-level, strategic insights into the multifaceted challenges and opportunities surrounding solar-powered irrigation. The primary purpose was to explore systemic barriers, existing policies, potential financing models, and the specific contributions that various influential stakeholders could make. Our sample for KIIs included individuals holding senior positions, such as senior government officials from relevant ministries (e.g., Director or Deputy Directors in Agriculture , Water Resources), representatives from major private sector companies (e.g., solar technology providers, agribusinesses), key personnel from development partners involved in renewable energy or agricultural initiatives, and respected traditional leaders who understand community dynamics and local governance (refer to Annex II for the semi-structured KII guide). These interviews provided invaluable perspectives on the broader enabling environment and high-level strategies for scaling SPIS.

For Key Informant Interviews (KIIs), participants were primarily chosen based on their:

- Strategic position and influence: Individuals holding decision-making roles, policy-making power, or significant influence within their respective organizations and sectors (e.g., senior government officials from Ministries of Agriculture, heads of agricultural development agencies, CEOs of major solar technology firms, leaders of prominent financial institutions).
- Expertise and knowledge: Those with deep technical, policy, financial, or market expertise related to solar irrigation, agricultural development, energy access, or rural livelihoods. This includes experts from service providers (e.g., solar installers, technicians), local NGOs involved in climate-smart agriculture, and seasoned agribusiness leaders.
- Broad perspective: Individuals capable of offering a macro-level view of the challenges, opportunities, and systemic barriers in the solar irrigation sector, as well as insights into inter-organizational relationships and potential collaborations.
- Representativeness: Ensuring a selection that spans the different stakeholder categories (public sector, private sector, financial institutions, service providers, local NGOs, community structures) to capture diverse perspectives from across the value chain.
- Geographic relevance: KIIs were conducted with individuals knowledgeable about or operating within the specific LGAs and states of interest (Kebbi, Kano, Kaduna), including their regional dynamics

Focus Group Discussions (FGDs)

FGDs served a complementary but distinct purpose: to gather rich, diverse perspectives directly from the ground level. These sessions aimed to explore current agricultural practices, identify specific needs of farming communities, understand the everyday constraints faced by smallholder farmers, and collectively brainstorm community-level solutions for irrigation challenges (refer to Annex III for the semi-structured FGD guide). The sample for FGDs primarily consisted of

smallholder farmers and other community members deeply involved in or affected by agricultural activities. This approach allowed for dynamic group interactions, revealing shared experiences, perceptions, and potential solutions from those directly engaged in farming and living within the target regions.

FGD participants were also selected using purposeful sampling, with an emphasis on creating homogeneous groups internally while ensuring heterogeneity across groups (Morgan, 1997; Krueger and Casey, 2014). This approach facilitates open discussion within groups and provides diverse perspectives. The criteria included:

- Homogeneity for open dialogue: Grouping participants with similar socio-economic backgrounds, roles, or experiences to foster a comfortable environment for open and candid discussions. This primarily involved smallholder farmers, segmented by location (e.g., specific communities within Argungu/Augie, Bunkure, Koro/Kagarko/Jere) and potentially by existing irrigation practices or interest levels.
- Direct experience: Individuals with firsthand experience in farming, irrigation practices, water access challenges, and interactions with agricultural inputs or technology providers.
- Community representation: Including members of farmer organizations and community structures (e.g., traditional rulers, community leaders) to capture collective experiences, community-level challenges, and existing informal governance structures related to shared resources.
- Diverse perspectives within groups: While striving for overall homogeneity per group, ensuring that each group still allows for a range of experiences (e.g., different farm sizes, specific crops grown) is relevant to understanding diverse needs and perceptions of solar irrigation. Emphasis was also placed on including the perspectives of women and youth to capture specific barriers or opportunities they face in accessing and benefiting from irrigation technologies.

Dataset

A total of 53 Key Informant Interviews (KIIs) and 12 Focus Group Discussions (FGDs) (See Table 1) were conducted across Kebbi, Kano, and Kaduna States, engaging a diverse mix of stakeholders. The KIIs included senior officials from government ministries of agriculture (6), irrigation departments (2), and local government authorities (3); managers and staff of commercial and agricultural banks (11), microfinance institutions (1), and insurance corporations (1); leaders of farmers' associations and cooperatives (3); traditional rulers and district heads (5); as well as private-sector actors such as solar technicians (5), service providers (8), development and agribusiness entrepreneurs (7) (See Annex I for details). The FGDs brought together farmers' groups, men, women, and youth, across key irrigation communities, alongside officials from agricultural development agencies such as KARDA (Kebbi), KNARDA (Kano), and KADA (Kaduna). These group discussions captured community-level perspectives on irrigation practices, gendered experiences, and youth involvement, thereby complementing the institutional and technical insights from the KIIs. This combination of respondents provided a comprehensive understanding of the barriers, opportunities, and lived realities surrounding solar-powered irrigation adoption in the three states.

Table 1: Showing the list and total number of KIIs and FGDs

State	KII conducted	FGD conducted
Kebbi	17 interviews	5 discussions
Kano	16 interviews	3 discussions
Kaduna	20 interviews	4 discussions
Total	**53**	**12**

2.4 Data Analysis

After the rigorous data collection phase, the wealth of insights from both Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs) underwent a thorough analysis. Given that many of these engagements were conducted in the local language (Hausa), the process began with meticulous translation and rendering into written text. This crucial step ensured that every detail, initially expressed in local dialects, was accurately captured and prepared for in-depth review, preserving the authenticity and richness of the data (Bryman, 2016).

Once the qualitative data were effectively analyzed, they were subjected to thematic analysis, a systematic approach widely used to identify patterns of meaning within qualitative data (Braun & Clarke, 2006). This involved carefully reviewing the translated texts to identify recurring themes, unpack core issues, spot promising opportunities, and highlight differing perspectives voiced by the various stakeholders. Through a process of coding and categorizing these emergent themes, we were able to distill vast amounts of qualitative information into coherent, meaningful patterns. This rigorous process was instrumental in uncovering critical insights into the real-world suitability of solar irrigation, identifying the practical barriers currently hindering its adoption, and determining the most viable pathways for effectively scaling this technology across Kebbi, Kano, and Kaduna States.

The analysis further identifies stakeholders and critically examines their current and potential roles within the solar irrigation ecosystem. Each actor's resources were mapped, including their capacity, technical expertise, and networks, to understand what they are doing and what they could be doing to scale SPIS. By examining the relationships between these stakeholders, we identify existing collaborations, weak linkages, and areas that require coordination. This holistic approach enables us to identify synergies for more effective partnerships and anticipate potential conflicts, allowing us to co-design scaling pathways that are not only technically sound but also socially and institutionally viable across Kebbi, Kano, and Kaduna States.

The methodological approach to understanding and fostering the adoption of Solar-Powered Irrigation Systems (SPIS) in Northern Nigeria, specifically in Kebbi, Kano, and Kaduna States, is as aforementioned and presented. By strategically selecting communities such as Argungu and Augie in Kebbi State, Kumurya and Dunsusu in Kano State (specifically, the Alkamawa communities in Kano State), and Koro, Kagarko, and Jere in Kaduna State, the study targets areas with high agricultural potential, existing irrigation practices, and confirmed shallow groundwater resources. Through a meticulous stakeholder identification process, refined to include key players from public, private, financial, service, NGO, and community sectors, we conducted fifty-five (53) Key Informant Interviews (KIIs) to gather high-level insights on policy, finance, and systemic barriers across the states. Complementing this, eleven (12) Focus Group Discussions (FGDs) engaged smallholder farmers and community members, providing rich, ground-level perspectives on their needs, constraints, and proposed solutions. The data, initially collected in the local

language, underwent rigorous translation and thematic analysis, allowing for a proper understanding of current roles, available resources, existing relationships, and potential synergies or conflicts, ultimately informing the co-design of effective and sustainable SPIS scaling pathways.

3.0 Results

3.1 Solar-based irrigation landscape in the study areas

Across Kebbi, Kano, and Kaduna States, stakeholder perspectives from both KIIs and FGDs reveal a varied yet generally growing awareness of solar irrigation technology among smallholder farmers. While direct adoption levels remain remarkably low (the lowest in Kaduna state), most farmers have at least heard of solar pumps, often through word-of-mouth from early adopters, extension agencies, donor-funded projects such as FADAMA-AF, Sasakawa, and ACReSAL, or local vendors. Perceptions of solar irrigation frequently highlight its potential to reduce fuel costs and enhance water access reliability, especially in the wake of recent fuel subsidy removals. However, this awareness often coexists with skepticism or limited understanding of the technology's practicalities, long-term durability (though Kebbi state reported 5 years before a "*brush*" component is replaced for 3" solar pumps), and actual affordability. Many perceive it as an aspirational, rather than immediately accessible, solution.

The current low adoption of solar irrigation, despite growing awareness, is influenced by a complex interplay of factors, as revealed by KIIs and FGDs with various stakeholders. A significant barrier remains the high upfront cost of solar-powered irrigation systems (SPIS). While farmers understand the long-term savings on fuel, the initial investment for panels, pumps, and installation is often prohibitive for smallholders who typically have limited access to capital. This is compounded by limited access to formal credit and subsidies, with many financial institutions hesitant to offer tailored products for this nascent market. Government support schemes, although available in pieces and bits, are not yet widely reaching the grassroots.

Moreover, the quality and reliability of information and support systems are inconsistent and sometimes non-existent. There is a lack of awareness not just about the technology itself, but also about the available models, financing options, and maintenance protocols. Weak extension services mean farmers often lack reliable, impartial advice on suitable systems for their specific needs or on how to operate and maintain the equipment properly. This leads to poor market coordination and a fragmented solar supply chain, characterized by a scarcity of reliable suppliers and maintenance services, especially in rural areas. Farmers voiced concerns about inconsistent quality standards of available products, the risk of purchasing substandard equipment, especially in Kebbi state, and the difficulty in accessing timely repairs and spare parts, all of which erode confidence in the technology.

Solar irrigation technologies primarily entered the region through a mix of formal and informal channels. Formally, equipment is often imported by larger distributors and companies, some of whom have established regional depots (e.g., Exulted Eagles Solar Co., headquartered in Port Harcourt, has branches in Kaduna, Lagos, Benin, Kano, and Abuja; A.B. Ramadan Solar has branches in Kano and Sokoto). These distributors then sell to smaller retailers, installers, or directly to government projects. However, a significant portion of the market, particularly for smaller, portable pumps, operates through informal channels with barely company names. This includes local vendors in major markets who procure equipment from various sources (sometimes leading to the proliferation of lower-quality or uncertified products, many of which are in Argungu, Bwari-Abuja, and Birni Kebbi) from open markets in Lagos, Sokoto, and Kano.

Farmers often learned about and acquired these technologies through:

- Local dealers and informal markets: Small-scale vendors in urban and semi-urban centers act as key points of sale.
- Word-of-mouth and peer influence: Successful early adopters often inspire neighbours, leading to informal diffusion.

- NGO and development projects: Some initiatives from state governments introduce solar pumps through pilot programmes or subsidized schemes, creating initial entry points.

3.2 Institutional environment for SPIS

Nationally, the National Economic Council has approved plans to introduce solar-powered irrigation pumps, developed by the National Agency for Science and Engineering Infrastructure (NASENI), to replace petrol-powered systems starting with the 2025 dry season farming. The project, pending presidential approval, will be financed and scaled up for nationwide distribution to strengthen food security, support farmers, and leverage environmental initiatives such as carbon credits. This aligns with broader efforts, including farmer insurance programmes, a value-addition bill, and a ₦250 billion Bank of Agriculture facility for smallholders' initiative, being promised[8]. The initiatives are awaiting enforcement in the states across Nigeria. Meanwhile, the institutional environment for SPIS across Kebbi, Kano, and Kaduna States is a fragmented and complex landscape with both supportive elements and significant barriers. While various government agencies, development-funded projects, and financial institutions are present, their actions are often uncoordinated, resulting in inconsistent support and policy implementation. This environment ultimately contributes to the low adoption rate of SPIS, despite growing interest among farmers. A critical finding is that government support, while present, is often inconsistent in its reach and application.

In Kebbi State, for instance, ACReSAL has distributed solar pumps to farmers, signifying a strong commitment to modernizing agriculture. Similarly, the Kano State government also facilitated the distribution of solar pumps through the Kano State Agro-pastoral Development Project (KSADP) in collaboration with Sasakawa. However, in Kaduna State, government initiatives aimed at providing solar pumps to irrigation farmers have primarily focused on formal irrigation schemes, leaving many informal, farmer-controlled schemes in areas like Kargarko without support and with notably low SPIS awareness.

The public sector's role is further hindered by fragmentation. The intended function of institutions like States' Ministries of Agriculture and Agricultural Development Agencies (ADPs) is to provide extension services, create supportive policies, and offer subsidies where necessary. However, findings highlight that policy implementation is fragmented and cross-ministerial coordination is often weak. This lack of a cohesive policy framework and weak coordination between government, energy, and environmental agencies limits the potential for a unified push for SPIS adoption.

Financial institutions, though identified as critical supporting organizations, are reluctant to finance smallholder farmers. While institutions like the Bank of Agriculture and microfinance banks have the potential to offer tailored loan products, commercial banks are often hesitant to fund smallholder ventures due to perceived high risks and past experiences with farmers. This creates a significant disconnect, where farmers express a strong preference for individual ownership but are unable to access the necessary capital to overcome the high upfront costs associated with it. Special intervention projects also include components that promote solar irrigation solutions. For example, REA, under the National Electrification Programme and as the implementing agency of the World Bank's $ 750 million Distributed Access through Renewable Energy Scale-up (DARES) facility, focuses on expanding energy access to underserved communities, including through mini-grids and standalone solar systems. While REA does not explicitly target irrigation, the potential for private developers working with REA in the DARES project to develop solutions focusing on smallholder irrigation is noteworthy.

[8] https://agronigeria.ng/nec-approves-national-rollout-of-solar-powered-irrigation-pumps/#:~:text=The%20council%20met%20for%20its,at%20supporting%20small-scale%20farmers.

