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Multi-Stakeholder Validation Workshop: Preferences, Financing Models, and Scaling Pathways for Solar-Based Irrigation in Northern Nigeria

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Executive Summary

The Multi-Stakeholder Validation Workshop (December 2025) confirmed that scaling Solar-Based Irrigation Systems (SBIS) in Northern Nigeria requires a radical departure from "one-size-fits-all" models. Evidence from the states; Kaduna, Kebbi, and Kano confirms that adoption is driven entirely by local context: security risks in Kaduna demand mobile, individual systems, while social cohesion in Kebbi and Kano favors cost-effective, shared fixed models. To move from potential to impact, stakeholders must immediately pivot their strategies as follows:

1. What Government Should Do Differently

To move beyond the limitations of current interventions, the government must shift from generic support to targeted de-risking by deploying specific fiscal incentives, such as tax waivers and duty exemptions on imported solar components, to directly counter the sector's vulnerability to foreign exchange volatility. Simultaneously, this financial strategy must be underpinned by harmonized institutional mandates, where the Ministries of Agriculture, Water Resources, and Energy operationalize a joint framework to resolve the cross-cutting adoption barriers of land tenure insecurity and regional safety that currently stall infrastructure investment.

2. What Should Change in the Financiers' Schemes

Financiers must fundamentally restructure their lending models by immediately reconsidering rigid monthly repayment schedules, which were confirmed to stifle uptake due to their misalignment with agricultural cash flows, in favor of seasonal or annual lump-sum repayments. Simultaneously, institutions must segment their portfolios to deploy context-specific products: offering 1-year commercial loans for Kaduna farmers, 2-year + tenors for clustered smallholders in Kebbi, and strictly Islamic financing products, such as Murabaha, to effectively unlock the Kano market.

3. What CGIAR/IWMI/Researchers Should Prioritize Next

CGIAR and IWMI must shift their immediate priority from simple technology transfer to holistic ecosystem building by investing heavily in the sector's "software", specifically through local technical training and the establishment of reliable spare-part supply chains, to prevent the "undersized system" failures identified by experts. Simultaneously, scaling efforts should operationalize a "micro-clustering" model that organizes farmers into small groups of two to three; this validated approach serves as a critical lever for balancing social accountability with creditworthiness, ensuring that marginalized groups, particularly women and youth, are not excluded from the transition.

1. Introduction

1.1. Background

The transition toward sustainable solar-based irrigation systems (SBIS) in Nigeria represents a critical frontier for a Just Transition, protecting smallholder farmers from the dual economic shocks of fuel subsidy removal and intensifying climate variability. While hydrogeological studies confirm the technical suitability of groundwater irrigation across Northern states like Kebbi, Kano, and Kaduna, the reliance on fossil-fuel pumps remains a significant barrier to both economic stability and national decarbonization goals. Widespread adoption is currently stifled by high capital costs and fragmented supply chains; however, SBIS offers a strategic pathway to operationalize Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement by simultaneously mitigating greenhouse gas emissions and enhancing agricultural adaptation to climate change. Shifting from top-down technology transfer to evidence-based, farmer-centric solutions is therefore essential to unlock the climate resilience potential of the region's vast, untapped agricultural landscape.

This validation workshop serves as a pivotal platform for designing actionable scaling pathways that leverage climate finance to bridge the affordability gap for smallholders. Aligned with the CGIAR mandate for food system transformation, the initiative emphasizes a co-creation approach to foster genuine technology ownership. By synthesizing granular data from household surveys with insights from diverse stakeholders—including government agencies committed to climate-resilient production—this process ensures that scaling strategies are not only technically viable but also attract the necessary green investment. Ultimately, by integrating private-sector engagement with policy frameworks that prioritize low-carbon development, this collaborative effort aims to transform solar irrigation from a niche technology into a cornerstone of rural livelihoods and Nigeria's climate adaptation strategy.

1.2. Purpose and Objectives of Meeting

A household survey and Discrete Choice Experiment (DCE) of solar-based irrigation systems SBIS was conducted in three states of Kano, Kaduna, and Kebbi between August and September 2025. The exercise focused on fact-finding on the current use of fossil-fuel-based irrigation systems, associated challenges, and the need to adopt solar-based irrigation systems. It also examined financing options, ownership models, and repayment mechanisms for solar-based irrigation technologies. The outcomes of the household survey and the DCE were presented to relevant sector stakeholders on 11 December 2025 for validation.

The specific objectives of the stakeholder validation meeting were to:

1. Validate the evidence
 - Confirm whether the DCE findings align with stakeholder experience.
 - Check the realism of farmer-preferred financing, ownership, and technology attributes.
 - Test assumptions from the profitability analysis and groundwater/climate insights.
 - Assess the SBIS options to confirm the scalable options that are crop-targeted, risk-mitigated, and ensure profitable, resilient adoption.
2. Improve the interpretability of results
 - Identify contextual factors (cultural, financial, agronomic, gender-related) that may modify uptake.
 - Highlight differences between states and farming systems.
3. Co-refine proposed financing and ownership models

- Assess feasibility from the perspective of lenders, suppliers, and cooperatives.
 - Identify risks and risk-mitigation options from each stakeholder group.
4. Validate and refine the proposed scaling pathways
- Ensure that roles, incentives, and responsibilities are realistic.
 - Identify enabling policies and institutional reforms needed for scale.
 - Define the use of tiered commercialization with required risk-mitigation tools to secure low-margin crop investments.

