CGIAR SCALING FOR IMPACT

IWMI International Water Management Institute

TECHNICAL REPORT

Co-Designing Scaling Pathways for Solar Irrigation Technology Ownership in Nigeria: Household Survey/Discrete Choice Experiment

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Summary

Nigeria's agricultural sector faces a "climate dilemma" that affects cropping systems, available water for crop production, and the practice of irrigated agriculture. The unsustainable nature of energy from fossil fuels for irrigation requires an urgent transition to Solar-Based Irrigation Systems (SBIS) to ensure water security and mitigate emissions, has become imperative. However, prohibitive costs and rigid financing mechanisms stifle the adoption of SBIS. Evidence from Northern Nigeria confirms that unlocking the SBIS market, which offers returns on investment exceeding 200% for staples and 300% for high-value horticultural crops, demands replacing "one-size-fits-all" financing models with context-specific strategies, such as offering two-year, harvest-synced, or Islamic financing – instead of rejected one-year loans – and promoting ownership structures that vary from security-focused individual systems in Kaduna to equity-enhancing shared micro-clusters in Kebbi. To drive scalable impact over the next 12–24 months, policymakers must immediately de-risk the market through fiscal incentives and strict quality assurance, while financiers and development partners innovate with shared-liability products and invest heavily in the "software" of technical training and supply chains, ensuring that infrastructure is not only affordable but also sustainable and inclusive for women and youth.

Introduction

Agriculture serves as the backbone of Nigeria's economy, contributing approximately 25% to the GDP and employing 70% of the workforce, yet its heavy dependence on rain-fed systems exposes the sector to severe climate risks that necessitate urgent adaptation strategies. While the strategic shift toward smallholder, groundwater-based irrigation in the northern floodplains offers a solution to water insecurity, the prevailing reliance on fuel-powered pumps contributes to the negative impacts of "climate dilemma" by increasing operational costs and carbon emissions, thereby undermining national mitigation goals. Solar-Based Irrigation Systems (SBIS) present a transformative, dual-benefit alternative that addresses both climate adaptation, by decoupling production from erratic rainfall, and mitigation through the displacement of fossil fuels with clean energy. However, adoption is currently stifled by high upfront costs, restricted credit access, and policy gaps; in response, the CGIAR Scaling for Impact (S4I) program is utilizing participatory research, including household surveys and discrete choice experiments, to co-design inclusive, market-aligned business models that overcome these barriers, aiming to foster food security, green job creation, and resilient low-carbon development across the region.

Opportunities and Constraints in SBIS in Nigeria

Nigeria possesses abundant solar radiation (5.25–7.0 kWh/m²/day) and extensive shallow groundwater reserves, particularly in the northern regions, but adoption of SBIS remains limited due to high upfront investment costs, restricted access to credit, and weak extension services (Gebrezgabher et al., 2021; Osunmuyiwa et al., 2021). Systemic challenges include reliance on imported equipment, fragmented supply chains, and limited institutional coordination, collectively constraining smallholder access to affordable and reliable SBIS. Key opportunities for scaling through innovative financing and ownership models, strengthening policy frameworks, local manufacturing, and technical capacity have been identified (Xie et al., 2023; Oke et al., 2024; Ojeleye et al., 2025). Comparative insights from other sub-Saharan African countries underscore the importance of integrated policies, public–private partnerships, and gender-inclusive interventions to promote equitable access.

Methodological Approach

To examine farmers' preferences and investment decisions regarding solar irrigation technologies and based on one unit acre as a standard of measurement, a discrete choice experiment (DCE) was conducted as part of a broader household survey across three states in northern Nigeria (Kebbi, Kano and Kaduna States). The methodological design followed a five-stage process to ensure scientific rigor, contextual relevance, and stakeholder validation.

Stage 1: An extensive literature review and background assessment were first undertaken to identify the key attributes influencing the adoption of irrigation technologies among smallholder farmers. This review focused on prior studies related to physical and institutional environment, agricultural financing schemes, irrigation supply models, and groundwater-based irrigation systems. In addition, a cost–benefit analysis was done to evaluate the economic feasibility of solar-powered irrigation, thereby informing the selection of attributes and levels for inclusion in the DCE.