The role of NGOs and development projects, such as Sasakawa and FADAMA-AF, is primarily as a facilitator and capacity builder. These organizations bridge the gap between farmers and formal institutions by providing technical training, raising awareness, and coordinating demonstrations to promote sustainable practices. In some cases, they also directly supply equipment as part of incentives or subsidies, as was the case in Kebbi and Kano States. However, their reach is often limited by funding and capacity, which restricts their ability to provide direct support on a widespread scale.

The private sector's role is observed to be one of a fragmented supply chain and a lack of formalized networks. While major distributors import solar equipment, smaller private players struggle with consistent supply and particularly quality control, and larger ones often lack "last-mile" reach to rural areas. This fragmentation leads to the proliferation of lower-quality or uncertified products, particularly in informal markets. Moreover, there is a scarcity of certified technicians and a lack of standardized training for after-sales support, which erodes farmers' confidence in the technology.

The community structures, including traditional rulers and farmer cooperatives, play a pivotal role at the grassroots level. They are crucial for mobilizing communities, fostering trust, and can act as collective bargaining units for shared ownership models. However, their capacity for formal engagement with external stakeholders, such as large financial institutions and private companies, is often limited, which can impede larger-scale initiatives.

Table 2: Showing the Various Institutions for SPIS

Institution Type	Institutions/Actors	Role/Function	Notes
Government Agencies	- State Ministries of Agriculture - Agricultural Development Programmes (ADPs)	- Policy development and extension services - Subsidy provision - Equipment distribution	Fragmented implementation; weak cross-ministerial coordination
Federal/State Projects	- ACReSAL - KSADP - FADAMA-AF - NASENI	- Distribute equipment - Support awareness and training	ACReSAL is active in Kebbi; KSADP & Sasakawa in Kano; Kaduna focuses on formal irrigation
NGOs & Development Orgs	- Sasakawa - FADAMA-AF - Other local NGOs	- Capacity building - Demonstrations and training - Technical assistance	Facilitate adoption and bridge farmers with formal institutions; limited by funding
Financial Institutions	- Bank of Agriculture - Microfinance Banks - Commercial Banks	- Offer (potential) loan products - Provide financial services	Risk-averse; commercial banks reluctant to lend to smallholders; disconnect between farmer demand and finance
Private Sector	- Major solar equipment distributors - Local retailers - Independent technicians	- Supply and distribution of solar irrigation equipment - Maintenance and repair services	Fragmented supply chain; quality control issues; lack of certified technicians; limited rural access

Community Structures	- Farmer cooperatives - Traditional leaders	- Mobilize communities - Foster trust - Coordinate group-based models	Critical at the grassroots level but limited in formal engagement with banks/private sector
Farmers	- Smallholder individual farmers -Informal irrigation scheme participants	- End users and primary stakeholders - Express preference for ownership	High interest in SPIS but face awareness and capital constraints

3.3 Intervention and support for SPIS

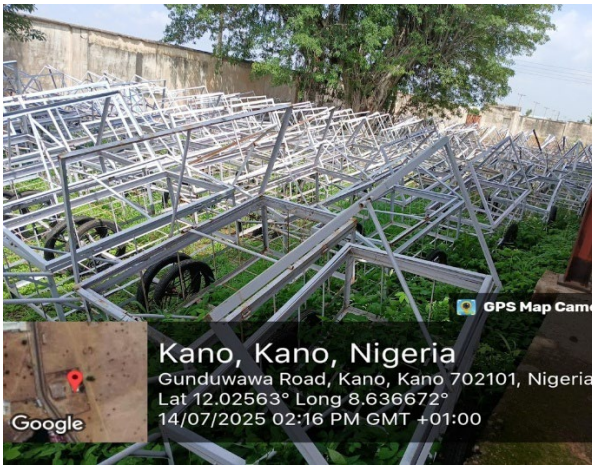
Kebbi State. Intervention and support are most visible and impactful in Kebbi State, largely driven by large-scale projects and government initiatives. The introduction of SPIS has notably occurred within the last three years, marking a significant push towards modernizing agricultural practices. The State government has been at the forefront of this initiative, distributing a substantial 10,000 units of both 2-inch and 3-inch solar pumps along with their necessary accessories. These units were provided as direct grants to farmers across the state, facilitated through the Kebbi Agricultural Supply Company (KASCO). Complementing these efforts, the ACReSAL programme has also contributed significantly, having already distributed 500 units. Looking ahead, the ACReSAL programme is poised to further expand its reach by providing an additional 300 units to farmer groups within the state soon. In addition, in a clear commitment to support local farmers, who constitute most of the population, the state governor has publicly promised to give an additional 20,000 free solar pumps to farmers statewide. This combination of grants has created a more robust support environment compared to the other states.

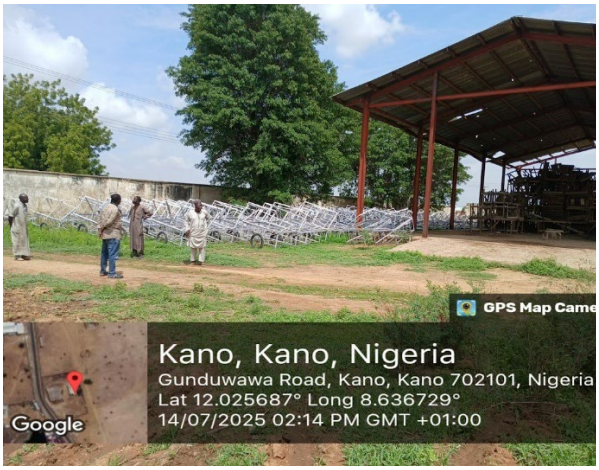
In a chat with the Permanent Secretary, MoA, Kebbi State

With the ACReSAL State Coordinator, Kebbi State

Kano State. In Kano State, support for SPIS is also evident but appears to be more project-specific and collaborative. Sasakawa, in conjunction with the Kano State Agro-pastoral Development Project (KSADP), which is jointly funded by the Kano State Government, the Islamic Development Bank (IsDB), and the Lives and Livelihood Fund (LLF), has successfully distributed 1,000 smart irrigation pumps to farmers. These distributions were provided to farmers in the form of grants, aiming to directly support agricultural productivity. Based on the valuable feedback received from this exercise, Sasakawa is now planning an enhancement to these systems: they are set to increase the number of solar panels to three, each with a capacity of 320 watts, to achieve a higher yield of water. An innovative mobility solution has also been introduced, with the incorporation of carts to facilitate the easy movement of panels across various farm fields. These ongoing efforts and strategic distributions underscore a commitment to improving access to

efficient and adaptable irrigation solutions for farmers in Kano State. Moreover, the presence of financial institutions, such as Jaiz Bank and Alternative Bank, that have shown interest in the SPIS initiative, suggests a potential for future financial products and support. However, the support seems to be tied to these specific projects rather than a broad, state-wide policy.



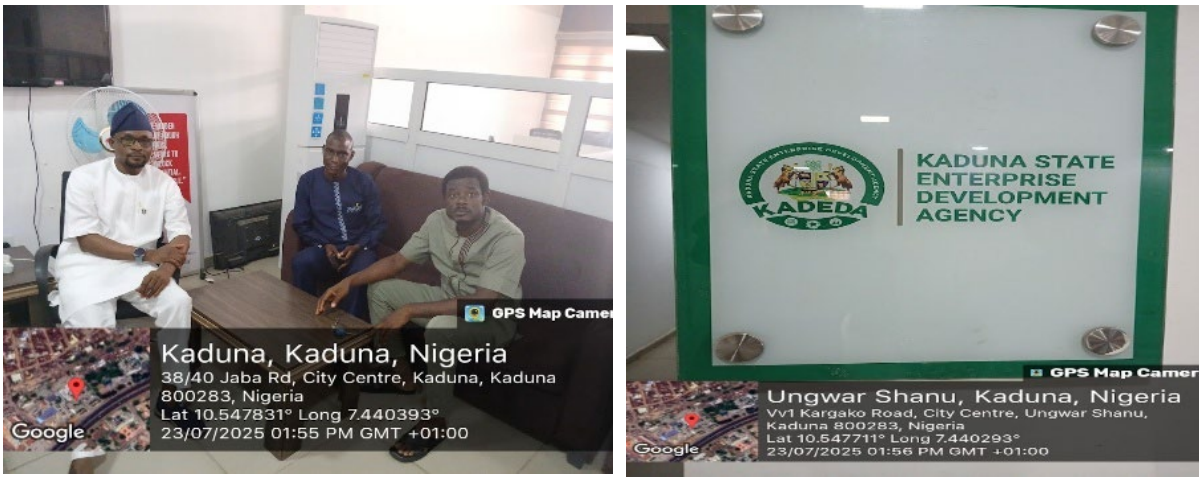


Solar panel carriers/carts billed for distribution to farmers in Kano State by Sasakawa

At the Alternative Bank, Hotoro, Kano

In a chat with Jaiz Bank Manager, Hotoro Branch, Kano

Kaduna State. Kaduna State presents a more uneven and less inclusive picture of intervention and support. The state government has distributed approximately 500 units of SPIS through the Kaduna State Agricultural Development Agency (KADA). The efforts have been principally directed towards its nine (9) formal irrigation schemes across the state. Observations from specific areas, such as Kargarko, where our survey was conducted, reveal a different scenario. The prominent scheme in this area, the Gurara Scheme, operates under the control of the Federal Government. Alongside it, there are numerous informal, farmer-controlled schemes situated around the floodplains. These informal schemes did not benefit from the grants provided by the state government. Consequently, awareness and adoption of SPIS in and around the Gurara scheme remain notably low, indicating a disparity in the reach and impact of the state's distribution efforts. This selective approach created the disparity, where many farmers are left without support and have low awareness of SPIS. The Kaduna State Enterprise Development Agency (KADEDA) has, however, demonstrated the capacity to fund agricultural initiatives, including SPIS, but the focus remains on more structured, formal projects.



At the Kaduna State Enterprise Development Agency

Across all three states, a common issue is the inconsistency and fragmentation of support. There are significant gaps in training and capacity building, with a scarcity of skilled technicians and a lack of consistent after-sales service, which erodes farmers' confidence in the technology. While NGOs like FADAMA-AF, both Kebbi and Kaduna States, are crucial for providing capacity building and grants, their reach is often limited. The high upfront cost of SPIS remains the most significant barrier, and while financial institutions have shown interest, their traditional, stringent requirements often make loans inaccessible to most smallholder farmers. The true picture, therefore, is one of promising but scattered efforts that have yet to fully address the systemic challenges of finance, technical expertise, and equitable distribution.

3.4 Solar irrigation supply chain and support systems

The solar irrigation supply chain in Nigeria is a layered system that begins with international manufacturers and importers, moving through national distributors, regional dealers, and local vendors before reaching farmers. Local firms and installers play a key role in setting up systems, but weak after-sales services, limited skilled technicians, and scarce spare parts—especially in rural areas—remain major challenges. This structure highlights both the opportunities for access and the persistent gaps undermining long-term sustainability.

Importers and Wholesalers

The importation and wholesale distribution of solar-powered irrigation systems (SPIS) in Nigeria are dominated by a few major companies, such as Exulted Eagles Solar Co. and A.B. Ramadan Solar, which source equipment internationally and supply to regional depots in cities like Kaduna, Kano, Port Harcourt and Abuja. These firms act as key intermediaries, channeling products to smaller retailers, installers, and government or donor-led projects. However, the market remains fragmented, with informal importation and wholesale practices contributing to the spread of uncertified, lower-quality products—especially in major trading hubs such as Lagos, Sokoto, and Kano. This uneven structure creates both opportunities for market expansion and risks of eroded farmer confidence due to poor quality control and weak after-sales support.

Distributors and Sales Points

Distributors and sales outlets for SPIS operate through both formal and informal channels. Larger distributors often maintain regional branches or partnerships with state-level projects, while smaller vendors and local dealers in urban and peri-urban markets serve as primary sales points for farmers. Informal sales dominate the market for portable pumps, but these channels frequently lack quality assurance, technical guidance, and reliable after-sales service. As a result, while distributors and

sales points are critical for farmer access, the absence of standardized networks and certified products continues to limit trust and widespread adoption.

After-sales and Maintenance Services

After-sales and maintenance services for SPIS in Nigeria are weak and inconsistently available, especially in rural areas. Farmers often struggle to access spare parts or certified technicians, leading to delays in repairs and reduced confidence in the technology's durability. While some major distributors provide limited support through regional depots, most informal vendors lack structured service systems, leaving farmers reliant on ad-hoc local technicians. This gap in reliable maintenance undermines long-term adoption and highlights the need for standardized training, certification, and stronger service networks.