2. Methodology

2.1. Multi-Stakeholder Dialogue Settings

Forty (40) invited participants attended the meeting, held in the Conference Hall of Casa De Lucy Hotel, No. 585 David Jemibewon Crescent, Apo, off Mobolaji John Road, Gudu, Abuja (Figure 2.1). The participants included the Director of Irrigation Services, Federal Ministry of Water Resources and Sanitation; the Director of Agricultural Extension, Federal Ministry of Agriculture and Food Security; the Programme Director of the Agricultural Policy Research Network (APRNet); the Director of Irrigation Services, Ministry of Agriculture, Kaduna State; the Assistant Director, FADAMA CARES, Kaduna State; representatives of the Ministry of Agriculture and Natural Resources, Kebbi State; representatives of the Agricultural Development Programmes (ADP), Kebbi State; a representative of the Kano State Agricultural and Rural Development Authority (KNARDA); a representative of the International Food Policy Research Institute (IFPRI); representatives of the Bank of Agriculture (BOA); the Rural Electrification Agency of Nigeria; CEESOLAR, Utako, Abuja; and the Green Habitat Initiative, Abuja. Also in attendance were representatives of solar panel distributors from Abuja, Kebbi, Kano, and Kaduna States; the Chairman of Alkamawa FADAMA, Kano State; representatives of farmers from Kaduna, Kano, and Kebbi States; representatives of non-governmental organizations; and members of the academic community from the University of Abuja, the Federal University of Lafia (Nasarawa State), and Ahmadu Bello University, Zaria. (See Annex A).





Figure 1. Participants at the workshop (*photo:* Oluwaseun Adebayo Ojeleye)

2.2. The Presentations

The validation meeting with opening remarks and participant self-introductions. This was followed by a clear outline of the objectives and scope of the validation exercise, emphasizing the role of stakeholder engagement in strengthening the credibility, relevance, and policy applicability of the Discrete Choice Experiment (DCE) on solar-based irrigation systems.

2.2.1. Presentation one: overview of IWMI and solar-based irrigation systems

The first presentation, by Dr Oke (Figure 2.2) provided an overview of the International Water Management Institute (IWMI), its mandate, and ongoing work across water, energy, food, and environmental sustainability. The presentation highlighted IWMI’s role in supporting evidence-based research and policy engagement to improve water management practices and promote sustainable agricultural intensification, particularly in smallholder farming systems.

The presentation further introduced solar-based irrigation systems, outlining their technical components, modes of operation, and potential benefits relative to conventional fossil-fuel-based irrigation technologies. Key issues discussed included the high and volatile fuel costs, maintenance challenges associated with diesel and petrol pumps, greenhouse gas emissions, and the environmental implications of continued reliance on fossil fuels.

The advantages of solar-based irrigation systems were highlighted, including reduced operational costs over time, lower environmental footprint, improved reliability, and alignment with national and global climate-smart agriculture and energy transition goals. The presentation also discussed common challenges associated with solar irrigation, including high upfront investment costs, limited access to appropriate financing, maintenance and after-sales service constraints, and the need for adequate institutional and policy support. Participants were encouraged to reflect on these issues based on their practical experiences within Kano, Kaduna, and Kebbi States.



Figure 2. Dr. Adebayo Oke making a presentation (*photo:* Oluwaseun Adebayo Ojeleye)

2.2.2. Presentation two: household survey, discrete choice experiment (DCE), and investment case findings

The second presentation focused on the results of the Household Survey and Discrete Choice Experiment (DCE), complemented by detailed Investment Case analyses for selected crop enterprises, to assess farmers' preferences, trade-offs, and the financial viability of alternative solar-based irrigation system (SBIS) configurations. The presentation, by Prof Ojeleye (figure 2.3) began with a brief explanation of the DCE methodology, emphasizing its relevance for understanding farmer decision-making under multiple constraints and for informing the design of responsive irrigation, ownership, and financing models. This was followed by an overview of the investment analysis framework used to evaluate SBIS's economic performance across key crops.

The DCE results were then presented, highlighting farmers' stated preferences across core system attributes, including ownership models (individual versus group-based systems), system configuration (with or without cart), financing mechanisms (no loan, conventional bank loans, Islamic finance, hybrid financing, and pay-as-you-use models), repayment duration, and cost levels. Differences in preferences across farmer categories, including smallholders, women, and youth, were discussed where applicable. In parallel, the presentation introduced the Investment Case analyses for Rice, Wheat, and Pepper, presenting comparative results on profitability, cost-benefit analyses, payback periods, Net Present Value (NPV), Internal Rate of Return (IRR), and sensitivity to revenue and cost shocks under different SBIS configurations.

The presentation further outlined the combined implications of the DCE and Investment Case findings for policy formulation, financing design, and private sector engagement. Particular emphasis was placed on how financial viability differs by crop and system type, and how these insights can inform the structuring of affordable and risk-adjusted financing products, the selection of appropriate ownership and delivery models, and the prioritization of crop segments for SBIS scaling in line with farmers' needs, repayment capacity, and risk exposure.

Following the presentation, participants were invited to ask questions, validate both the preference and investment findings against their own experiences, and provide feedback on the realism and interpretability of the results. The ensuing discussions confirmed broad alignment with the observed DCE trends and investment outcomes and generated constructive input on cost assumptions, market risks, and financing feasibility, which were subsequently carried forward into the syndicate group discussions and plenary sessions.



Figure 3. Prof. Oluwaseun Ojeleye and Dr. Yinka Calvin making presentations (*photo: Oluwaseun Adebayo Ojeleye*)

2.3. Syndicate Groupings and Validation Process

Following the presentations, the validation exercise proceeded to a structured syndicate session designed to facilitate in-depth discussions, promote inclusive participation, and generate practical feedback on both the DCE and Investment Case findings. Two complementary grouping approaches were used to capture cross-sectoral perspectives and sector-specific insights: heterogeneous grouping and homogeneous grouping.

2.3.1. Heterogeneous grouping

In the first phase, participants were organized into heterogeneous groups comprising a deliberate mix of stakeholders from government institutions, research and academic organizations, private sector actors, financial institutions, non-governmental organizations, and farmers/community representatives. This grouping approach was adopted to encourage cross-learning, broaden perspectives, and foster dialogue across institutional and professional boundaries, and also to co-refine proposed financing and ownership models

The heterogeneous groups were tasked with jointly reviewing the key findings presented earlier, which are the results of the Discrete Choice Experiment presentation. Discussions focused on validating the overall relevance, clarity, and plausibility of the findings, and on identifying areas of convergence and divergence across stakeholder experiences.