Stage 2: Thereafter, a Key Informant Interview (KIIs)/Focus Group Discussion (FGDs) survey was conducted with relevant stakeholders across the irrigation value chain and governance spectrum, including policymakers, equipment suppliers, financial institutions, extension agents, and farmer cooperatives. This participatory process provided insights into institutional arrangements,

market dynamics, and farmers' behavioural tendencies, ensuring that the experimental design accurately captured real-world constraints and opportunities.

Stage 3: The third stage involved constructing choice sets that were orthogonal, balanced, and efficient, minimizing attribute overlap while maintaining experimental validity. To ensure the reliability and clarity of the DCE design, an enumerators' training session was conducted before data collection, and a pilot survey was conducted to test the comprehensibility, relevance, and sequencing of the choice sets.

Stage 4: This stage involved a randomized sampling strategy to select survey respondents. Before administering the experiment, a structured onboarding session was conducted to ensure that participants clearly understood the choice tasks, the meaning of each attribute, and the hypothetical nature of the scenarios. This stage was essential to minimize response bias, enhance comprehension, and improve the internal validity of the DCE results.

Stage 5: Finally, a synthesis and stakeholder validation workshop in Abuja engaged public and private stakeholders to review key findings through homogeneous and heterogeneous syndicate and plenary sessions. This collaborative process validated the study's results against practical experiences, ensuring the final recommendations are actionable and contextually grounded.

Summary of Key Findings

The current agricultural landscape is characterized by a heavy reliance on traditional monocropping, with Rice and Wheat representing over 70% of production as shown in Table 1. Rice emerges as the primary efficiency leader, with high adoption and a 215.78% return on investment (ROI). Significant untapped potential exists in high-value mixed cropping systems, which offer ROIs exceeding 300%, yet these remain rare due to steep entry costs, averaging over ₦1M (about USD714.3) per acre for crops like pepper, and possibly technical barriers. Consequently, the lower performance of standalone vegetable crops relative to mixed systems implies that market volatility and post-harvest risks continue to constrain the financial viability of high-cost vegetable production for smallholders.

Table 1. Average profitability analysis for some irrigated crops across the states

Crop	Observations freq. (%)	Avg. Cost USD[1]/acre)	Avg. Revenue USD/acre)	Gross Margin USD/acre)	ROI (%)
Red pepper Amaranthus	1 (0.2%)	317.14	1,361.79	1,044.64	329.39
Pepper Spinach Okra	1 (0.2%)	177.14	706.19	529.05	298.66
Rice	281 (45%)	226.61	653.78	427.17	215.78
Onion	8 (1.3%)	190.89	528.33	337.44	189.55
Tomatoes Amaranthus Pepper	1 (0.2%)	85.07	226.39	141.32	166.12
Tomatoes	33 (5.3%)	342.21	1,120.68	778.47	139.51
Pepper	82 (13.1%)	716.50	1,167.53	451.03	132.48
Maize Amaranthus Pepper	1 (0.2%)	107.50	242.00	134.50	125.12
Okra Onion	1 (0.2%)	384.64	828.57	443.93	115.41
Okra	6 (1%)	168.82	280.81	111.98	105.25

[1] USD 1 = 1400 Nigerian Naira at the time of reporting this study

Maize	26 (4.2%)	374.33	706.12	331.79	103.45
Wheat	158 (25.3%)	320.82	498.54	177.71	92.78
Red pepper	13 (2.1%)	479.40	666.28	186.89	37

SBIS Solution

While SBIS configurations may vary, a solar-powered water pump comprising a 3-inch × 3-inch DC brushless motor pump, with a maximum flow rate of 27 m^3/hr, a power rating of 1.2–1.5 hp, and a minimum solar capacity of 900 W—typically provided by three 400 W solar panels—has been found suitable for dry-season irrigation of at least one acre (See Figure 1).

This system may be combined with a mobile cart for safe transportation and storage. Although optional, the cart is particularly important in areas with security challenges, where it may be unsafe to leave solar installations permanently on the farm.