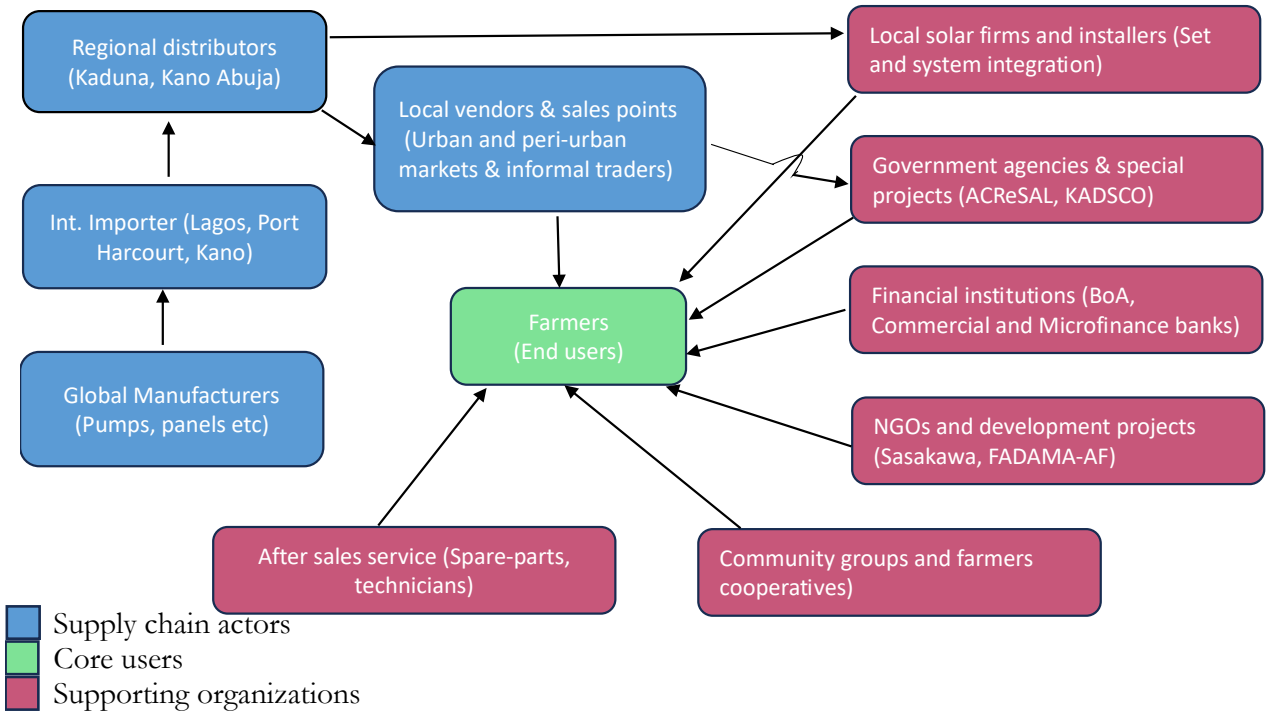


Figure 2: Solar Irrigation Supply Chain and Support Systems in Nigeria

Critical supporting organizations

Driving successful agricultural and community development initiatives hinges on a robust network of supporting organizations. These organizations and institutions are possible and essential providers of resources, expertise, and vital connections that will enable the SPIS initiative to achieve lasting and widespread impact. The exploration into these critical organizations highlights their diverse roles, drawing on specific presence in Kebbi, Kano, and Kaduna States in Nigeria.

(1) *Financial Institutions:*

- Bank of Agriculture (BoA): A federal development bank with a mandate to support agriculture, offering potential for tailored loan products. BoA branches in the 3 states were reached. The headquarters in Kaduna was also contacted
- Microfinance Banks: Located closer to rural communities, these banks can provide accessible, albeit smaller, loans to individual farmers or small groups. Bunkasa Microfinance Bank is in Jere and has indicated interest.

- Commercial Banks: While generally requiring more stringent collateral, some commercial banks have agricultural financing windows that could be explored for larger cooperative projects. Access and UBA banks in Birni Kebbi, Jaiz Bank and Alternative Bank Hotoro, Kano indicated possible interest with the SPIS initiative.

(2) Government-Related Agencies and Projects:

- Kebbi Development Fund (KDF), Kebbi State, engages in local development and has the potential for SPIS initiative. It had a successful outing with the Anchor Borrower Programme (ABP) of the Federal Government of Nigeria in the state through the Access Bank.
- Kebbi Agricultural Supply Company (KASCO) is an input provider; KASCO could integrate solar solutions into its offerings or support.
- Kano State Agro-pastoral Development Project (KSADP) [Kano State], collaborating with partners like Sasakawa Africa Association, KSADP is involved in various agricultural development interventions, including those that could leverage solar technology. They also distributed 1000 units to farmers in the last 3 years in Kano state, and are further making efforts to increase the number.
- Kaduna Enterprise Development Agency (KEDA), Kaduna State, is a state agency promoting enterprise. KEDA has demonstrated the capacity to fund agricultural initiatives, including SPIS.

(3) Non-Governmental Organizations (NGOs)

- ACReSAL Project in Kebbi State, for example (also in other states), is a World Bank-assisted project with a focus on climate resilience, actively involved in procuring and distributing solar-powered irrigation machines. They distributed 500 units of SPIS and added about 2,000 units in the Kebbi state
- Sasakawa Africa Association (SAA) is active in agricultural extension and technology dissemination across various states, partnering with government projects like KSADP.
- FADAMA-AF is crucial for direct project implementation as they are present in the three states, building essential farmer capacity, technical expertise, and giving grants through strengthened Agricultural Development Programmes (ADPs) in the states.

(4) Other Critical Support Systems

- Agricultural Development Programme (ADPs) are the state's extension bodies, crucial for disseminating information and training farmers on solar irrigation best practices.
- Active Community Groups and Farmer Cooperatives abound in the communities. These local structures are vital for collective action, shared ownership models, and peer-to-peer learning, and can serve as direct beneficiaries and implementation partners.

3.5 Farmers' investment in SPIS

Farmers' investment in solar-powered irrigation in Kebbi, Kano, and Kaduna states is a complex issue, characterized by high interest, significant barriers, and a clear preference for individual ownership. The recent removal of fuel subsidies has dramatically increased the cost of traditional fuel-powered pumps, intensifying farmers' interest in solar alternatives despite a low overall adoption rate. The key findings paint a picture of this dynamic across the states.

Adoption. The adoption of solar-based irrigation systems (SBIS) is currently very low among smallholder farmers in the States, lowest in Kaduna. Despite the immense potential due to abundant solar resources and accessible shallow groundwater, farmers in these states still predominantly rely on costly and inefficient fuel-powered pumps. This slow adoption is a direct result of several systemic barriers, including the high upfront cost of SPIS, a weak supply chain, and a lack of reliable technical support.

Willingness to Invest. The willingness of farmers to invest in SPIS has been significantly heightened by the rising costs of fuel. The economic pressure from the fuel subsidy removal has made the operational savings of solar technology an increasingly attractive proposition. However, this willingness is often met with skepticism, stemming from affordability concerns, inconsistent equipment quality, and the lack of reliable after-sales services. Successful initiatives, such as the Dankwali Rice Cluster in Kebbi (See next section), demonstrate that when these barriers are overcome, farmers are not only willing to invest but are also capable of self-organizing to manage shared systems effectively.

Ability to Invest. A significant barrier to farmer investment is the high upfront cost of the technology, which most smallholders struggle to afford. This financial constraint is compounded by the fact that smallholder farmers have limited access to affordable credit and tailored loan products from financial institutions. Though a successful model in the Kebbi Anchor Borrowers Programme (ABP), discussed in the next section, where a required 30% farmer equity contribution was a key factor in its success, can be leveraged on. This model demonstrates that with a structured financial framework and support, farmers can contribute to the investment, which also enhances their commitment and reduces default risk.

Farmers in Kebbi, Kano, and Kaduna states are increasingly interested in adopting SBIS as the recent removal of fuel subsidies makes traditional pumps less viable. This heightened willingness to invest is driven by the significant operational savings offered by solar technology. While adoption rates are currently low, the success of initiatives like the Dankwali Rice Cluster in Kebbi demonstrates that farmers are capable of self-organizing and managing shared systems effectively when supported. Also, the Kebbi Anchor Borrowers Programme proved that with a structured financial framework, such as a 30% farmer equity contribution, farmers can contribute to their own investment, which strengthens their commitment. These examples show that with the right support and financial models, farmers are poised to embrace SBIS to enhance their agricultural practices.

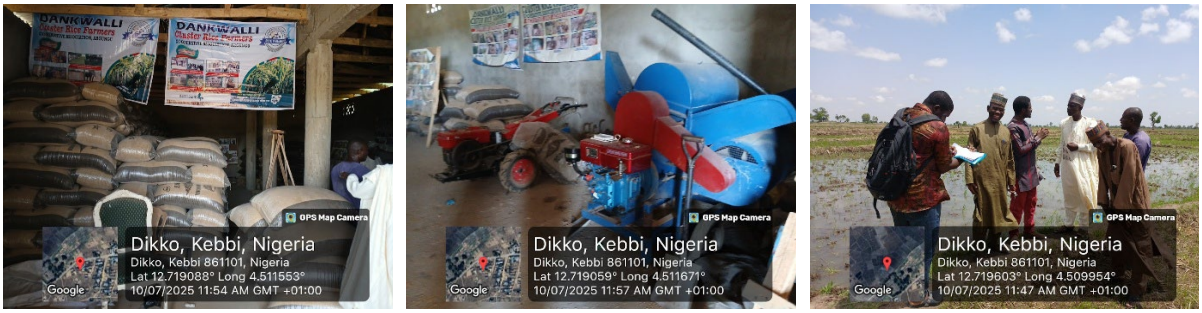
Besides, for a typical rice farmer cultivating one hectare, reliance on fuel-powered pumps requires about ₦7,000 to ₦9,000 per irrigation session, with 30–45 sessions per season depending on soil type. This translates into ₦210,000 to ₦405,000 per season, or roughly ₦630,000 to ₦1.2 million per year if two to three rice cycles are attempted. Note that this fuel expenditure does not include the cost of servicing, which must be carried out at least fortnightly for the pump to last three years, adding to production costs. By contrast, an investment of about ₦1 million (including SPIS set and solar panel cart) in SPIS eliminates both recurring fuel and frequent servicing expenses, while ensuring reliable year-round irrigation.

With average yields of 4.5 to 5 MT of rice per hectare per season, and given that a 100 kg bag of rice sells for about ₦60,000 or more, a single harvest can generate ₦1.35 to ₦1.5 million in gross revenue. Critically, while fuel costs often limit farmers to one or two cropping cycles annually, SPIS enables the possibility of up to three rice harvests per year, significantly multiplying output and income. Over just a few seasons, the fuel savings combined with increased production capacity allow the system to effectively pay for itself. Although the upfront cost of SPIS is substantial, the long-term economic benefits, reduced operating costs, avoidance of fuel and servicing expenses, resilience to fuel price volatility, and higher cropping intensity make it a far more sustainable and

profitable investment for smallholder rice farmers compared to continued reliance on fuel-powered pumps.

Ownership and governance models. Farmers overwhelmingly express a strong preference for individual ownership of solar irrigation equipment, perceiving it as the most reliable and efficient model. This inclination stems from the desire for immediate and unrestricted access to the pump, enabling them to irrigate precisely when needed without having to negotiate schedules or face delays. Individual ownership eliminates the complexities and potential conflicts associated with shared resources, such as disputes over usage time, maintenance responsibilities, or payment defaults by others. It also provides a greater sense of security and control over a vital asset, as the owner is solely responsible for its upkeep and performance. For many farmers, the autonomy and direct benefit derived from their own equipment far outweigh the initial capital investment, solidifying individual ownership as their preferred path to solar-powered irrigation.

However, a successful model of shared agricultural equipment, particularly within the surveyed communities, was found to thrive on strong organizational structures, clear rules, and mutual trust. A prime example is the Dankwali Rice Production Cluster in Argungu, Kebbi State (other clusters abound, too, in Argungu and Alkamawa in Kano State). Here, a cooperative model facilitates the sharing of essential equipment, such as pumps, power tillers, and threshers. The success of Dankwali lies in its well-defined governance; members pay a reduced rental price for equipment use, fostering affordability and accessibility. The cooperative also provides inputs to its members and, in turn, receives repayment in the form of paddy rice at harvest. This integrated approach, combined with the fact that members often farm in clusters, ensures efficient equipment deployment and produce collection, creating a self-sustaining system that benefits all participants by reducing individual capital outlay and operational costs while enhancing productivity. This communal approach addresses the significant barrier of high upfront costs for individual farmers and promotes a sense of collective ownership and responsibility.



Dankwali Rice Production Cluster in Argungu, Kebbi State

Numerous communal agricultural equipment initiatives in Nigeria have struggled, despite the potential of shared resources, primarily due to the absence of clear ownership and accountability, which leads to neglect, misuse, and equipment falling into disrepair when no one is tasked with maintenance (Agunbiade, 2015; Lawal, 2025). Disputes over scheduling and access are also common, with more influential members often monopolizing resources, which can cause resentment and disengagement —a frequent theme in discussions of Nigerian cooperative challenges, such as "elite capture" and poor governance (Cooperatives First, 2017). In addition, the lack of a sustainable financial model for repairs, spare parts, and consumables often dooms projects once initial grants are exhausted, while security concerns and a decline in enthusiasm without sustained support also contribute to widespread failures, leaving communities with non-functional machinery and eroded trust (Agunbiade, 2015; Lawal, 2025; Madukwe, n.d.).

For shared SPIS initiatives to succeed among a limited set of individuals, establishing robust mechanisms for usage, maintenance, and repair payments is paramount. This directly prevents conflicts and ensures the equipment's long-term functionality. It is crucial to implement clear,

mutually agreed-upon rules governing pump usage schedules, ensuring equitable access for all co-owners and preventing monopolization by any single individual. Additionally, a strong and accountable leadership structure will be responsible for enforcing established rules, managing financial contributions for upkeep, overseeing maintenance tasks, and mediating any disputes swiftly and fairly, thereby fostering trust and ensuring the shared solar irrigation system's enduring viability.

3.6 Systemic Barriers and Opportunities in the SPIS Ecosystem

Barriers

The high upfront cost of SPIS and the severely limited access to finance remain the most critical barriers to adoption across all Focus Group Discussions (FGDs) conducted in Kebbi, Kano, and Kaduna (Figure 3). This view was echoed in several Key Informant Interviews (KIIs) as well, with more than 70% of respondents, including officials in the MoAs, ADPs, FADAMA offices, and cooperative leaders, stressing that most smallholder farmers simply cannot afford the initial investment without external support. Traditional financial institutions are ill-suited to farmers' needs, often imposing stringent collateral requirements and interest rates that effectively exclude smallholders. Moreover, low levels of awareness about SPIS benefits and operation, coupled with challenges linked to land tenure and shared infrastructure, further discourage long-term investment in irrigation technology.