This approach enabled participants to collectively interrogate the findings, ensuring that technical, financial, policy, and user-level considerations were examined simultaneously. It also helped bridge information gaps among stakeholders, foster mutual understanding, and reduce the risk of dominance by any single group during discussions.

2.3.2. Homogeneous grouping

In the second phase of the syndicate process, participants were reorganized into homogeneous groups based on their primary area of engagement and expertise to confirm whether the DCE findings align with stakeholder experience. The groups were classified as follows:

- Government institutions;
- Research and academic institutions;
- Private sector actors (including solar technology providers and service companies);
- Financial institutions (banks and financing agencies);
- Farmers and community representatives; and
- Non-governmental organizations (NGOs).

The homogeneous grouping approach enabled participants to engage in more focused and sector-specific discussions, drawing on shared experiences, mandates, and operational realities. Each group was tasked with validating the DCE findings from their sector's perspective, identifying sector-specific opportunities and constraints, and proposing actionable recommendations relevant to their roles in the solar irrigation value chain.

Particular attention was given to assessing the realism of the DCE attributes and results, including ownership models, financing and repayment mechanisms, affordability, and institutional support requirements. The groups also discussed the implications of the findings for policy formulation, product financing design, private-sector engagement, farmer adoption, and the inclusive participation of women and youth.

Furthermore, the group provided answers to the following questions;

1. What do you really think of a solar-based irrigation system (SBIS) in northern Nigeria? Is the technology adoptable?
2. Identify 2–3 critical gaps in the current supply chain (e.g., supply, financing, training/usage, maintenance). Which actors could best address what?
3. 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 SBIS and services?
4. What role do you see your organization playing (specific contributions) in a process aimed at scaling solar irrigation ownership in Nigeria?
5. What are your key recommendations for sustainable scaling pathways for solar irrigation technology ownership in Nigeria, considering the various challenges and opportunities we have discussed?



Figure 4. Participants at the plenary (*photo: Oluwaseun Adebayo Ojeleye*)

2.3.3. Validation processing and plenary feedback

Following the group discussions, each syndicate presented its key observations and recommendations during a plenary session. Issues raised by the groups were openly discussed, clarified, and, where necessary, harmonized to reflect a shared understanding among stakeholders.

The validation process emphasized consensus-building, with facilitators guiding discussions to distinguish between context-specific observations and broader issues. Feedback from both heterogeneous and homogeneous group sessions was systematically documented and subsequently used to strengthen the interpretation and presentation of the DCE results.

The combined use of heterogeneous and homogeneous grouping methods proved effective in capturing both integrated and sector-specific perspectives, thereby enhancing the robustness, credibility, and practical relevance of the validated findings.

3. Validation Workshop Outcomes and Stakeholder Feedback

3.1. Kaduna State

Stakeholders in Kaduna validated a strong preference for individual ownership and mobile (cart-based) systems, financed through short-term (1-year) bank loans. This profile is driven by the state's higher purchasing power, diverse cropping systems (vegetables/cereals), and heterogeneous social structure, which create trust deficits in shared models. The preference for mobility is a direct response to insecurity, necessitating the daily transport of assets to safety.

Critical Implications:

- **Security-Driven Design:** SBIS adoption here hinges on portability. Fixed systems will likely fail due to theft fears, making the "mobile cart" a non-negotiable feature despite its higher cost.
- **Segmented Sales Strategy:** Marketing should target individual, higher-income farmers who value autonomy and have the cash flow to service aggressive 1-year loan repayments, rather than attempting to force cooperative models where social trust is low.

3.2. Kebbi State

Kebbi farmers prefer dual (shared) ownership of fixed (without-cart) systems, supported by medium-term (2-year) bank financing. This model is enabled by high social homogeneity, strong kinship ties, and the physical proximity of farms in river basins, which simplifies resource sharing. The rejection of mobile carts stems from a lower security risk environment and a prioritization of cost minimization.

Critical Implications:

- **Cluster-Based Deployment:** Interventions should leverage existing social cohesion to deploy units to small kinship-based groups (2-3 farmers) rather than individuals, significantly lowering the per-farmer investment barrier.
- **Capital Efficiency:** The preference for fixed systems and shared ownership creates the lowest cost-per-user ratio. Financiers should view Kebbi as a high-impact market for "economy" SBIS packages.

3.3. Kano State

Similar to Kebbi, Kano farmers favor dual (shared) ownership and fixed systems, but strictly prefer Islamic (non-interest) financing. This preference is rooted in religious norms (avoidance of *riba*) and a deep culture of cooperative farming. The choice of shared, fixed systems is driven by risk-mitigation strategies and community-based security arrangements that reduce the need for expensive mobile units.

Critical Implications:

- **Financial Product Innovation:** Conventional interest-based loans will face high rejection rates. Scaling SBIS requires Sharia-compliant products (e.g., *Murabaha* or crop-backed repayment) to align with local ethical frameworks.
- **Institutional Channeling:** Deployment should strictly route through existing cooperatives and informal farmer groups, utilizing their established governance structures to manage shared assets and repayments.

3.4. Cross-State Summary and Comparative Insights

To synthesize the state-level validation outcomes, Table 1 presents a comparative summary of validated preferences across Kaduna, Kebbi, and Kano States. The table highlights convergence and divergence in ownership models, system configuration, and financing mechanisms, as confirmed during the validation workshop.