Solar pump

Solar panels mounted on a cart

Figure 1. The SBIS solution (*photo:* Oluwaseun Ojeleye Adebayo)

Discrete Choice Experiment/Top Predicted Utilities

Across Kebbi, Kano, and Kaduna States, a consistent preference for shared ownership models and long-term financing options, particularly Islamic and Bank of Agriculture (BOA) 2-year loans, as the key drivers of farmers' utility (See Figures 2 to 5). However, distinct state variations underscore the need for localized scaling strategies. In Kebbi, farmers are the most cost-sensitive, strongly favouring fixed, cart-less systems under 2- or 3-member ownership structures with multi-year financing, highlighting the importance of affordability and collective investment. In Kano, where farming is more commercialized, Islamic financing dominates preferences, reflecting the deep influence of religious compliance and cultural norms on financing choices. While a smaller segment shows interest in cash purchases with mobile systems, the broader market still prefers shared, Sharia-compliant models. In Kaduna, by contrast, a more diverse and risk-tolerant market emerges, with individual ownership and cart-based systems. While the majority requires derisked, cooperative models (Shared Ownership + Long-term Finance), "a one-size-fits-all" strategy will fail in high-value commercial zones like Kaduna, where individual ownership and mobility are prioritized.

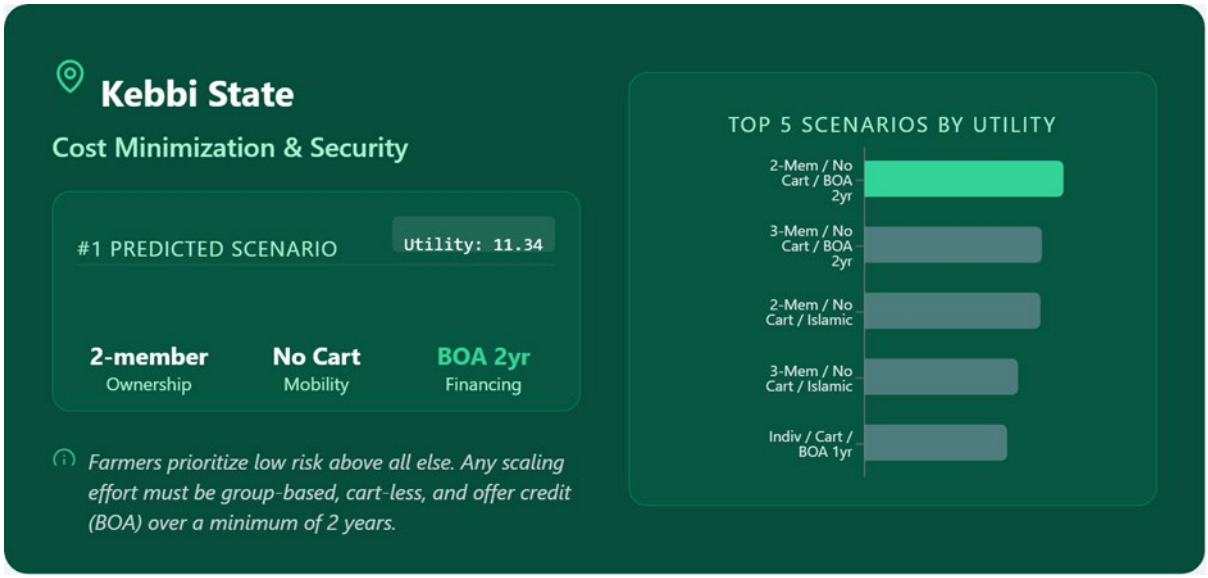

Figure 2. Showing the dominant choice in Kebbi state and the top 5 predicted utilities