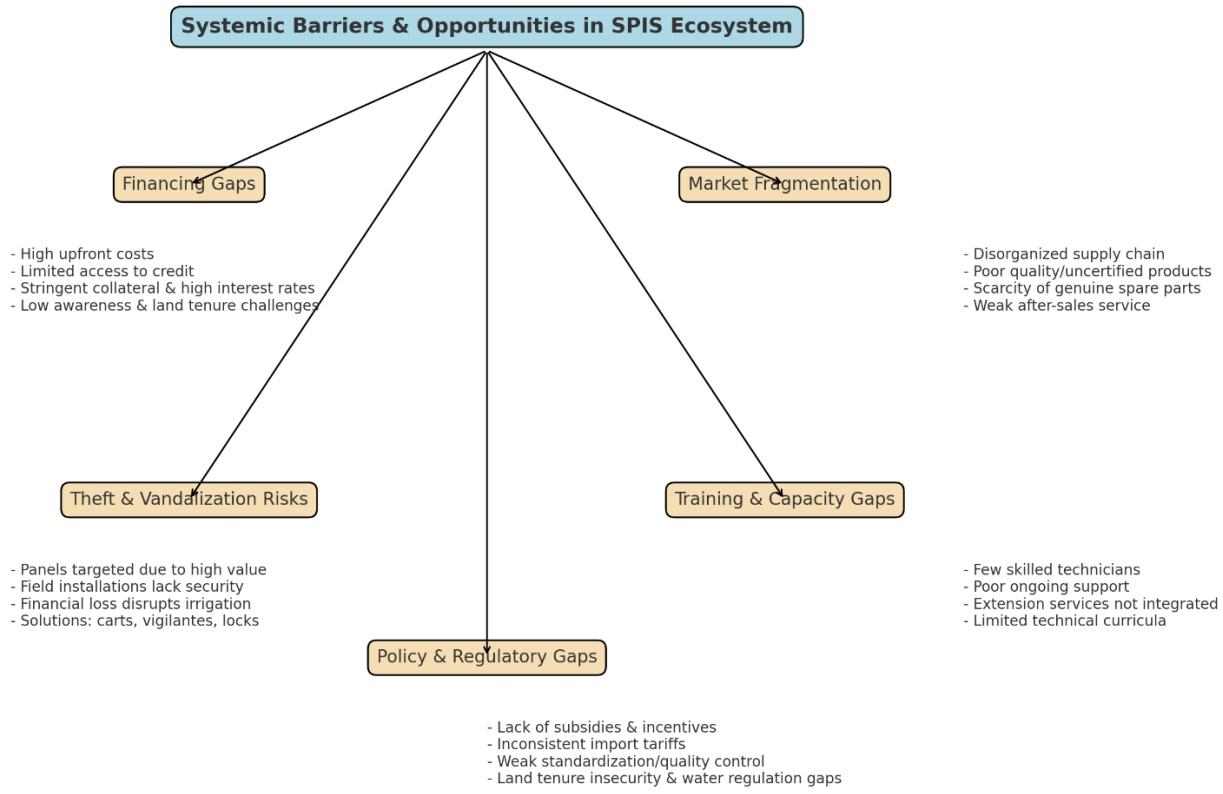


Figure 3: Thematic systemic barriers to SPIS

Fragmented market and disorganized supply chain is the second most critical barrier to the adoption of SPIS, as highlighted in nearly all FGDs and reinforced by about 60% of KII respondents (particularly cooperative leaders and state agricultural officials). This systemic weakness erodes farmer trust in the technology and creates long-term sustainability concerns. Farmers and stakeholders noted that the absence of a cohesive supply chain has led to the proliferation of

uncertified or poor-quality products, alongside a scarcity of genuine spare parts in rural markets. This makes maintenance both costly and unreliable. In addition, the lack of standardized training for local technicians results in weak after-sales service, leaving farmers vulnerable when systems fail. According to respondents, this fragmentation compounds the financing barrier, as even those willing to invest hesitate when they cannot be assured of consistent quality, reliable servicing, or affordable spare parts—making the supply chain gap the second-ranked constraint to scaling SPIS across the states.

Theft and vandalism of solar panels installed in the field is a significant barrier identified in both FGDs and KIIs, particularly among farmers in Kebbi and Kano. Farmers reported that the high value of solar panels makes them attractive targets, especially in isolated farm locations without security. Such risks create strong disincentives for farmers to invest in SPIS, as losing panels or pumps not only represents a major financial setback but also disrupts irrigation schedules and undermines trust in the technology's viability. For smallholders already struggling with high upfront costs, the prospect of theft makes adoption appear even riskier. Some solutions can be the use of solar panel carts, which allow farmers to move panels back to their homes or community centers after irrigation, reducing exposure to theft in the field. In addition, farmers with plots located in close proximity can pool resources to collectively hire local vigilantes or community-based security groups to guard shared installations, especially for cooperative or group-owned systems. These strategies not only address the theft and vandalism barrier but also strengthen collective action and trust among farmers. Addressing this challenge presents opportunities for targeted support. Equipment suppliers can design more affordable, mobile panel cart options suited to smallholders, while government and NGOs could integrate community-based security models into cooperative SPIS projects. Over time, developing innovative, farmer-friendly security solutions, whether through technology (e.g., anti-theft panel locks) or social structures (e.g., community guards), will be critical to ensuring farmers' confidence in making long-term investments in SPIS.

A significant training and capacity gap exists in the widespread availability of skilled technicians for installation, operation, and particularly, maintenance and repair, especially in remote areas. Local solar equipment firms and installers often provide initial setup, but ongoing support is inconsistent. Agricultural Development Programmes (ADPs), as state extension bodies, are critical actors here. They can integrate solar irrigation training into their extension services, disseminating best practices for usage and basic troubleshooting. Non-Governmental Organizations (NGOs) like Sasakawa Africa Association (SAA), already active in agricultural extension with KSADP, can expand their training programmes to include solar technology, potentially partnering with technical/vocational training centers to develop specialized curricula for solar irrigation technicians. Community groups and farmer cooperatives can also serve as hubs for peer-to-peer training, facilitated by expert organizations.

The existing policy and regulatory environment present a mixed bag and gaps for SPIS adoption. While there's a general push for agricultural development and renewable energy, specific policy gaps impede widespread SPIS uptake. These include a lack of clear, long-term subsidies or incentives specifically for solar irrigation, inconsistent import tariffs on components, and insufficient standardization or quality control mechanisms for solar equipment entering the market. Policies around land tenure often create insecurity for farmers, discouraging long-term investments like SPIS. Furthermore, a fragmented approach to water resource management can lead to unsustainable groundwater extraction, which SPIS adoption could exacerbate without proper regulation. Effective policies are needed to encourage local assembly/manufacturing, reduce import barriers for quality components, and provide structured financial support to farmers and SPIS providers.

Addressing these gaps through collaborative efforts between financial institutions, government agencies, NGOs, and local community structures will be vital for scaling up solar irrigation adoption and ensuring its long-term success and sustainability for Nigerian farmers.

Opportunities

While critical systemic barriers exist, there are also inherent opportunities for strategic intervention in scaling SPIS around the study areas (Figure 4). Significant opportunities exist to scale Solar-Powered Irrigation Systems (SPIS) through coordinated financial, institutional, and market interventions. Financial institutions—including the Bank of Agriculture, microfinance banks (such as Bunkasa Microfinance Bank), and interested commercial banks (like Access, UBA, Jaiz, and Alternative Bank)—can design tailored, farmer-friendly loan products with flexible repayment schedules and relaxed collateral requirements. Meanwhile, government agencies such as the Kebbi Development Fund (KDF), Kebbi Agricultural Supply Company (KASCO), Kano State Agro-pastoral Development Project (KSADP), and Kaduna Enterprise Development Agency (KEDA) can catalyze adoption by providing subsidies, grants, or establishing revolving funds to make SPIS technologies more affordable for smallholder farmers.

Addressing market fragmentation offers another key opportunity. National and regional distributors can strengthen last-mile delivery networks and ensure the availability of genuine spare parts, while government projects like ACReSAL can develop sustainable maintenance frameworks through technician training and supply chain development. NGOs can complement these efforts by establishing community-based maintenance and service models, which foster local enterprise, enhance trust, and improve long-term sustainability.

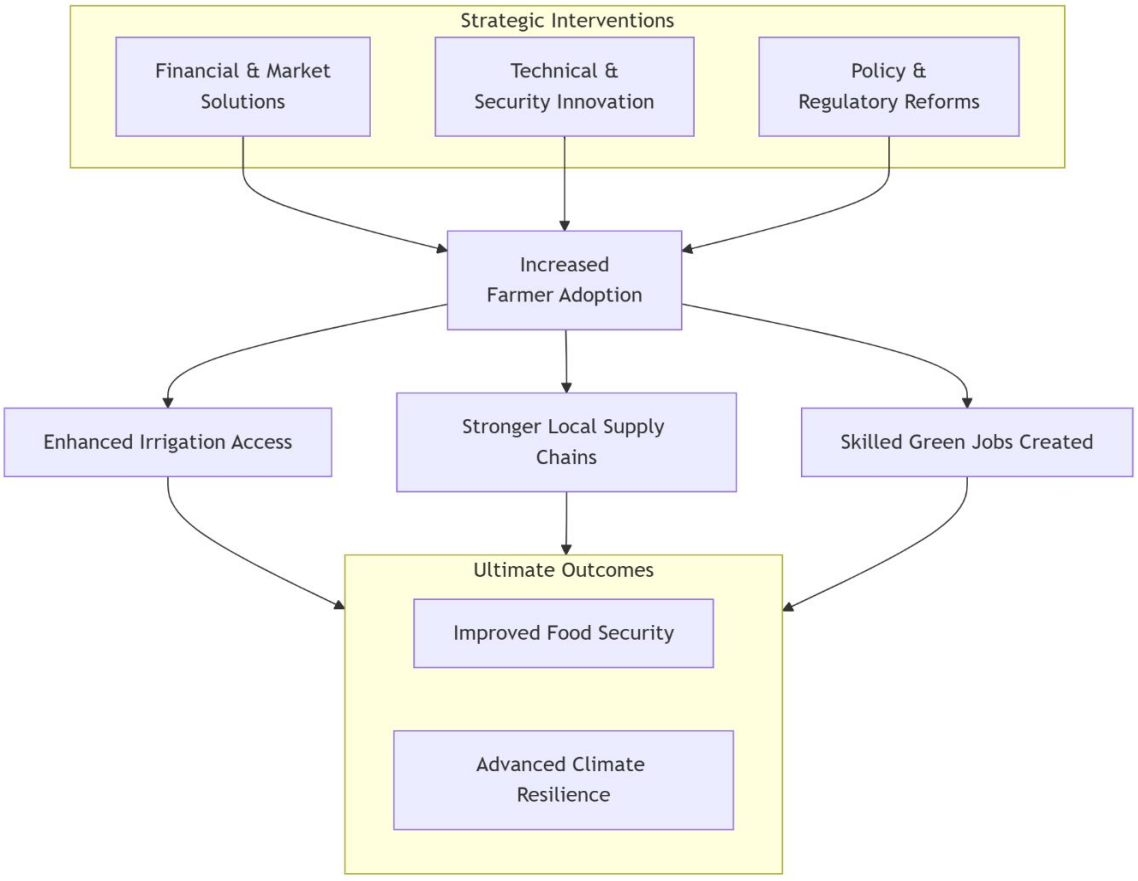


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Figure 4. Opportunities and drivers for the adoption of SPIS

Further opportunities lie in innovation and capacity building—developing mobile or theft-resistant solar technologies, community security arrangements, and technical training programs through ADPs, NGOs (e.g., SAA), and vocational centers. At the policy level, reforms promoting local assembly, consistent import tariffs, and quality assurance can stimulate private-sector participation.

Together, these interventions can expand irrigation access, improve food security, create green jobs, and advance Nigeria's climate resilience and rural development goals.

3.7 Pathways for Scaling SPIS in Kebbi, Kano, and Kaduna States

Based on a comprehensive analysis of the institutional environment, intervention and support mechanisms, the solar-powered irrigation supply chain, farmer investment patterns, and the systemic barriers and opportunities, we have identified and detailed three pathways for SPIS expansion in Kebbi, Kano, and Kaduna States; each pathway leverages different combinations of actors, financing strategies, and governance structures to address the complex challenges within the three states. These pathways include:

- Enabled collective and individual investment and ownership in solar-based irrigation
- Develop a structure for solar-based irrigation services
- Foster the self-sustaining SPIS ecosystem

Deployment of these pathways is expected to achieve significant outcomes and impact that include, but are not limited to:

- 30,000 smallholder farmers gain access to solar irrigation solutions.
- 50,000 hectares supported under solar-based irrigation.
- At least 10,000 jobs created along irrigated agricultural value chains.
- Increase in annual yields of irrigated crops per unit area (30–50% improvement).
- Improved food security, reduced poverty, and enhanced climate resilience.
- Support additional investment of USD250 million to expand irrigated agriculture and increase food production in Nigeria.
- 30–40% reduction in irrigation-related GHG emissions.
- 20 structures established to provide solar-based irrigation services at a large scale.
- Women will experience greater economic empowerment through reduced labor and new agribusiness opportunities.
- A thousand local technicians and entrepreneurs will be trained to sustain and expand the green technology ecosystem.

3.7.1 Enabled collective and individual investment and ownership in solar-based irrigation

This pathway centres on individual farmers and farmer cooperatives/groups/enterprises investing and owning solar-based irrigation systems that they invest in. Key ***activities*** in this path include:

- **Accelerate individual ownership of solar-based irrigation systems with tailored financing:** Individual farmers acquire and own Solar-Powered Irrigation System (SPIS) units through access to flexible financial products. This activity is primarily driven by the collaborative efforts of financial institutions providing capital, government agencies offering crucial subsidies, and Non-Governmental Organizations (NGOs) facilitating farmer mobilization. The key mechanisms enabling this model include low-interest loans, advantageous grace periods, reduced collateral requirements, or innovative equity models, such as the 30% farmer equity contribution seen in the Anchor Borrowers Programme (ABP). Its primary strengths lie in ensuring high individual accountability for the system,

providing farmers with complete autonomy in its use, and effectively reducing potential scheduling conflicts often associated with shared resources. However, this model carries inherent risks, as it tends to be limited to well-off or creditworthy farmers, and it also entails a persistent risk of loan default.