Table 1. Cross-state validation summary of SBIS preferences

Dimension	Kaduna State	Kebbi State	Kano State
Preferred Ownership Model	Individual ownership	Dual ownership	Dual ownership
Key Justification	Higher purchasing power; heterogeneous society; security concerns; operational flexibility	Social homogeneity, farm proximity, and cost sharing	Strong collective culture; risk-sharing norms
Preferred Cart Option	With a cart (mobile system)	Without a cart (fixed system)	Without a cart (fixed system)
Key Justification	High security risks; need to move and secure solar panels	Lower security risks; cost minimization	Similar to Kebbi, cost and communal security
Preferred Financing Option	BOA loan (1 year)	BOA loan (2 years)	Islamic (Sharia-compliant) financing
Key Justification	Strong repayment capacity; acceptance of interest-based loans	Reduced repayment pressure; alignment with income cycles	Religious and cultural norms; non-interest-based finance

4. Conclusions

The validation exercise provided critical empirical and stakeholder-based confirmation of the Discrete Choice Experiment (DCE) findings, grounding the quantitative data in the lived realities of farmers, policymakers, and private-sector actors. The consensus across all groups, particularly among smallholders in Kaduna, Kebbi, and Kano, strongly endorsed the identified preferences for cart configuration, flexible financing, and ownership structures. A central theme of the validation was that technological suitability alone is insufficient; successful adoption depends on a "human-centered" design that accounts for crop-specific water requirements, seasonal income flows, and the acute security challenges of northern Nigeria. Ultimately, the exercise confirmed that for solar irrigation to transition from a niche technology to a mainstream agricultural tool, it must be supported by a robust ecosystem that addresses land tenure, technical maintenance, and financial inclusivity.

4.1. Operational Sequencing for Scaling Pathways

The transition from validation to large-scale implementation requires moving beyond uniform assumptions to a phased, operationally sequenced approach. To move from evidence to impact, stakeholders must adopt a strategy that prioritizes immediate regulatory and financial "quick wins" before pursuing wide-scale expansion. This scaling process evolves through three distinct phases:

Phase 1: Regulatory De-Risking and Financial Piloting (0–12 Months) The immediate priority is to de-risk the sector through concurrent regulatory enforcement and "proof-of-concept" financial pilots.

- **Regulatory & Fiscal:** The Standards Organization of Nigeria (SON) must rigorously enforce quality standards to curb substandard imports, while the Federal Ministry of Finance approves fiscal incentives, such as duty exemptions, to immediately reduce upfront system costs.
- **Financial & Social:** Simultaneously, the Bank of Agriculture (BOA) should pilot 2-year harvest-synced loans targeting pre-verified "micro-clusters" (2–3 members) in Kebbi and Kano. This phase validates social cohesion and cost-sharing models on contiguous lands, utilizing temporary smart subsidies to lower entry barriers and accelerate early adoption learning.

Phase 2: Ecosystem Institutionalization and Service Deepening (12–24 Months)

Once adoption models are validated, the focus shifts to institutionalizing support structures and building the "after-sales" infrastructure required for sustainability.

- **Institutional Integration:** State ADPs must integrate solar irrigation operation and maintenance into extension curricula to bridge the technical "software" gap.
- **Scaling Finance:** Islamic finance providers should scale Sharia-compliant products like Murabaha in culturally aligned zones (e.g., Kano), leveraging the foundational credit history established in Phase 1.
- **Service Networks:** This phase establishes decentralized maintenance networks and local spare-part supply chains to ensure system reliability—a primary driver of farmer confidence—while connecting farmers to off-takers to ensure the consistent cash flows necessary for commercial repayment.

Phase 3: Systemic Localization and Resilience (24+ Months)

The long-term goal is to transition from import dependence to domestic resilience.

- **Localization:** This requires supporting domestic manufacturing and assembly of solar components to strengthen local supply chains and create jobs.
- **Governance:** Institutional governance is formalized by empowering Water Users Associations (WUAs) to manage shared assets and resolve resource conflicts.
- **Adaptive Management:** Ultimately, this phase cements a market-driven ecosystem where public-private partnerships drive innovation, while continuous monitoring and evaluation (M&E) loops allow policymakers to adapt interventions based on real-time productivity data.

Strategic Action Matrix: Scaling Pathways

Table 2 details the core recommendations, linking action areas to specific entry points and key actors for sustainable scaling.

Table 2. Recommendations, Goals, and Actors for SBIS Scaling in Nigeria

Action Area	Core Recommendations & Entry Points	Primary Goal	Key Actors
1. Financial Innovation & Risk Mitigation	<p>Entry Point: Transition from 1-year rigid loans to 2+ year harvest-synced repayment models.</p> <p>Action: Mandate the development of Islamic finance products (e.g., Murabaha) and hybrid credit schemes that align repayment with crop cycles.</p>	Improve affordability, reduce default rates, and stabilize the sector against foreign exchange volatility on imported components.	BOA, MFIs, Islamic Finance Providers, FMWR, FMAFS

2. Cooperative Ownership & Governance	<p>Entry Point: Shift focus from large cooperatives to "micro-clusters" (2–3 members).</p> <p>Action: Use existing FBO structures to validate these small clusters, building social accountability and creditworthiness from the bottom up.</p>	Reduce default risk, lower individual investment costs, and leverage close peer relationships for operational success.	FBOs, NGOs, State ADPs, Extension Services
3. Technical & Agronomic Linkages	<p>Entry Point: Prioritize "software" (human capacity) over hardware distribution.</p> <p>Action: Bundle SBIS hardware with mandatory technical training and establish local spare-part networks. Link farmers to high-value crop markets to ensure ROI covers technology costs.</p>	Ensure system durability, prevent failure from "undersized" units, and maximize productivity of high-value crops.	Solar Firms, Research Institutes (IWMI), Input Suppliers, Agribusinesses, Development Partners
4. Quality Assurance & Policy Integration	<p>Entry Point: Fiscal Policy & Standardization.</p> <p>Action: Enforce strict quality standards to protect the market and implement tax waivers to reduce landed costs of solar components.</p>	Ensure technical reliability and provide an enabling policy environment for inclusive, equitable scaling.	SON, NERC, NGOs, Ministries of Agriculture and Energy, Development Partners

Annex A. Overview of the Validation Exercise

Overview of the validation discussions

The validation workshop convened a broad range of stakeholders, including representatives from federal and state government agencies, academia, non-governmental organizations (NGOs), private-sector actors, financial institutions, and farmer groups. The primary objective of the session was to validate and contextualize the findings of the Discrete Choice Experiment (DCE) conducted on Solar-Based Irrigation Systems (SBIS) across Kaduna, Kebbi, and Kano States.