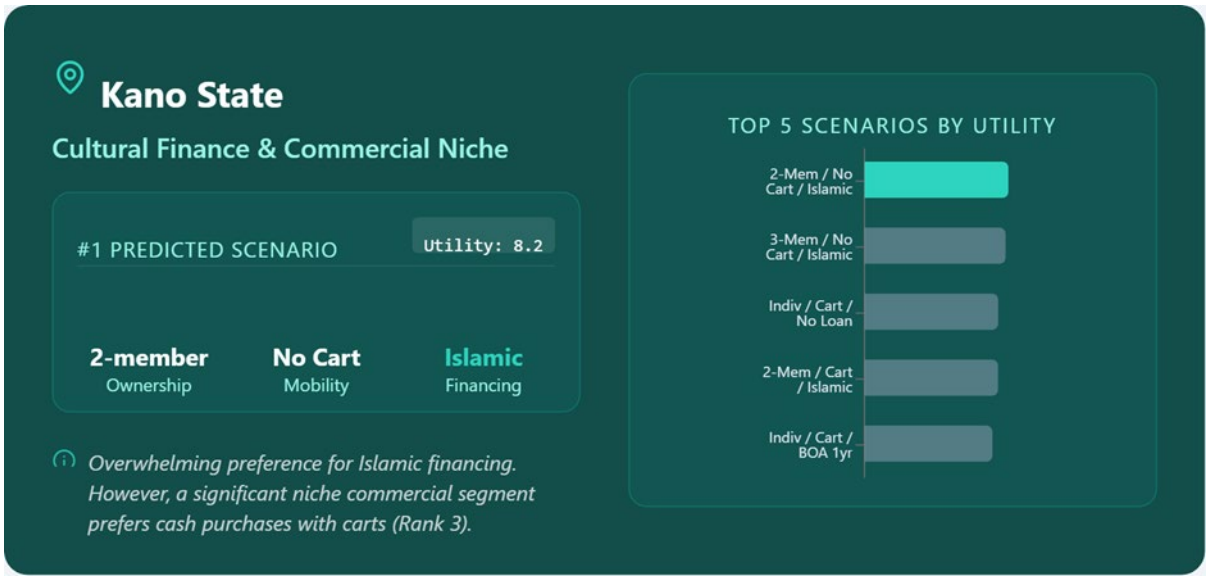

Figure 3. Showing the dominant choice in Kano state and the top 5 predicted utilities

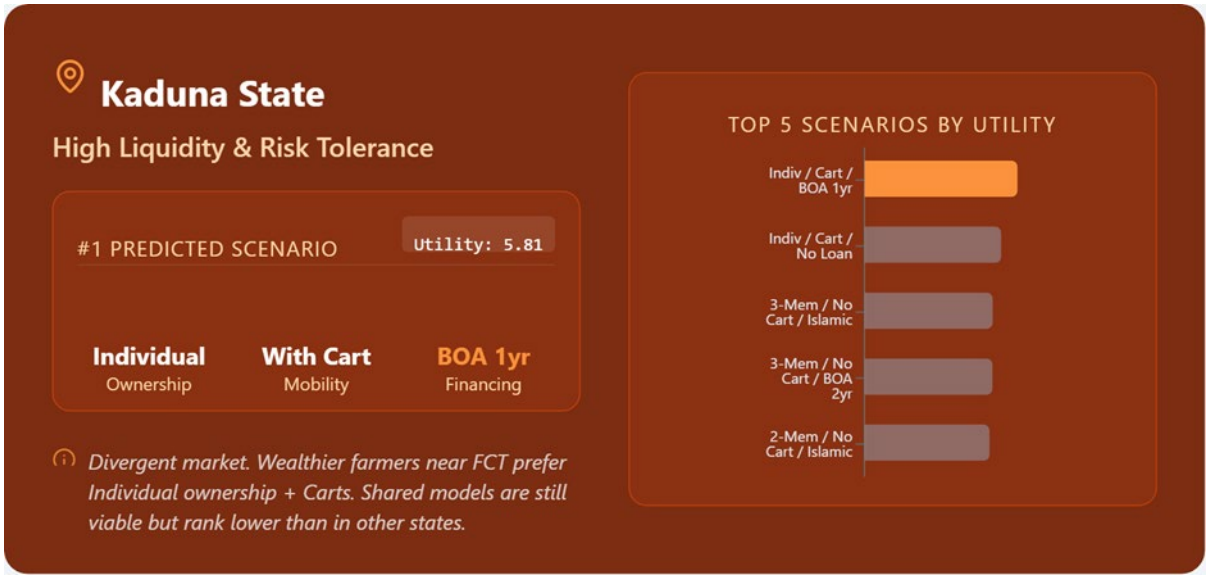

Figure 4. Showing the dominant choice in Kaduna state and the top 5 predicted utilities