- **Deploy Pay-As-You-Go (PAYG) and Leasing Models:** Farmers pay incrementally for the use of Solar-Powered Irrigation System (SPIS) units, frequently utilizing mobile payment systems. This innovative approach is primarily driven by Non-Governmental Organizations (NGOs), the private sector, and FinTech providers. The key mechanisms involve farmers making monthly installment payments, with the equipment remaining provider-owned until the full repayment is completed. The main strength of this model is its ability to significantly reduce the upfront financial barrier, thereby making SPIS accessible to a broader range of smallholder farmers. However, it also carries inherent risks, including the requirement for a high administrative and technological setup, and the necessity for reliable tracking of farmers' income to ensure consistent repayments.
- **Catalyse cooperative ownership model (Cluster-Based):** Farmers will form new, or strengthen existing, cooperatives to jointly own and manage Solar-Powered Irrigation System (SPIS) units. This model is primarily driven by the engagement of community groups, existing farmer cooperatives, and the crucial involvement of traditional institutions. Its mechanisms rely on establishing shared governance structures, clear and transparent usage rules, and pooled maintenance fees, ensuring collective responsibility. The primary strengths of this approach include significantly reducing the individual cost burden for farmers, promoting effective peer monitoring among members, and proving ideal for clustered farm settings, as exemplified by the successful Dankwali Rice Cluster. However, this model is not without its risks, notably the potential for governance failure, elite capture where benefits are disproportionately held by a few, and conflicts arising over usage if the established rules are weak or poorly enforced.
- **Provide integrated financial and technical support to farmers and SBIS investors**: This activity ensures the simultaneous provision of accessible, tailored financing and robust technical assistance to farmers and farmer cooperatives/groups/enterprises. It's not enough to just offer loans; these must be tailored to farmers' realities, featuring flexible repayment schedules, lower interest rates, and potentially reduced collateral requirements, as envisioned with entities like the Bank of Agriculture (BoA) or microfinance banks. This financial bridge must be seamlessly coupled with the supply of high-quality, durable solar components and professional installation. Farmers need assurance that their investment will yield reliable, long-term returns. Technical support extends beyond initial setup to include hands-on training for farmers on operation and basic troubleshooting, along with the availability of skilled technicians for maintenance and repairs. This holistic approach builds farmer confidence, ensures optimal system performance, and justifies the upfront investment by guaranteeing sustained operational benefits and reduced running costs.

Successful deployment of this pathway requires certain resources, partners and partnerships.

Resources needed

Based on the pathway described, the successful deployment of individual and cooperative investment in solar-based irrigation requires a combination of financial, human, and technical resources. Financially, a substantial and accessible capital base is essential. This includes dedicated funds, say up to 100 million dollars, for providing low-interest loans, leasing arrangements, and subsidies to reduce upfront costs for farmers. Furthermore, resources must be allocated to develop

and manage the technological infrastructure for Pay-As-You-Go (PAYG) systems and to create risk-guarantee facilities that protect financial institutions against potential loan defaults, thereby encouraging their participation.

Beyond capital, critical human and physical resources are needed. This involves a skilled workforce for technical tasks, including certified installers and maintenance technicians to ensure the longevity and efficiency of the systems. A robust supply chain for high-quality, durable solar components—such as panels, pumps, and efficient irrigation equipment—must be established to prevent bottlenecks and ensure reliability. Finally, resources must be dedicated to capacity building, including training programs for farmers on system operation, financial management for cooperatives, and support for partners to effectively mobilize and educate potential beneficiaries.

Stakeholders, partners and partnership

For a successful solar irrigation initiative, there are a few central actors working in concert, as successful initiatives have taught. In the case of the Dankwali Rice Production Cluster in Argungu, the farmers themselves, organized into a robust cooperative, formed the core of the success. Their ability to self-organize and adhere to established rules for shared equipment usage, often facilitated by strong local leadership, was paramount. Key factors aiding their success included a transparent system for cost and profit-sharing for maintenance and investments, and a mutually beneficial arrangement for repaying inputs with harvested paddy. This integrated approach fostered collective responsibility and ensured the long-term viability of their shared resources.

Similarly, the success of the Anchor Borrowers Programme (ABP) collaboration in Kebbi State offers another powerful illustration of effective multi-actor engagement. Here, the Kebbi Development Fund (KDF) acted as a pivotal facilitator and fund manager, forging a crucial partnership with a commercial bank (Access Bank) to unlock financial access for farmers. A significant factor in this programme's success was the strategic involvement of traditional institutions, which leveraged their deep community ties to accurately identify genuine farmers. This crucial step helped in mitigating moral hazard and ensuring resources reached the intended beneficiaries. In addition, the requirement for farmers to pay a 30% equity stake before accessing ABP loans instilled a sense of ownership and commitment, drastically reducing default risks. This collaborative ecosystem, encompassing KDF, Access Bank, off-takers, traditional leaders, and the farmers themselves, exemplifies how shared accountability and a commitment to direct farmer engagement can overcome significant financial and logistical hurdles, paving the way for widespread adoption.

Building on the successful lessons learned from initiatives like the Dankwali Rice Production Cluster and the Kebbi ABP, a multi-faceted approach to collaboration and partnership is essential for a successful SPIS (Solar Powered Irrigation System) scaling pathway in Nigeria. No single entity can drive widespread SPIS adoption alone; success is often a result of synergistic partnerships. A compelling example of such successful collaboration is the Kebbi Development Fund (KDF)'s experience with the Anchor Borrowers Programme (ABP) in Kebbi State. Working closely with Access Bank, KDF effectively leveraged the influence of traditional leaders to identify genuine farmers. This model also required farmers to pay a 30% equity stake before accessing ABP loans, ensuring commitment and reducing default risks. This collaborative ecosystem, involving KDF, Access Bank, off-takers, traditional institutions, and the farmers themselves, highlights how integrated efforts can overcome significant hurdles. The private sector, encompassing importers, distributors, and local installers, is essential for ensuring the availability of quality technology and efficient market delivery. In addition, linking these efforts with various financial institutions ensures that the necessary capital is accessible. This multi-stakeholder approach ensures a comprehensive response to the complex challenges of affordability, access, and sustainability.

3.7.2 Develop a structure for solar-based irrigation services

This pathway centres on developing technological, business, and institutional structures to provide solar-based irrigation as services to smallholder farmers, especially for those at the bottom of the pyramids of the market. Key activities in this path include:

- **Establish community-managed rental/service Hub:** Community-managed enterprise would own Solar-Powered Irrigation System (SPIS) units and then rent them out to individual farmers. This is primarily driven by the active participation of cooperatives, Non-Governmental Organizations (NGOs), and local entrepreneurs. The key mechanism involves these solar service providers charging a fee for irrigation per session or per season. This activity provides shared access to SPIS without requiring individual farmers to bear the burden of full ownership, and it also contributes to local economic development by creating jobs for local operators. However, this model carries inherent risks, such as potential coordination challenges among community members or the enterprise, and the critical need for a solid business model and robust governance structures to ensure its long-term viability.
- **Develop Public-Private Partnership (PPP) Distribution Scheme:** Government entities, the private sector, and Non-Governmental Organizations (NGOs) will coordinate efforts to distribute Solar-Powered Irrigation Systems (SPIS) bolstered by subsidies, comprehensive technical training, and reliable after-sales support. This activity is primarily driven by the active participation of government agencies such as KSADP, KEDA, and KDF, alongside NGOs like FADAMA and ACReSAL, and private importers and installers. Its mechanisms involve public procurement combined with private installation services, complemented by NGO-led capacity building initiatives. The key strengths of this approach include a coordinated rollout, ensuring standardized quality of equipment and services, and a significant potential for widespread scaling. However, inherent risks include potential bureaucratic delays and challenges in ensuring sustainability beyond the initial project phase.
- **Increase off-taker–backed SPIS access:** Agribusinesses, acting as off-takers, will provide Solar-Powered Irrigation Systems (SPIS) or direct financing for them in return for produce contracts from farmers. This activity is primarily driven by the involvement of off-takers themselves, supported by financial institutions and farmer cooperatives. Its key mechanisms involve an embedded finance structure, where SPIS units are provided on credit, and the repayment is directly tied to, and often facilitated by, the proceeds from the farmers' harvest. It is a built-in repayment structure that simplifies financial transactions and provides farmers with guaranteed market access for their produce. However, it also carries inherent risks, such as a potential power imbalance between the off-taker and the farmer, and the exposure of farmers to price volatility risks in the agricultural market.
- **Deploy grant-driven government/NGO distribution:** Solar-Powered Irrigation System (SPIS) units will be provided to farmers as demonstration or at heavily subsidized rates, typically managed by government entities or Non-Governmental Organizations (NGOs). It is primarily driven by large-scale government projects, such as ACReSAL and KASCO, and by various international donors. The main mechanism involves the direct distribution of SPIS units, usually accompanied by basic training for farmers. This activity builds capacity for rapid deployment and its effectiveness in directly addressing the significant affordability gap faced by many farmers. However, it also carries notable risks, including the potential for poor ownership leading to underutilization or neglect, and limited long-term sustainability if a comprehensive maintenance plan is not integrated into the programme.

- **Strengthen strong community-level governance and cooperative structures**: This fosters a sense of collective ownership and responsibility, contrasting sharply with the common pitfalls of shared resources that lack clear accountability and dispute resolution mechanisms. Where shared equipment is involved, the success hinges on well-defined community governance and strong cooperative models. The example of the Dankwali Rice Production Cluster in Argungu illustrates this perfectly clear, collectively agreed-upon rules for usage scheduling prevent conflicts and ensure equitable access. Crucially, a transparent financial mechanism for contributing towards maintenance, repairs, and potentially even future upgrades (often derived from usage fees or proportional contributions) is established and rigorously managed. An accountable leadership structure, comprising trusted community members, is vital for enforcing these rules, overseeing the financial pool, managing maintenance logistics, and mediating disputes swiftly and fairly.

Successful deployment of this pathway requires certain resources, partners and partnerships.

Resources needed

Based on the service-based pathway described, significant financial and institutional resources are paramount. A substantial initial investment capital, say 50 million dollars, is required to establish community rental hubs, fund Public-Private Partnership (PPP) schemes, and launch grant-driven distribution programmes. This must be supported by dedicated funding streams for subsidies, technical training, and the creation of a robust administrative framework to manage these initiatives and prevent bureaucratic delays. Financial resources are needed to develop and manage the embedded finance structures for off-taker models and to establish a transparent financial pool for the ongoing maintenance and repairs of communally managed assets, ensuring their long-term operational viability.

Concurrently, a strong foundation of human, technical, and physical resources is essential. This includes a reliable supply chain for high-quality, durable solar components to support widespread distribution and a skilled workforce of technicians for installation, maintenance, and after-sales support. Critically, resources must be allocated to build and strengthen institutional capacity at the community level. This involves focused efforts on governance training to establish accountable leadership, clear usage rules, and effective dispute-resolution mechanisms within cooperatives and community enterprises. This human and institutional infrastructure is vital to prevent governance failure, elite capture, and equipment neglect, thereby ensuring the sustainability and equitable impact of the service-based models.

Stakeholders, partners and partnerships

Based on the service-based pathway, a multi-tiered network of stakeholders is essential for success, with each partner playing a distinct yet interconnected role. At the core are the community-level actors, including farmer cooperatives, traditional leaders, and local entrepreneurs. As demonstrated by the Dankwali Rice Cluster, robust cooperatives are the operational backbone for community-managed rental hubs, ensuring equitable access and collective maintenance through strong local governance. Traditional institutions are crucial for mobilizing farmers, legitimizing initiatives, and leveraging social capital to enforce agreements, while local entrepreneurs act as direct service providers, operating and maintaining the rental hubs to create a sustainable local enterprise.

Driving the scaling and coordination of these services requires a synergistic partnership between the public sector, development partners, and the private sector. Government agencies like ACReSAL, state-level ministries, and programmes such as KSADP are pivotal. They provide public funding, subsidies, and policy support, while also leading Public-Private Partnership (PPP) schemes to ensure quality and coordinated rollout. Development Partners and NGOs, including FADAMA

and international donors, complement these efforts by facilitating grant-driven distribution, providing critical technical assistance, and building the governance capacity of community enterprises to mitigate risks of failure.

Finally, ensuring market linkage and commercial sustainability necessitates the active involvement of financial institutions and agribusinesses. Commercial banks and microfinance institutions provide the essential capital for scaling PPP schemes and financing the initial inventory for service hubs, potentially using the equipment as collateral. Agribusiness Off-takers are key partners in the embedded finance model, supplying SPIS units in exchange for produce, thereby guaranteeing farmers a market while securing their own supply chains. This collaborative ecosystem, uniting community initiative, public support, and private sector efficiency, creates a resilient structure capable of delivering irrigation as a service to those who need it most.