Participants engaged in structured discussions to assess whether the estimated preferences reflected on-the-ground realities and decision-making processes among farmers and other actors within the SBIS ecosystem. Key areas of focus included ownership arrangements, cart versus non-cart system configurations, financing mechanisms, repayment structures, and broader enabling conditions such as security, social cohesion, land tenure, and institutional support. The discussions provided critical insights into state-specific dynamics and helped identify areas where the DCE results required clarification, refinement, or additional contextual interpretation.

State-Level Validation of DCE Results

Kebbi State

Ownership Preference: Dual Ownership

The validation exercise confirmed that farmers in Kebbi State clearly prefer dual (shared) ownership of solar-based irrigation systems. Participants consistently linked this preference to social cohesion, spatial proximity of farms, and financial considerations.

Unlike in Kaduna State, Kebbi farming communities are largely socially homogeneous, with strong kinship ties, shared cultural values, and long-standing traditions of collective farming. This social cohesion fosters trust, cooperation, and mutual accountability, making shared ownership arrangements both practical and socially acceptable. Stakeholders emphasized that farmers in Kebbi are accustomed to sharing productive assets and jointly managing agricultural resources, thereby reducing the likelihood of conflicts arising from co-ownership.

Proximity to farms was also identified as a significant enabling factor. Many irrigated plots in Kebbi are located within contiguous or closely clustered areas, particularly around river basins and floodplains. This spatial closeness simplifies coordination in system use, scheduling, and maintenance, thereby making dual ownership operationally efficient. Participants noted that when farms are located near one another, the logistical challenges of sharing irrigation equipment are significantly reduced.

From a financial perspective, dual ownership was viewed as a mechanism to reduce individual financial burdens. By sharing acquisition and maintenance costs, farmers can better access solar-based irrigation systems that might otherwise be unaffordable when purchased individually. This cost-sharing arrangement was considered especially important for smallholder farmers with limited capital, as it lowers entry barriers and spreads financial risk across partners.

Cart Option: Without Cart

Participants in Kebbi State indicated a preference for fixed (without-cart) solar irrigation systems, citing lower security risks and cost considerations as the primary drivers.

Stakeholders explained that security challenges in many irrigation areas in Kebbi are less pronounced than in Kaduna State. In several communities, farmers can leave equipment, including harvested produce, on their farms overnight without significant risk of theft. This relatively secure environment reduces the need for mobile systems that can be transported after use.

Cost considerations further reinforced this preference. Without-cart systems are less expensive than cart-mounted alternatives, making them more attractive to farmers who prioritize affordability. Given the already reduced financial burden of dual ownership, farmers in Kebbi see limited justification for incurring additional mobility costs when perceived security risks are low.

Financing Option: Bank of Agriculture (BOA) Two-Year Loan

The validation workshop confirmed that farmers in Kebbi State favour a two-year loan facility from the Bank of Agriculture (BOA). This preference reflects an alignment between financing structure and farmers' income cycles and risk profiles.

Participants emphasized that a more extended repayment period helps reduce repayment pressure, particularly for farmers who depend on seasonal crop income. Unlike short-term loans, a two-year repayment horizon allows farmers to spread payments across multiple production cycles, thereby improving cash flow management and reducing default risk.

The BOA financing option was also perceived as institutionally familiar and accessible, with repayment terms considered more flexible and better suited to the realities of smallholder agriculture in Kebbi State. Stakeholders noted that longer repayment periods allow farmers to stabilize production, build confidence in the technology, and generate sufficient returns before completing loan repayments.

Kano State

Ownership Preference: Dual Ownership

The validation discussions confirmed that farmers in Kano State strongly prefer dual (shared) ownership of solar-based irrigation systems. This preference is deeply rooted in long-standing traditions of collective action, cooperative farming, and risk-sharing arrangements within the state's agricultural landscape.

Participants explained that Kano has a well-established culture of farmer groups, cooperatives, and informal associations, which facilitates shared decision-making and joint management of productive assets. In this context, dual ownership is not a constraint but a mechanism to enhance access to technology while spreading financial and operational risks among partners.

Risk-sharing emerged as a particularly important factor. Given the uncertainties in agriculture, including climate variability, market price fluctuations, and production risks, farmers in Kano view shared ownership as a practical strategy to mitigate individual exposure to financial losses. By pooling resources, farmers are better positioned to adopt solar-based irrigation technologies that may otherwise be out of reach for individual smallholders.

Cart Option: Without Cart

As in Kebbi State, validation participants in Kano State confirmed a preference for fixed (without cart) solar irrigation systems. This preference was driven primarily by cost considerations and relatively manageable security conditions in many irrigated farming communities.

Stakeholders noted that the absence of severe security threats in several irrigation zones reduces the perceived need for mobile systems. Farmers are generally comfortable leaving fixed installations on their farms, particularly in areas with intense community surveillance and shared responsibility for asset protection.

Cost savings were again emphasized as a key determinant. Without-cart systems have lower capital costs than cart-mounted alternatives, making them more attractive in shared ownership arrangements. Participants explained that when farmers already share costs under dual ownership, adding the extra expense of a cart system yields limited additional benefit unless security risks are unusually high.

Financing Option: Islamic Financing

The validation process strongly supported the DCE finding that Islamic financing mechanisms are the preferred financing option among farmers in Kano State. This preference is closely linked to religious, cultural, and ethical considerations that shape financial decision-making in the state.

Participants emphasized that many farmers in Kano avoid conventional interest-based loans due to religious prohibitions against interest (*riba*). As a result, Islamic financing models, such as asset-based financing, cost-plus arrangements (*murabaha*), and produce-backed repayment mechanisms, are viewed as more acceptable and trustworthy.

Stakeholders also highlighted farmers' openness to non-cash repayment structures, including produce-based or asset-backed repayment models. These arrangements align well with agricultural income patterns and reduce pressure on farmers to make fixed cash payments during periods of low liquidity.

Importantly, participants noted that the preference for Islamic financing does not imply resistance to formal financial institutions. Instead, it underscores the need for culturally compatible, context-sensitive financial products. When appropriately designed, Islamic financing models have strong potential to enhance the adoption and sustainability of solar-based irrigation systems in Kano State.