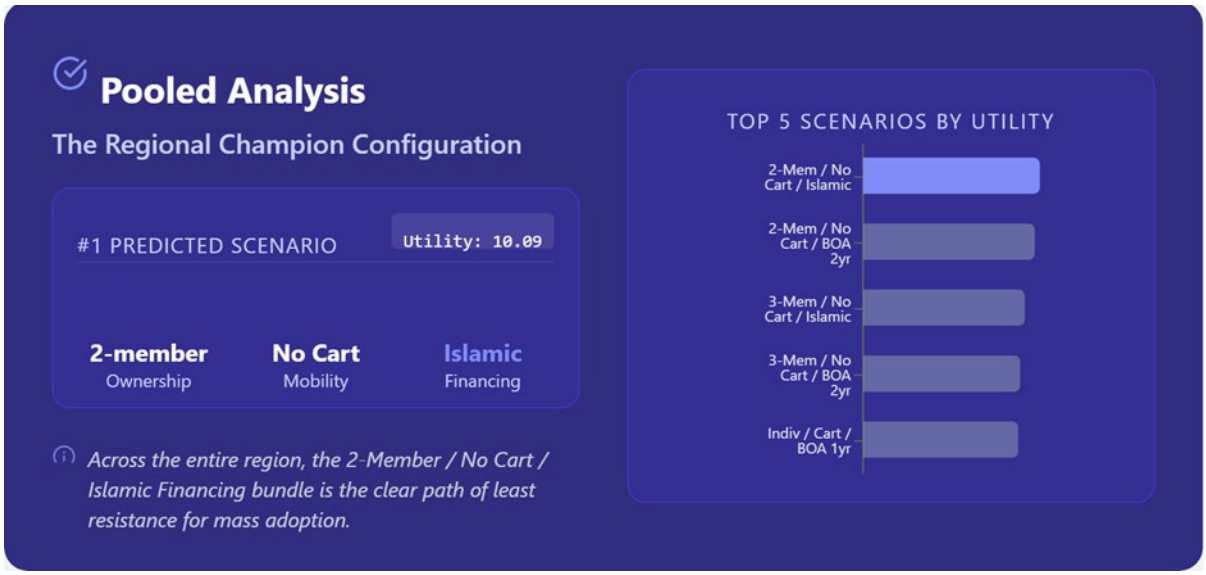

Figure 5. Showing the pooled dominant choice and the top 5 predicted utilities

Willingness to Invest (WTI)

Farmers across Kebbi, Kano, and Kaduna States, Nigeria, show strong willingness to invest in shared ownership models (particularly 3-member and 2-member groups) to reduce individual costs and risks. Islamic, BOA 2-year, and hybrid financing options are highly valued due to their alignment with farmers' cash flow cycles and religious considerations (See Figure 6). In contrast, BOA 1-year loans are broadly unpopular. Heterogeneity in responses highlights varying levels of risk tolerance and credit sensitivity, with Kano farmers appearing more conservative in financial commitments.