3.7.3 Foster the self-sustaining SPIS ecosystem

This path centres on fostering self-sustaining SPIS ecosystem that addresses financial, technical, and social barriers, and other bottlenecks ultimately enhancing agricultural productivity and farmer livelihoods across states. Key activities in this path include:

- **Invest in robust capacity training and After-Sales Support**: Sustainable SPIS adoption fundamentally relies on building local capacity. This involves comprehensive training for local ecosystem actors not just on how to use the pumps, but also on basic maintenance, daily monitoring, and recognizing common issues. Equally important is the development of a strong pool of local technicians capable of installation, complex repairs, and troubleshooting. Agricultural Development Programmes (ADPs) and vocational training centers are critical avenues for this. Beyond training, the consistent availability of genuine spare parts and reliable after-sales service is non-negotiable. Without quick access to repairs and components, a broken pump quickly becomes a disused asset, eroding farmer trust and discouraging further investment. Investing in this localized support infrastructure empowers communities, reduces downtime, and ensures the long-term functionality and economic viability of their solar irrigation systems.
- **Foster strategic financial partnerships for accessibility:** To tackle the high upfront costs, deep collaboration with financial institutions is paramount. This involves working with the Bank of Agriculture (BoA) to expand its agricultural loan offerings with specific, tailored products for SPIS, potentially incorporating longer repayment periods and more flexible collateral requirements. Partnerships with Microfinance Banks (like Bunkasa Microfinance Bank) are crucial for reaching grassroots farmers with smaller, more accessible loans, potentially supported by guarantee funds from development partners or state governments to de-risk lending. Active engagement with Commercial Banks (such as Access Bank, UBA, Jaiz Bank, and Alternative Bank) should focus on developing specialized agricultural financing windows for larger cooperative or cluster-based SPIS projects, drawing lessons from KDF's successful risk-sharing model with Access Bank in the ABP. Government agencies like the Kebbi Development Fund (KDF), Kano State Agro-pastoral Development Project (KSADP), and Kaduna Enterprise Development Agency (KEDA) can initiate dedicated grant schemes, revolving funds, or co-financing arrangements, potentially requiring a farmer equity contribution (e.g., the 30% ABP model) to ensure commitment and ownership.
- **Strengthen SBIS supply chain and technical support through Public-Private Partnerships**: Scaling SPIS requires a robust supply chain that delivers quality technology and reliable after-sales service. Collaboration with private sector importers and distributors

is key to ensuring the availability of high-quality solar panels and pumps across the country. Partnerships with local solar equipment firms and installers are vital for effective last-mile delivery, professional installation, and localized maintenance. State governments, through Agricultural Development Programmes (ADPs) and vocational training centers, should partner with these private firms and relevant NGOs like FADAMA-AF to establish and expand comprehensive capacity-building programmes. These programmes must train a significant pool of local technicians in SPIS installation, troubleshooting, and repairs, simultaneously educating farmers on basic operational best practices and preventive maintenance. This public-private synergy will ensure both the technical expertise and the consistent availability of genuine spare parts, addressing critical bottlenecks in after-sales support.

- **Foster traditional institutions' functions to facilitate community ownership and governance**. For the long-term sustainability of SPIS, especially in communal or shared models, active engagement with and empowerment of community groups and farmer cooperatives is non-negotiable. Lessons from the Dankwali Rice Production Cluster emphasize the need to co-design clear rules for usage, transparent payment systems for maintenance, and effective conflict resolution mechanisms from the outset. Crucially, leveraging the influence and established structures of traditional institutions (as successfully demonstrated by KDF in the ABP) can significantly aid in farmer identification, community mobilization, enforcing collective agreements, and building trust. Their involvement can bridge the gap between formal interventions and local realities, ensuring that programmes are culturally appropriate and widely accepted, thereby mitigating disputes and fostering genuine collective ownership.

Successful deployment of this pathway requires certain resources, partners and partnerships.

Resources:

Based on the goal of fostering a self-sustaining SPIS ecosystem, a significant investment in human and institutional resources is the primary requirement. The cornerstone of this pathway is a comprehensive and continuous capacity-building program. This requires dedicated funding and logistical support to establish and run training centres, develop standardized curricula, and deploy skilled trainers. The objective is to create a self-replicating network of expertise by training a large pool of local technicians in installation, repair, and maintenance, while simultaneously educating farmers, cooperative leaders, and traditional institutions on system operation, financial management, and robust community governance. This human capital development is essential for reducing system downtime, building local ownership, and ensuring the long-term functionality of the technology.

Concurrently, a parallel investment in financial and physical infrastructure is critical to address systemic bottlenecks. This includes the capital to establish financial de-risking instruments, such as guarantee funds for microfinance institutions, and to capitalize revolving loan schemes and grant co-financing arrangements managed by entities like the Bank of Agriculture and state development agencies. Furthermore, resources must be allocated to build a resilient and widespread supply chain, ensuring the consistent availability of high-quality solar components and genuine spare parts across rural areas. This involves supporting private sector partners with logistics and inventory management, as well as investing in the physical infrastructure for local service centres that can provide reliable after-sales support, thereby closing the loop between capacity building and practical, on-the-ground service delivery

Stakeholders, partners and partnership

The ecosystem's core comprises the end-users and direct facilitators. Smallholder farmers, organized into cooperatives and clusters, are the central beneficiaries and active participants whose buy-in is crucial for sustainability. Their engagement is effectively mobilized and structured by traditional institutions and community leaders, who leverage their social capital to ensure genuine participation and enforce collective agreements. Operating at this level are the technical executors, including local technicians, solar installers, and agribusiness off-takers. These actors are responsible for the hands-on work of installation, maintenance, and creating market linkages, forming the operational backbone of the ecosystem on the ground.

To overcome the significant hurdle of upfront costs, a coalition of financial enablers is required. This includes public financial institutions like the Bank of Agriculture (BoA) to offer tailored loans, Microfinance Banks for grassroots accessibility, and Commercial Banks (e.g., Access Bank, Jaiz Bank) for larger cooperative projects, often facilitated by risk-sharing models with development funds. Parallel to this, the capacity-building partners are vital. Government initiatives like ACReSAL, KSADP, and state-level Agricultural Development Programmes (ADPs) provide public funding and coordinate large-scale training efforts. They are complemented by NGOs and vocational training centers who specialize in delivering the essential training for farmers on system use and for local youth on technical repair and maintenance, ensuring long-term operational knowledge.

The final layer consists of partners who provide the overarching framework for scaling and quality assurance. Federal and State Government agencies play a critical role as policy makers and programme orchestrators, creating an enabling environment through supportive policies, subsidies, and standard setting. The private sector, specifically solar equipment importers and distributors, ensures a reliable supply chain for high-quality components. Ultimately, the success of this entire network hinges on strategic partnerships that blend public funding, private sector efficiency, and community-driven governance. These synergistic relationships, such as the successful KDF and Access Bank model, are what de-risk investment, build local capacity, and ultimately create a resilient, self-sustaining SPIS market that can operate without perpetual external support.

3.8 Stakeholder Contributions to Co-creation and Scaling Solar-Based Irrigation

Scaling Solar Powered Irrigation Systems (SPIS) ownership in Nigeria requires a concerted co-creation effort, with each stakeholder playing a distinct yet interconnected role (Figure 4). The most beneficial partnerships are those that address financial, technical, and social barriers collaboratively.

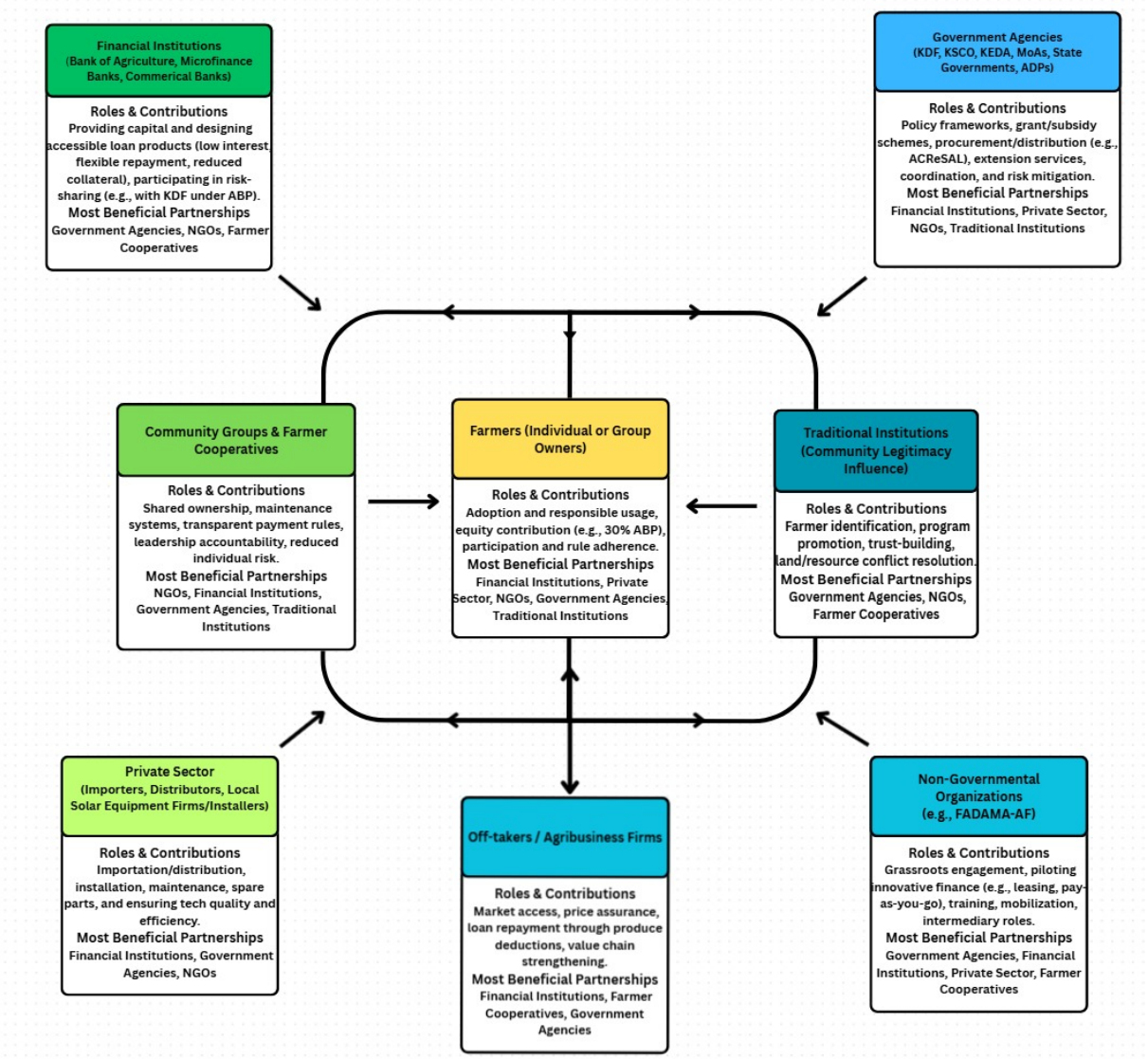

Figure 4: Stakeholder Contributions to Co-creation of SPIS

Financial Institutions

Financial institutions, such as Bank of Agriculture, Microfinance Banks, Commercial Banks, play a primary role in providing the necessary capital, co-creating solutions by designing and offering tailored loan products. These products feature flexible repayment schedules, lower interest rates, and reduced collateral requirements, thereby making Solar-Powered Irrigation Systems (SPIS) accessible to smallholder farmers. These institutions also contribute significantly by participating in risk-sharing models, exemplified by Access Bank's collaboration with the Kebbi Development Fund (KDF) in the Anchor Borrowers Programme (ABP). For these financial entities, the most beneficial partnerships involve collaboration with government agencies for elements such as loan guarantees, interest rate buy-downs, or revolving funds; with Non-Governmental Organizations (NGOs) for effective farmer mobilization and financial literacy initiatives; and with farmer cooperatives for facilitating group lending schemes and peer guarantees.

Government Agencies, such as, KDF, KSADP, KEDA, MoAs, State Governments/ADPs, play a crucial role in co-creating the enabling environment and providing direct catalytic support for Solar-Powered Irrigation Systems (SPIS) initiatives. Their contributions include establishing essential policy frameworks, initiating grant schemes, subsidies, or revolving funds (as exemplified by entities like the Kebbi Development Fund (KDF), Kano State Agro-pastoral Development

Project (KSADP), and Kaduna Enterprise Development Agency (KEDA)). Furthermore, they are involved in procuring and distributing SPIS units (like the ACReSAL project) and leveraging existing structures such as Agricultural Development Programmes (ADPs) for effective extension services and farmer mobilization. Often, their role extends to strategic coordination and risk mitigation across various programmes. For governments, the most beneficial partnerships are those with financial institutions (for co-financing models), the private sector (for bulk procurement and quality assurance), Non-Governmental Organizations (NGOs) (for grassroots implementation and capacity building), and traditional institutions (for facilitating community entry and accurate farmer identification.

Non-Governmental Organizations (NGOs) are crucial for grassroots engagement and fostering innovation within the solar irrigation sector. NGOs like ACReSAL, FADAMA-AF co-create solutions by piloting innovative financing models, providing direct capacity-building and training to farmers, facilitating community mobilization, and frequently acting as intermediaries connecting communities with government bodies and financial institutions. NGOs are vital for ensuring inclusivity and effectively reaching marginalized groups. For NGOs, the most beneficial partnerships involve collaboration with government agencies (for policy support and integration into larger programmes), financial institutions (for structured loan schemes), the private sector (for technology provision and technical support), and community groups or farmer cooperatives (for direct implementation and fostering a sense of ownership).

Private Sector's co-creation role is essential for ensuring market efficiency and maintaining technological quality within the solar irrigation ecosystem. Importers, distributors, local solar equipment firms/installers contribute significantly by importing and distributing high-quality solar components, providing professional installation services, and offering crucial after-sales support and maintenance. Local solar firms are key to providing accessible, on-the-ground technical expertise and readily available spare parts. For the private sector, the most beneficial partnerships involve collaborations with financial institutions (for consumer financing options), government agencies (for supportive policies, market incentives, and bulk purchasing), and NGOs (for establishing last-mile distribution networks and technical training initiatives).

Off-takers play a crucial role in securing the agricultural value chain, thereby indirectly supporting the adoption of Solar-Powered Irrigation Systems (SPIS). Their contribution lies in ensuring a guaranteed market for farmers' produce, which significantly strengthens the financial viability of farmers' investments in SPIS. Furthermore, off-takers can facilitate loan repayments through direct deductions from produce sales, providing critical market assurance for financial institutions and reducing risk for farmers. For off-takers, the most beneficial partnerships involve collaboration with financial institutions (for integrated financing and repayment models), farmer cooperatives (for bulk supply contracts and quality control), and government agencies (for market linkage policies and price stabilization initiatives).