Kaduna State

Ownership Preference: Individual Ownership

The validation workshop strongly confirmed the Discrete Choice Experiment (DCE) finding that farmers in Kaduna State show a clear preference for individual ownership of solar-based irrigation systems. Stakeholders consistently emphasized that a combination of economic capacity, social structure, production diversity, security realities, and operational considerations shapes this preference.

First, participants noted that farmers in Kaduna generally have higher purchasing power than their counterparts in other states covered by the study. This financial strength enables many farmers to independently acquire irrigation technologies without relying on shared ownership arrangements. As a result, individual ownership is perceived as both feasible and desirable.

Second, the heterogeneous social composition of Kaduna State was identified as a critical factor influencing ownership decisions. Unlike more socially homogeneous farming communities, Kaduna farmers are ethnically, religiously, and production-orientationally diverse, and vary in farm size. These differences can give rise to trust deficits and compatibility challenges, making shared ownership arrangements difficult to sustain over time. Participants explained that disagreements over system use, maintenance responsibilities, and cost-sharing are more likely to occur in such settings.

Third, farmers in Kaduna typically engage in diverse cropping systems, including vegetables, cereals, and mixed farming enterprises. Each crop has distinct water requirements and irrigation schedules, which complicates joint use of irrigation infrastructure. Individual ownership allows farmers to independently manage irrigation timing and water application according to their specific crop needs, without negotiating with co-owners.

Security concerns also featured prominently in the validation discussion. Participants noted that insecurity in some irrigated areas of Kaduna State discourages shared asset ownership because collective responsibility for asset protection is often unclear. Individual ownership simplifies accountability and enables farmers to make independent arrangements for safeguarding their equipment.

Operational flexibility further reinforces the preference for individual ownership. Farmers emphasized that owning the system outright allows them to operate the equipment at any time, adjust irrigation schedules as needed, and make quick decisions without requiring partner approval.

This flexibility is crucial during peak irrigation periods when delays can negatively affect crop performance.

Finally, stakeholders noted higher awareness and exposure to irrigation technologies among Kaduna farmers, driven by improved access to extension services and markets, as well as prior experience with mechanized farming. This exposure increases confidence in independently adopting and managing solar-based irrigation systems.

Cart Option: With Cart

The preference for cart-based (mobile) solar irrigation systems in Kaduna State was strongly validated and closely linked to security-related considerations. Participants repeatedly stressed that solar panels, pumps, and associated components are vulnerable to theft when left unattended on farms.

Given prevailing security challenges, farmers prefer systems that can be easily transported from the farm to secure locations, such as their homes or community storage facilities, after use. Although cart-based systems entail higher upfront costs, farmers view mobility as essential to protecting their investment.

Stakeholders emphasized that cost considerations are secondary to asset security in this context. Farmers are willing to incur additional expenses for cart systems if they reduce the risk of loss and ensure continued access to irrigation services.

Financing Option: One-Year Bank of Agriculture (BOA) Loan

Validation discussions confirmed that Kaduna farmers favour a one-year financing option through the Bank of Agriculture (BOA). This preference reflects both economic capacity and risk management considerations.

Participants explained that farmers' stronger purchasing power and higher expected returns enable them to commit to shorter repayment periods. A one-year loan minimizes long-term financial exposure, reduces cumulative interest payments, and allows farmers to achieve full ownership of the irrigation system quickly.

Additionally, stakeholders indicated that BOA loan conditions, including interest rates and processing timelines, were considered manageable and acceptable within Kaduna's farming context. A shorter loan duration was also viewed as a safeguard against uncertainty stemming from market fluctuations, climate variability, and security risks.

Group-based validation insights

Beyond state-level preferences, the validation workshop generated key group-level insights into how Solar-Based Irrigation Systems (SBIS) can be deployed more effectively through collective arrangements and appropriately designed financing structures. These insights cut across stakeholder categories and provide practical guidance for implementation and scale-up.

Cluster and cooperative models

Participants strongly emphasized the importance of small-group ownership embedded within larger cluster arrangements as a viable pathway for SBIS deployment. The consensus view was that an optimal operational group size of two to three farmers strikes a balance between cooperation and manageability. Such small groups were considered easier to coordinate, less prone to conflict, and more compatible with community-level trust dynamics.

These micro-groups, however, are not expected to operate in isolation. Instead, participants proposed organizing them into larger clusters on contiguous or adjacent parcels. This clustered configuration was widely validated for several reasons. First, it strengthens social capital by reinforcing repeated interaction, peer accountability, and collective problem-solving among farmers. Second, a cluster-based organization was viewed as enhancing creditworthiness, as financial

institutions and development partners often perceive organized groups as lower-risk borrowers compared to isolated individuals.

Third, clustering was seen as a practical approach for monitoring, supervision, and technical support, particularly for private-sector service providers, extension agents, and NGOs. Concentrating beneficiaries within a defined geographic space reduces transaction costs and facilitates routine maintenance, training, and performance tracking. Finally, participants noted that cluster models could serve as a foundation for future infrastructure expansion, including shared water conveyance systems, storage facilities, and mini-grid or hybrid energy solutions to power additional agricultural or post-harvest activities.

Despite these advantages, participants flagged land tenure and land management issues as critical constraints. Unclear ownership rights, fragmented holdings, short-term rental arrangements, and weak land governance were identified as potential barriers to the formation of stable clusters. Participants emphasized the need for supportive land-use policies, community-level agreements, and government facilitation to ensure tenure security and reduce conflict risks in deploying clustered SBIS.

Financing structure and repayment design

The validation discussions revealed strong consensus that financing design is central to the sustainability of SBIS adoption, and that conventional loan structures often fail to align with agricultural realities. One key recommendation was the need to replace the reporting of “cost value” with explicit repayment amounts when communicating financing options to farmers. Participants argued that farmers respond more effectively to clear information on the amount they are expected to repay than to abstract total investment costs.

In addition, participants strongly advised against monthly repayment schedules, noting that such arrangements are poorly aligned with agricultural cash flows, which are typically seasonal and highly variable. Instead, they recommended seasonal, quarterly, or annual lump-sum repayment plans, preferably timed to coincide with harvest periods when farmers’ liquidity is highest.