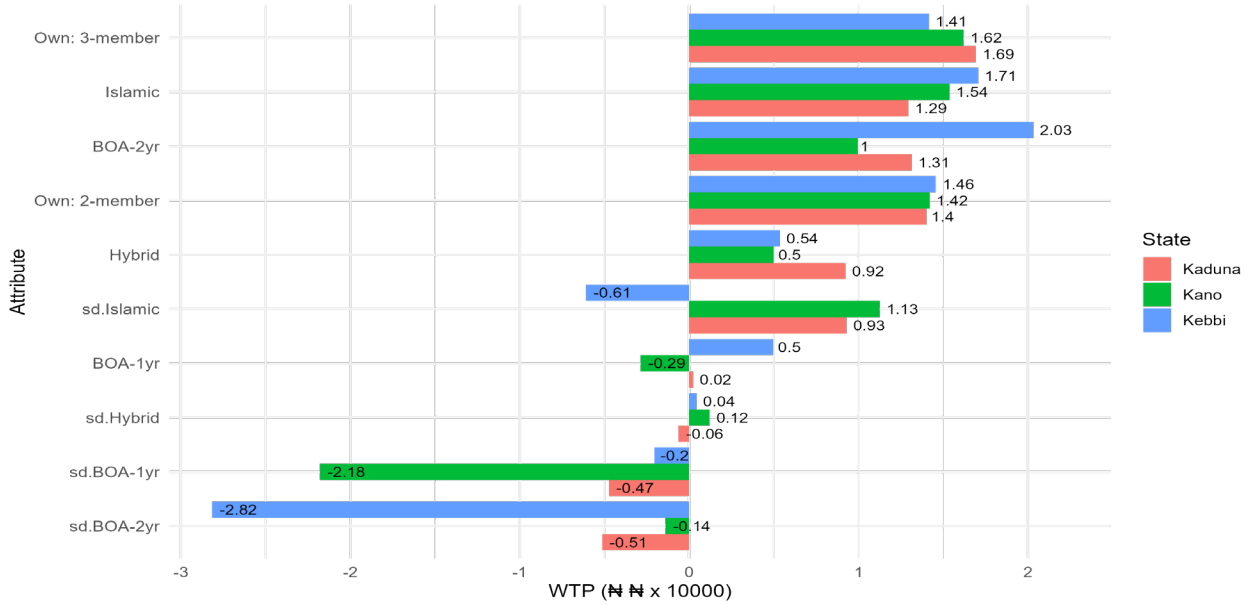

Figure 6. Showing farmers' willingness to invest across the states (*Source*: author's creation).

Conclusion

The successful and equitable scaling of Solar-Based Irrigation Systems (SBIS) in Northern Nigeria necessitates a context-specific strategy that aligns technology with regional realities while proactively dismantling barriers for marginalized groups. Evidence highlights a stark divergence in preferences: whereas wealthier farmers in Kaduna prioritize individual mobile systems to mitigate security risks, resource-constrained farmers in Kebbi and Kano favor shared, fixed models supported by Islamic or Bank of Agriculture financing. To prevent scaling from exacerbating inequality, these shared ownership models must be leveraged as critical entry points for women, youth, and marginal farmers, supported by deliberate inclusion strategies to prevent elite capture. Furthermore, ensuring sustainability requires a shift from rigid credit to flexible, harvest-synced repayment schedules that buffer smallholders against economic volatility, coupled with targeted "software" investments in technical training and local supply chains that empower women and youth as active managers and technicians rather than passive beneficiaries.

Prioritized Recommendations and Policy Sequencing

To move from evidence to impact, stakeholders must adopt a phased strategy that prioritizes immediate regulatory and financial "quick wins" over the next 12 to 24 months before pursuing wide-scale expansion. In the initial 12-month de-risking phase, the Standards Organization of Nigeria (SON) must rigorously enforce quality standards to curb substandard imports, while the Federal Ministry of Finance concurrently approves fiscal incentives, such as duty exemptions, to reduce upfront costs; simultaneously, the Bank of Agriculture (BOA) should pilot 2-year harvest-synced loans targeting pre-verified micro-clusters in Kebbi and Kano. Following this, the 12-to-24-month phase should focus on institutionalization, where State ADPs integrate solar irrigation operation and maintenance into extension curricula to bridge technical gaps, and Islamic finance providers scale Sharia-compliant products like Murabaha in culturally aligned zones, leveraging the foundational success of the initial micro-cluster pilots.

Strategic Action Matrix: Scaling Pathways

Table 2 provides details of the core recommendations, explicitly linking action areas to key actors and strategic goals for sustainable scaling.

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

Action Area	Core Recommendations & Entry Points	Primary Goal	Key Actors
1. Financial Innovation & Risk Mitigation	**Entry Point:** Transition from 1-year rigid loans to 2+ year harvest-synced repayment models. **Action:** Mandate the development of Islamic finance products (e.g., Murabaha) and hybrid credit schemes that align repayment with crop cycles.	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	**Entry Point:** Shift focus from large cooperatives to "micro-clusters" (2–3 members). **Action:** Use existing FBO structures to validate these small clusters, building social accountability and	Reduce default risk, lower individual investment costs, and leverage close peer relationships for operational success.	FBOs, NGOs, State ADPs, Extension Services

	creditworthiness from the bottom up.		
3. Technical & Agronomic Linkages	**Entry Point:** Prioritize "software" (human capacity) over hardware distribution. **Action:** Bundle SBIS hardware with mandatory technical training and establish local spare-part networks. Link farmers to high-value crop market to ensure ROI covers technology costs.	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	**Entry Point:** Fiscal Policy & Standardization. **Action:** Enforce strict quality standards to protect the market and implement tax waivers to reduce landed costs of solar components.	Ensure technical reliability and provide an enabling policy environment for inclusive, equitable scaling.	SON, NERC, NGOs, Ministries of Agriculture and Energy, Development Partners

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