Community Groups and Farmer Cooperatives are central to fostering collective ownership and sustainable management of Solar-Powered Irrigation Systems (SPIS). They co-create by establishing clear internal rules for shared equipment usage, developing transparent payment systems for maintenance and repair, and selecting accountable leadership for managing communal assets. Their collective action effectively reduces individual risk and facilitates access to resources that single farmers might otherwise not be able to afford. For these groups, the most beneficial partnerships involve collaboration with Non-Governmental Organizations (NGOs) for organizational development and capacity building, financial institutions for securing group loans, government agencies for policy support and direct project implementation, and traditional institutions for validation and conflict resolution.

Traditional Institutions and their leaders are invaluable for their community legitimacy and influence within the context of solar irrigation initiatives. They co-create by facilitating crucial farmer identification (as demonstrated effectively in the Anchor Borrowers Programme, or ABP), promoting programme uptake, mobilizing communities, and playing a critical role in conflict resolution, especially concerning shared resources or land tenure. Their endorsement significantly builds trust and ensures that programmes are culturally appropriate and widely accepted. For traditional institutions, the most beneficial partnerships involve collaboration with government agencies (for programme endorsement and community entry), Non-Governmental Organizations (NGOs) (for effective community mobilization), and farmer cooperatives (for internal governance support).

Farmer(s)/Sole or Group Ownership, as the ultimate end-users and primary beneficiaries, are fundamental to the success and sustainability of any Solar-Powered Irrigation System (SPIS) initiative. Their direct contributions include adopting the SPIS technology, diligently adhering to established usage and maintenance rules (especially in shared ownership models), and contributing their equity stake towards the system's acquisition (as exemplified by the 30% contribution model in the Anchor Borrowers Programme, ABP). For farmers, the most beneficial partnerships are those with financial institutions (for tailored loans and grants), the private sector (for access to quality equipment and reliable installation and after-sales service), Non-Governmental Organizations (NGOs) (for capacity building and direct mobilization), government agencies (for subsidies and an enabling policy environment), and traditional institutions (for community buy-in and conflict resolution).

4.0 Conclusion

4.1 Highlights from the study

The study reveals critical insights into the potential and challenges of scaling Solar-Powered Irrigation Systems (SPIS) across Kebbi, Kano, and Kaduna States. Despite abundant solar resources and accessible shallow groundwater, SPIS adoption remains remarkably low, primarily due to the prohibitive high upfront costs, significant financing gaps, and a weak supply chain. While farmer awareness of solar irrigation is growing, skepticism persists, driven by concerns over affordability, the reliability of the technology, and the availability of adequate maintenance. However, the research highlights successful models, such as the cooperative structure of the Dankwali Rice Cluster in Kebbi and risk-sharing financial approaches like Kebbi's Anchor Borrowers Programme, which underscore the vital importance of robust community governance, substantial farmer equity contributions, and comprehensive multi-stakeholder collaboration for successful implementation. Ultimately, fragmented policies, inconsistent technical support, and the lack of reliable after-sales services represent significant systemic gaps that continue to hinder the long-term sustainability and widespread adoption of SPIS.

The findings underscore the need for integrated, context-specific solutions when co-designing scaling pathways for Solar-Powered Irrigation Systems (SPIS). This involves financial innovation, focusing on tailored loan products, such as flexible repayment options via the Bank of Agriculture (BoA), blended financing models that combine grants with farmer equity, and risk-sharing mechanisms that include off-takers. Additionally, strengthened supply chains are crucial, necessitating partnerships with private sector distributors to ensure the availability of quality equipment, localized technicians, and readily accessible spare parts. Success also hinges on community-centric governance, which means replicating cooperative success factors like clear usage rules, transparent cost-sharing, and leadership accountability to foster genuine shared ownership. Finally, policy alignment is essential, requiring advocacy for targeted subsidies,

standardized quality control measures, and effective water resource management to create a truly enabling environment for SPIS adoption.

These lessons provide the foundation for the design of the Discrete Choice Experiment (DCE), which directly incorporates the barriers, opportunities, and scaling pathways identified in the research. The DCE will be structured around four key attributes: ownership model, financing option, cart option, and community hub access/payment method, with multiple levels reflecting real-world scenarios: individual versus group or hub ownership, conventional versus Islamic and hybrid financing, inclusion or exclusion of panel carts, and pay-as-you-use models. Farmers will be presented with choice sets, divided into blocks, each comparing two alternative SPIS packages with varying combinations of these attributes. This design will allow for systematic testing of farmer trade-offs between cost, autonomy, risk-sharing, and flexibility, thereby capturing their revealed preferences for different scaling pathways. The integration of these carefully designed attributes into the DCE will not only mirror some of the scaling models identified in the study, but also provide empirical evidence on which configurations resonate most with farmers. By doing so, the DCE serves as a decision-support tool for policymakers, financial institutions, and development partners, enabling them to tailor interventions that align with farmers' willingness and capacity to invest.

Ultimately, scaling SPIS in Nigeria requires more than technical feasibility; it depends on aligning financial innovation, institutional support, and farmer-led governance with the lived realities of smallholders. The DCE results, derived from farmer preferences across experimental sets, will guide the co-design of irrigation packages that are not only technically sound and financially viable but also socially acceptable and environmentally sustainable. In this way, solar irrigation can move from a niche innovation to a mainstream solution, advancing climate-resilient agriculture, food security, and rural livelihoods across Nigeria.

4.2 Key Recommendations for Scaling Solar-Based Irrigation in Nigeria

To design inclusive and sustainable scaling pathways for Solar-Based Irrigation Systems (SPIS) in Nigeria, a comprehensive strategy must address identified challenges while leveraging successful elements. Consequently, the following are recommended:

Enhanced financial accessibility and innovative models. The primary barrier of high upfront costs and limited access to finance must be tackled through integrated financial partnerships. This includes actively working with the Bank of Agriculture (BoA) to expand tailored SPIS loan products with flexible repayment schedules and reduced collateral. Partnerships with Microfinance Banks (e.g., Bunkasa Microfinance Bank) are crucial for grassroots access to smaller, accessible loans, potentially de-risked by state government guarantee funds. Commercial banks (Access, UBA, Jaiz, Alternative Bank) should be engaged to develop specialized agricultural financing windows for cooperatives, learning from KDF's successful risk-sharing model with Access Bank in the ABP, which included a 30% farmer equity contribution to ensure commitment. Government agencies (like KDF, KSADP, KEDA etc.) must initiate dedicated grant schemes, revolving funds, or co-financing arrangements.

Uphold quality, technical expertise, and after-sales support. Addressing concerns about technology quality, scarcity of technical expertise, and limited availability of genuine spare parts is paramount for building farmer confidence. A robust public-private partnership approach is needed. This involves collaboration with private sector importers and distributors to ensure high-quality component availability nationwide. Local solar equipment firms and installers are vital for professional installation and localized maintenance. State governments, through Agricultural Development Programmes (ADPs) and vocational training centers, should partner with these private firms and NGOs like FADAMA-AF to establish and expand comprehensive capacity-

building programmes. These programmes must train a significant pool of local technicians and educate farmers on basic operation and maintenance. In addition, major national and regional distributors, alongside government projects like ACReSAL and KASCO, must establish robust networks for genuine spare parts distribution and sustainable maintenance frameworks to prevent pumps from becoming "disused assets".

Strengthen community governance and farmer engagement: For the long-term sustainability of SPIS, particularly in shared models, empowering community groups and farmer cooperatives is non-negotiable. Lessons from the Dankwali Rice Production Cluster emphasize the need to co-design clear usage rules, transparent payment systems for maintenance, and effective conflict resolution mechanisms from the outset. Leveraging the influence of traditional institutions (as demonstrated by KDF in the ABP) is crucial for accurate farmer identification, community mobilization, and enforcing collective agreements, thereby mitigating disputes and fostering genuine collective ownership. This also addresses low farmer awareness and skepticism.

Optimize policy and regulatory environment. Policy gaps present significant impediments. Recommendations include clear, long-term subsidies and incentives specifically for solar irrigation, consistent import tariffs on quality components, and robust standardization/quality control mechanisms to curb substandard products. Policies must also address land tenure insecurity to encourage long-term farm investments. Additionally, a coordinated approach to water resource management is needed to prevent unsustainable groundwater extraction as SPIS adoption increases. Policies should encourage local assembly/manufacturing and reduce import barriers for quality components.

Critical "hidden" Actors. Beyond the typically mapped organizations, two critical actors whose explicit involvement is vital for scaling pathways are: Off-takers. As demonstrated in the ABP, off-takers play a crucial role in ensuring a market for farmers' produce, which in turn strengthens the financial viability of SPIS investments and can even facilitate loan repayments through direct deductions. Their integration into financial models provides critical market assurance.

Farmers as co-investors. The ABP's requirement for a 30% farmer equity stake was a significant factor in its success, instilling ownership and drastically reducing default risks. While farmers are beneficiaries, their role as active co-investors, even with minimal initial outlay, is a powerful lever for commitment and sustainability.

5.0 References

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ANNEXES

Annex I: List of Stakeholders Engaged for KIIs and FGDs.

S/N	NAME	DESIGNATION	ORGANIZATIONAL	
1	Aminu Yusuf A	Manager	Bank of Agriculture Kebbi	
2	Abubakar Zaki Gwandu	Hop/ADP Desk Officer	Bank of Agriculture Kebbi	
3	Hassan Samaki	GM	KASCO	
4	Suleiman Usaman	Technician/Manager	Nayodi Solar Services Kebbi	
5	Ibrahim Haliru	Technician	Nayodi Solar Services Kebbi	
6	Ahmad Atiku Aliyu	Director Irrigation Services (Engineering Dept)., MoA	Ministry of Agric Kebbi	
7	Faruq Abubakar Kawara	Technician	Shamsu Solar System and Installation Company, Kebbi	
8	Chidera Okoro	Admin and HR	Labana Rice Mill, Kebbi	
9	Adamu Samaila Bagaye	District Head	Augie LGA Kebbi	
10	Alhaji Bashir Galadima	Owner/Manager	Bashir Electrical and Electronics, Argungu, Kebbi	
11	Abdullahi Hussaini Maisoki	Owner/Manager	Maisoki Electrical and Electronics, Argungu, Kebbi	
12	Abba Solar	Technician	Kebbi State	
13	Usman Solar	Technician	Kebbi State	
14	Samson Lucas	Branch Manager	Access Bank Birnin-Kebbi	
15	Ibrahim Sokoto	Regional Manager	United Bank for Africa, Kebbi	
16	Umar Faruq Udulu	NGKS-FADAMA III	Ministry of Agric, Kebbi	
17	Ahmad Isa Tella	Project Coordinator	Kebbi State (ACReSAl)	
KII in Kano State				
18	Engr Balarabe Shehu Wudilawa	Director Agric Service	Kano State Ministry of Agriculture	
19	Abdulrasheed Hamisu Kofarmata	Project Coordinator/Head of Market-Oriented Agriculture in Nigeria	Sasakawa	
20	Abubakar Salihu	Deputy Hod Agric Dept	Bunkure LGA	
21	Salihu Musa Murabus	Sarkin of Kumurya	Bunkure LGA	
22	Aminu Moh'd	Narki Village Head	Bunkure LGA	
23	Fatima Abubakar	Branch Manager	The Alternative Banking, Hotoro, Kano State	
24	Abdullahi Tijjani	Relationship Officer	The Alternative Banking, Hotoro, Kano State	
25	Zubairu Sani	Relationship Officer	The Alternative Banking, Hotoro, Kano State	
26	Hajia Rabi Kabiru Musa	Zonal Manager (North West)	Bank Of Agriculture, Kano State	
27	Dahiru Abana Girei	Bank Manager	Nigerian Agricultural Insurance Corporation, Kano	
28	Rahama Jibril Aliyu	Branch Manager	Jaiz Bank Hotoro Kano State	
29	Faud Garba Wudil	Managing Director	Salaha Electric and Electronics Wudil, Kano State	
30	Sani Muhammad	Maintenance and Repair	Wudil	
31	Arusi Garba	Maintenance and Repair	Wudil	
32	Awualu Sani	Maintenance and Repair	Wudil	
33	Saminu Hassan	Sales Manager Hotoro Office	A.B Ramadan Solar Electrical and Electronics	
KII in Kaduna State				