Another important insight was the need to disaggregate financial analysis by crop or enterprise type. Different crops vary significantly in production cycles, water requirements, profitability, and risk exposure. Aggregated financial models were therefore considered misleading, as they obscure crop-specific repayment capacity and risk profiles. Crop-disaggregated analysis was seen as essential for designing realistic financing packages and improving repayment performance.

For Islamic financing options, participants emphasized the need to clearly specify contract duration and repayment terms, as ambiguity can undermine trust and compliance. Transparent articulation of financing horizons was considered particularly important for Sharia-compliant models, where asset ownership, risk-sharing, and repayment conditions must be explicitly defined.

Finally, participants emphasized that production cost estimates should be comprehensive, incorporating not only SBIS-related expenses but also water charges, land lease or rental costs, and other location-specific fees. Excluding these costs, they argued, leads to overestimation of profitability and unrealistic expectations regarding repayment capacity.

Taken together, the group-based validation insights underscore that successful SBIS scale-up requires both institutional innovation and financial realism. Cluster-based organizational models can improve efficiency, accountability, and access to finance, but only if land tenure challenges are addressed. Similarly, financing structures must be tailored to agricultural production cycles, crop characteristics, and local norms to ensure affordability, transparency, and long-term sustainability.

Sector-specific perspectives

Sector-based group discussions were conducted to validate the discrete choice experiment (DCE) and choice set analysis (CSA) findings from institutional, operational, and policy standpoints.

Stakeholders were grouped into academia, NGOs/civil society, private sector, government, and farmers, and each group responded to a standard set of guiding questions. The perspectives presented below reflect direct validation inputs, observations, and recommendations expressed during the discussions.

Academia

Participants from academic and research institutions confirmed that solar-based irrigation systems (SBIS) are technically adoptable, provided that system capacity is correctly matched to crop water requirements and irrigation demand. They emphasized that many performance and adoption challenges arise when systems are undersized, resulting in inadequate water delivery and farmer dissatisfaction, rather than from inherent limitations in the technology itself.

The academic group stressed that farmer training and awareness are critical determinants of effective system use. To ensure consistency, credibility, and broad outreach, participants recommended that training and sensitization activities be coordinated through established public platforms, particularly the National Orientation Agency (NOA) and State Agricultural Development Programmes (ADPs). These institutions were identified as having the mandate and geographic coverage to support the structured, standardized dissemination of information on solar-based irrigation systems.

In addition, academic participants highlighted the need for rigorous evidence generation to inform policy decisions and investment strategies. They emphasized the importance of Randomized Controlled Trials (RCTs) for evaluating the performance and impact of solar-based irrigation technologies under varying conditions. Specifically, they recommended comparative trials involving:

- Properly sized solar-based irrigation systems;
- Under-capacity solar-based irrigation systems; and
- Conventional fossil fuel-powered irrigation systems.

Such trials were viewed as essential for objectively assessing productivity outcomes, cost-effectiveness, and efficiency differences associated with system sizing and energy sources.

Regarding financing and adoption pathways, the academic group recommended promoting cooperative-based financing arrangements to reduce individual financial risk and improve access to credit. They also proposed produce-based repayment options, whereby farmers repay financing obligations with harvested produce rather than cash. Furthermore, participants advocated using initial government subsidies as a temporary measure to lower entry barriers, accelerate early adoption, and support learning before transitioning to market-driven scaling mechanisms.

NGOs / Civil Society

Participants representing non-governmental organizations (NGOs) and civil society organizations shared perspectives grounded in their long-standing engagement with smallholder farmers, vulnerable groups, and rural communities. They emphasized that while solar-based irrigation systems (SBIS) hold significant potential, several structural and social gaps must be addressed for meaningful and inclusive adoption to occur.

The NGO group identified low awareness of solar-based irrigation technologies as a significant constraint. Many farmers were reported to have a limited understanding of how SBIS operates, of the long-term cost advantages, and of the financing options available. This information gap was seen as contributing to hesitation and mistrust, particularly among resource-poor farmers.

Limited access to appropriate financing was also highlighted as a critical barrier. Participants noted that many farmers lack the documentation, collateral, or credit history required by formal financial institutions. In addition, weak financial literacy among farmers further constrains their ability to engage with loan products and repayment schedules associated with SBIS adoption.

The group further identified weak farmer capacity as a limiting factor, particularly in basic system operation, routine maintenance, and simple troubleshooting. Without sustained capacity-building, participants cautioned that system failures or misuse could undermine confidence in solar irrigation technologies.

Security concerns were also raised, especially in areas prone to theft, vandalism, or communal conflicts. NGOs noted that insecurity increases the risk profile of SBIS investments and may discourage both farmers and financiers unless adequate safeguards and community-level arrangements are put in place.

In addition, participants emphasized the risk of gender and social exclusion, noting that women, youth, and persons with disabilities (PWDs) often face disproportionate barriers in accessing productive assets, financing, and decision-making platforms. Without deliberate inclusion strategies, the benefits of SBIS adoption may be bypassed by these groups.

In response to these challenges, NGOs and civil society organizations outlined several roles they can play to support the scaling of solar-based irrigation systems. These include advocacy and policy engagement to influence enabling frameworks; sensitization and awareness creation at the community level; and the development of farmer profiling and database systems to support targeted interventions and financing.

They also emphasized their role in capacity building, including training-of-trainers approaches and the delivery of extension support tailored to local contexts. NGOs highlighted their ability to support monitoring and evaluation, facilitate linkages between farmers and financial institutions, and promote inclusive approaches that intentionally target women, youth, and PWDs.

Overall, the NGO and civil society group underscored their role as intermediaries and facilitators, bridging gaps among farmers, the private sector, financial institutions, and government actors to enhance the equitable and sustainable adoption of solar-based irrigation systems.