34	Hajia Salima	Head Of Procurement	Bank of Agriculture Hq Kaduna			
35	Ganiyu Isiaka Abdulazeez	Managing Director	Bunkasa Micro Finance Bank, Jere Kaduna State			
36	Williams S Ejima	District Head Katugal District	Koro Chiefdom/District Head			
37	Happiness Alhassan	Farmer Total Bell Pepper	Jere, Kagarko LGA, Kaduna State			
38	Alh Garba Lawal	Sarkin Jere	Jere, Kagarko LGA, Kaduna State			
39	Abubakar Saad	Harkimin Jere	Jere, Kagarko LGA, Kaduna State			
40	Sunday Enjaiz	CEO/ Managing Director	Enjaiz Technology Nigeria Limited Bwari			
41	Ebuzogme Vincent	CEO/ Managing Director	Azubless Investment Bwari			
42	Asije O Samuel	Managing Director	Samtech Consult Limited, Bwari			
43	Haggai Turba	Block Extension Supervisor	Kagarko LGA, Kaduna State			
44	Ibrahim Salisu	Representative of FAMAN	Jere, Kagarko LGA, Kaduna State			
45	Shehu Sarkinkoffar	Representative of FAMAN	Jere, Kagarko LGA, Kaduna State			
46	Dauda Gideon Janari	Asst. Director Produce	Kaduna Ministry of Agric			
47	Engr Shehu Dalhat	Deputy Director Irrigation Service	Kaduna Ministry of Agric			
48	Musa Adamu	Head of Programme and Project	Kaduna Enterprise Development Agency			
49	Samaila Abdubaba	Procurement Officer FADAMA	FADAMA Office Kaduna State			
50	Esther Zakaria	MIS Office FADAMA	FADAMA Office Kaduna State			
51	Adamu Usman Muhammad	Director Agric Service	KADA			
52	Monday Ezra	Manager	Executed Eagles Solar Inverter, Kaduna			
53	Chukwunonso Ikejiofor	MD/CEO	Malach Electronics, Kaduna			
FGD Conducted in Kebbi with key KARDA officials						
54	Usman Bungudu	PM	KARDA Kebbi			
55	Abdullahi Yau	DPM	KARDA Kebbi			
56	Suleiman Hamisu	Director M & E	KARDA Kebbi			
57	Danladi Garba Isgogo	Director Extension	KARDA Kebbi			
FGD Conducted in Kebbi with key Dankwalli Rice Production Co-Operative officials						
58	Abubakar Adamu Argungu	Chairman	Dankwalli Rice Production Co-Operative Argungu Kebbi State			
59	Umar Muhammad	Secretary	Dankwalli Rice Production Co-Operative Argungu Kebbi State			
FGD Conducted in Kano with key KNARDA officials						
60	Haruna Kassim Jil	Director Finance	KNARDA Kano			
61	Abdulkadir Aliyu	Director TS	KNARDA Kano			
62	Muhammad Shittu	Director RID	KNARDA Kano			
63	Aminu Ibrahim	Director ES	KNARDA Kano			
64	Mani Muhammad Gwarzo	Director Engineering	KNARDA Kano			
65	Dr. Aliyu Shehu Minjibi	Director HD	KNARDA Kano			
66	Shaa'aibu Ja'afar	Aac Sumaila	KNARDA Kano			08022192480
	Focus Group Discussions		**Community**	**Men**	**Youth**	**Women**
67	Irrigation Farmers, Men and Youths		Augie, Kebbi	12	9	
68	Irrigation Farmers, Women only		Augie, Kebbi			3
69	Dankwali Rice Production Clusters		Argungu, Kebbi	4	2	

70	Irrigation Farmers, Men and Youths	Dunsusu, Kano	6	8	
71	Irrigation Farmers, Men and Youths	Kumurya, Kano	9	7	
72	Irrigation Farmers, Men and Youths	Koro, Kaduna	8	6	
73	Irrigation Farmers, Men and Youths	Kagarko, Kaduna	21	12	
74	Irrigation Farmers, Men and Youths	Jere, Kaduna	20	9	
75	Irrigation Farmers, Women only	Jere, Kaduna			6

Annex II: Semi-Structured KII Guide for Key Stakeholders

Project: Co-Designing Scaling Pathways for Solar Irrigation Technology Ownership in Nigeria

Respondent Name: _____

Respondent Number: _____

Designation/Role: _____

Organization/Institution: _____

Sector: Government / NGO / Private / Financial / Technical / Research

Interviewer Name: _____

Date: _____

Location: _____

1. Solar irrigation landscape

1. From your vantage point, what is the current level of awareness and adoption of solar irrigation technology among smallholder farmers here?
2. What factors do you believe contribute to this current status?
3. Describe how solar irrigation technologies currently enter this region.
4. What role does your organization play in this ecosystem? How do you interact with other actors (e.g., suppliers, farmers, financiers)?

2. Solar Irrigation Supply Chain and Relationships

5. Thinking about solar irrigation technology, who are the key actors involved at different stages, from manufacturing or import to the farmer's field?

   Probe*:* Who provides the solar panels, pumps, and other components? Who distributes them to rural areas? Who handles installation? Who provides after-sales service and repairs?

6. Beyond the technology providers, what other organizations or individuals play a critical role in supporting the adoption and use of solar irrigation (e.g., financial institutions, NGOs, government agencies, local community groups, extension workers, technical training providers)?
7. Identify 2–3 critical gaps in the current supply chain (e.g., financing, training, maintenance). Which actors could best address these?
8. Describe a recent case where solar irrigation succeeded or failed here.

3. Institutional Gaps and Bottlenecks

9. Based on your experience, what are the primary systemic gaps or bottlenecks that hinder smallholder farmers from adopting solar irrigation technology?

   Probe for specifics related to*:* Affordability/upfront costs, access to finance, quality of available technology, technical expertise for installation/maintenance, availability of spare parts, farmer awareness, land tenure, etc. Who could fix this?

10. From your organization's perspective, what are the biggest challenges or risks you face in promoting or supporting solar irrigation uptake in this region?

11. In your view, how do existing policies, regulations, or institutional frameworks either facilitate or impede the widespread adoption of solar irrigation? Are there any specific policy gaps?

12. What insights can you share regarding the quality and accessibility of borehole drilling services for small-scale irrigation? What are the common challenges farmers or technology providers face with drilling?

13. Are there particular barriers related to gender or youth that affect their ability to access or benefit from solar irrigation technology, especially within the existing supply chain or support systems?

4. Leverage Points for Co-Design

14. What successful examples of solar irrigation adoption or related agricultural technology initiatives have you observed in this region or elsewhere? What were the key elements that contributed to their success, and which actors were central to it?

15. In your opinion, what kind of collaborations or partnerships (e.g., Public-Private Partnerships, farmer-private sector linkages, inter-agency cooperation) could significantly improve the delivery and sustainability of solar irrigation technology and services? Could you provide specific examples?

16. What role do you see your organization playing in a co-creation process aimed at scaling solar irrigation ownership? What specific contributions could your organization make, and what kind of partnerships would be most beneficial to your work?

17. What are your key recommendations for designing inclusive and sustainable scaling pathways for solar irrigation technology ownership in Nigeria, considering the various challenges and opportunities we've discussed?

Who else should we speak to to fully understand this ecosystem? Are there 'hidden' actors we're missing?

Annex III: Semi-Structured FGD Guide (Farmers/Group/Community).

Project: Co-Designing Scaling Pathways for Solar Irrigation Technology Ownership in Nigeria

Facilitator Name: _____

Date: _____

Location: _____

Number of Participants:

Gender: Male [ ] Female [ ] Youth [ ]

Do you all consent to giving truthful, reliable information about irrigation practices in your community?

_____

Opening:

Let's discuss your experiences with irrigation and explore how solar technology could work for your community.

1. **Current Practices and Challenges**
    1. Walk us through a typical dry-season farming cycle: What crops do you prioritize, and why?
    2. Describe your current irrigation methods. What makes them work (or fail) for your needs?
    3. Where do you typically get the fuel, spare parts, or maintenance services for your current irrigation equipment? What are your experiences with these suppliers/service providers?
    4. How do you usually access water for irrigation (e.g., tube wells, rivers, boreholes)?
    5. What are the *hidden costs* (e.g., time, labor, stress) of your current irrigation system?
2. **Solar Irrigation Perceptions and Barriers**
    6. Have you encountered solar pumps in your area? What stories or rumors have you heard?
    7. Imagine a perfect solar irrigation system: How would it change your farming? What worries you about it?
    8. Who in your community would most likely adopt solar first? Who might resist? Why?
3. **Ownership and Governance**
    9. Share examples of shared equipment in your community. What made them succeed or fail?
    10. If your group owned a solar pump, how would you decide who uses it, maintains it, or pays for repairs?
    11. What rules or leaders would be needed to prevent conflicts?
4. **Supply Chain and Support Systems**
    12. Trace the journey of a solar Irrigation equipment: Who would supply it? Install it? Fix it? Train you? **(Probe: Local vs. external actors)**
    13. Where do farmers currently get advice or loans for irrigation?
    14. How do women/youth access equipment compared to others? What barriers exist?
5. **Vision for Adoption:**
    15. What would need to happen for solar irrigation to thrive here?
    16. What *one change* (e.g., training, financing, vendor access) would make the biggest difference?

Closing:

Is there anything we missed that's critical to making solar irrigation work for your community?

PICTURES

Chat with PS, MoA, Kebbi State

A SPIS sales point in B/Kebbi

With Admin and HR
Labana Rice Mill Kebbi

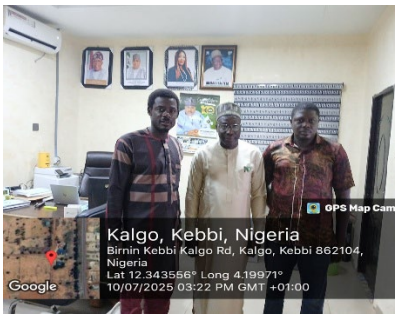
Augie FGD participants

SPIS sales points, Argungu, Kebbi State

A farmer with fuel-powered pump

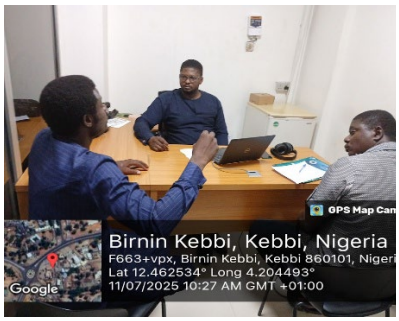
With GM, KASCO and Other
officials MoA, Kebbi

Chat with KARDA Directors,
Kebbi



With ACReSAL State Coordinator

With BoA Branch manager, Kebbi



With Access Bank Manager, Kebbi

With UBA Regional Manager,
Bebbi

With Sarki Noma, Kebbi

Dankwali rice cluster field

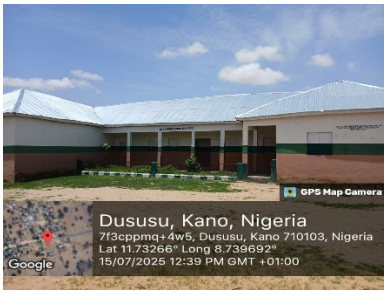
Chat with Director, Agric Services, MoA, Kano State

Chat with KNARDA Directors, Kano

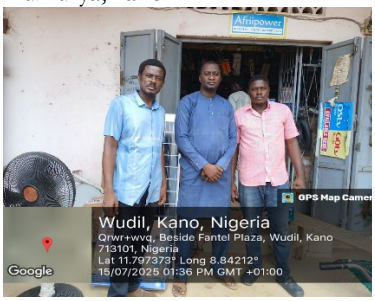
With Sasalawa State Cord, Kano

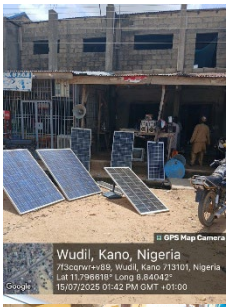
At the Palace of the District Head, Kumurya, kano

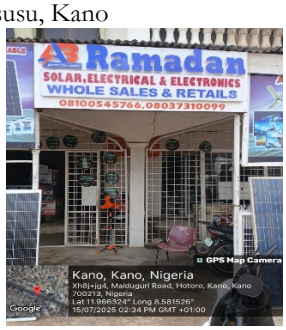
FGD at Dususu, Kano



A storehouse for a cluster group, Dususu, Kano







A SPIS sales points in Wudil, and Hotoro, Kano

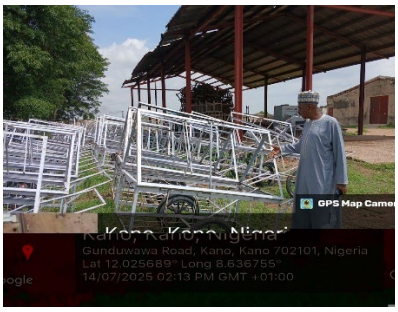
At BoA, Kano

With NAIC Manager, Kano

At the Alternative Bank, Kano

At Jaiz Bank, Kano

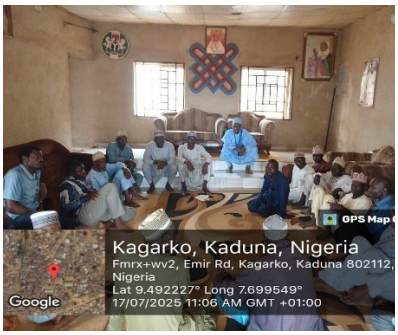
With Dep Director, Agric. Services, Bunkure LGA, Kano



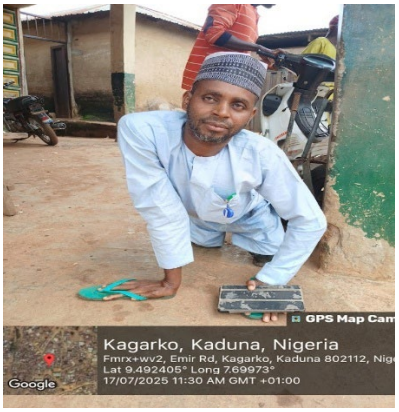
Panel carts for Sasakawa

FGD at Koro, Kagarko LGA, Kaduna

With the District Head, Koro

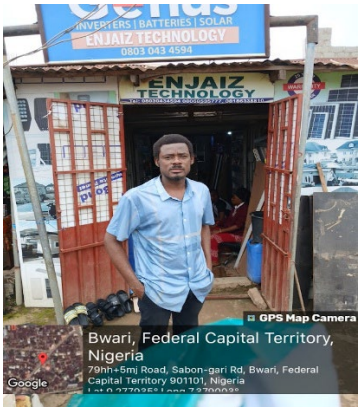


FGD at Kagarko, Kaduna



A physically challenged farmer in Kagarko

A lead woman farmer in Jere

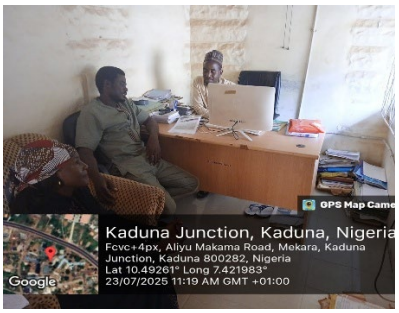


Solar sales point in Bwari FCT

FGD with women farmers in Jere

Chat with MD, Samtech Consult Limited, Bwari

BoA Hqts, Kaduna



Chat with FADAMA-AF, Kaduna

Chat with Director, Agric KADA

At MoA, Kaduna

At Kaduna State Enterprise Development Agency

Exulted solar store room

Scaling for Impact

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