Private sector

Private sector participants, particularly solar technology providers, equipment distributors, and service companies, affirmed the strong adoption potential of solar-based irrigation systems (SBIS) in Northern Nigeria. This potential was attributed primarily to the region's abundant solar radiation and the increasing cost and unreliability of diesel-powered irrigation systems, which make solar alternatives comparatively cost-effective over time.

Stakeholders from the private sector validated that, when properly deployed, SBIS can deliver significant operational savings for farmers by eliminating recurrent fuel costs and reducing mechanical maintenance requirements. However, they emphasized that sustained adoption depends not only on the availability of technology but also on the quality of deployment, support services, and financing arrangements.

A key concern raised was the adequacy of farmer training, particularly in system operation, basic maintenance, and early fault detection. Private-sector actors noted that insufficient user knowledge often leads to misuse, system damage, or unrealistic performance expectations, thereby undermining confidence in technology.

Related to this were issues with technical troubleshooting and after-sales service. Participants highlighted gaps in the availability of trained technicians at the local level, limited access to spare parts, and weak service networks, particularly in remote farming communities. These constraints were identified as significant risks to system longevity and customer satisfaction.

To address financing barriers, private-sector representatives recommend adopting flexible, lenient financing models tailored to agricultural production cycles. They proposed extended repayment periods, potentially up to 3 years, to align repayment schedules with farmers' income flows and reduce default risk.

Participants also emphasized the importance of value-chain integration as a mechanism to improve loan recovery. Linking SBIS financing to output markets, aggregators, or off-takers was considered a practical way to ensure predictable cash flows and strengthen repayment discipline.

In addition, private-sector actors expressed a willingness to absorb or co-finance training costs, recognizing that improved user capacity ultimately reduces system failure rates and reputational risks for suppliers. They also proposed agent-led monitoring and evaluation systems in which local agents or technicians regularly assess system performance, support users, and provide feedback to suppliers and financiers.

Finally, the private sector emphasized the need for robust stakeholder feedback loops that involve farmers, financiers, and public institutions. Such feedback mechanisms were viewed as essential for refining product design, improving service delivery, and adapting financing models to local realities.

Government institutions

Government representatives at the validation workshop affirmed that promoting solar-based irrigation systems (SBIS) is fully aligned with Nigeria's national development priorities and international climate commitments, including obligations under the Paris Agreement. Participants emphasized that SBIS offers a practical pathway to reduce dependence on fossil fuels, lower greenhouse gas emissions, and support climate-resilient agricultural production.

Stakeholders from federal and state government institutions highlighted the contribution of SBIS to dry-season agricultural productivity, noting that reliable irrigation access can stabilize production, increase cropping intensity, and improve farmer incomes. From a policy perspective, SBIS was viewed as a strategic intervention that integrates the objectives of water, energy, and food security.

Despite this alignment, government representatives identified several implementation gaps that need to be addressed to support sustainable adoption. These include limited awareness among farmers of available financing options, insufficient training on system operation and efficient water use, and concerns regarding the long-term sustainability of maintenance and repair services.

Participants also noted that the current supply chain for solar irrigation components remains highly dependent on imported equipment, exposing the sector to foreign exchange volatility, supply disruptions, and higher costs. This dependence was identified as a constraint on large-scale, affordable deployment.

In terms of government roles, participants emphasized the importance of subsidies and de-risking instruments to reduce entry barriers for farmers and encourage private-sector investment. Such instruments were considered particularly important during the early adoption phases. The provision of tax waivers and duty exemptions for imported solar components was also recommended to reduce system costs in the short term.

Government stakeholders further highlighted the need to support local manufacturing and assembly of solar irrigation components to strengthen domestic supply chains, create jobs, and reduce long-term costs. Improving rural security was identified as a complementary priority due to concerns about theft and vandalism of irrigation infrastructure.

The promotion and strengthening of Water Users Associations (WUAs) was identified as another key government responsibility. WUAs were regarded as important platforms for organizing farmers, managing shared irrigation assets, facilitating collective financing, and resolving conflicts over water use.

Finally, government representatives underscored their role in facilitating linkages between farmers and private sector actors, including solar technology providers and financial institutions. They also reaffirmed the importance of providing clear policy and regulatory support to create an enabling environment for investment, innovation, and the sustainable scaling of solar-based irrigation systems.

Farmers / Community Representatives

Farmers and community representatives provided practical insights drawn from their direct experience with irrigation, production constraints, and livelihood realities. Participants confirmed that irrigation is essential for dry-season farming and that rising fuel prices, fuel scarcity, and frequent breakdowns of petrol and diesel pumps significantly constrain productivity and profitability.

Farmers expressed strong interest in solar-based irrigation systems, particularly for their potential to reduce recurring fuel costs and improve reliability. However, they emphasized that affordability remains the primary barrier to adoption. High upfront investment costs are repeatedly cited as the primary reason many farmers are unable to transition from fossil-fuel-based irrigation systems, despite recognizing the long-term benefits of solar alternatives.

Participants emphasized the importance of flexible, farmer-friendly financing arrangements, including more extended repayment periods and schedules aligned with harvest cycles. Several farmers indicated a preference for group- or cluster-based ownership models, especially when farms are located close together, as this would enable cost-sharing and reduce individual financial exposure.

Farmers also highlighted the need for adequate training and technical support, noting that limited knowledge of system operation and maintenance increases the risk of misuse and system failure. They stressed that access to local technicians and spare parts is critical for sustaining system functionality and building confidence in solar irrigation technologies.

Land tenure and security concerns were also raised. Farmers noted that insecure land arrangements can discourage long-term investment in fixed irrigation infrastructure, while theft and vandalism of equipment pose additional risks. Participants emphasized that community-level agreements and government support are necessary to mitigate these risks.

Women and youth farmers specifically noted that access to finance and productive assets remains more constrained for them compared to other groups. They emphasized the need for deliberate inclusion measures to ensure equitable participation in solar-based irrigation initiatives.

Farmers affirmed their willingness to adopt solar-based irrigation systems if systems are appropriately sized, affordable, supported by reliable financing, and accompanied by training and maintenance services. They emphasized that adoption decisions are ultimately driven by practicality, cost, and perceived risk.



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