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Co-identifying Collective Investment Models for Solar-based Irrigation Bundles in Northern Ghana

Abena Ofusu, Thai Thi Minh, Desire Naab Dickson, Andrew Emmanuel Okem, Ibrahima Barry, and Petra Schmitter

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The Authors

Abena Ofosu, Senior Research Officer – Innovation Scaling, International Water Management Institute (IWMI), Accra, Ghana
Thai Thi Minh, Principal Researcher, IWMI, Vientiane, Lao PDR
Desire Naab Dickson, (Former) Consultant, IWMI, Accra, Ghana
Andrew Emmanuel Okem, Senior Specialist, Deltares, The Netherlands
Ibrahima Barry, Assistant Professor – Industrial Organization & Corporate Strategies, University of Nantes, Nantes, France
Petra Schmitter, Research Group Leader – Climate Mitigation & Adaptation Pathways, IWMI, Colombo, Sri Lanka

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Front cover and back cover photos: Barbara van Rijn

Contents

Acronyms

ACDEP	Association of Church-based Development NGOs
AEA	Agricultural extension agent
AfDB	African Development Bank
AFD	Agence Française de Développement
Africa RISING	Africa Research in Sustainable Intensification for the Next Generation
CIKOD	Centre for Indigenous Knowledge and Organizational Development
CI-in	Collective irrigation investment
CRS	Catholic Relief Services
FBO	Farmer-based organization
FLI	Farmer-led irrigation
GESI	Gender Equality and Social Inclusion
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GAC	Global Affairs Canada
HAP	Hydrogeological Assessment of the Northern Region of Ghana Project
HTC	Hatoum Trading Company
ILSSI	Innovation Lab for Small-Scale Irrigation
IP	Innovation Platform
IWMI	International Water Management Institute
LPG	Liquified petroleum gas
MOFA	Ministry of Food and Agriculture
MSD	Multistakeholder dialogue
NER	Northeast Region
NR	Northern Region
NGO	Non-governmental organizations
PAYGO	Pay-as-you-go
PAYOWN	Pay-as-you-own
SBIBs	Solar-based irrigation bundles
SPIP	Solar-powered irrigation pumps
UER	Upper East Region
USAID	United States Agency for International Development
UWR	Upper West Region
WASH	Water, Sanitation, and Hygiene

Summary

Collective action among smallholder farmers enhances resource mobilization and addresses challenges beyond individual capacity. In Northern Ghana, farmers collaborate in formal and informal groups to strengthen their farming activities. While collective investment in irrigation has improved yields, income, and nutrition, the solar-based irrigation supply chain often overlooks farmer groups and cooperatives. To address this gap, this study applies a mixed-method analysis of collective investment models in solar-based irrigation bundles (SBIBs). Collective irrigation investment (CI-in) is a form of collective action by farmer-based organizations, involving voluntary risk-taking to achieve shared irrigation goals. CI-in supports

cost-sharing, commercialization of irrigated farming, and better access to resources, technical assistance, and market information (Filippi et al. 2022). SBIBs integrate core products (e.g., solar pumps, boreholes, water application equipment), financial services (e.g., pay-as-you-go/ pay-as-you-own: PAYGO and PAYOWN are financial services designed to reduce upfront investment costs for farmers. PAYOWN allows farmers to buy solar-powered irrigation pumps through flexible installment plans until full ownership is achieved, whereas PAYGO provides water access on credit, with the pump operating only when payments are made, digital payments, tailored business models, sales and service networks), complementary services (extension, capacity strengthening, market linkages, storage and processing facilities), and scaling actions to meet diverse farmer needs.

Findings identify two distinct investor groups. Male and mixed-gender groups (up to 50 members) use an ownership model, pooling moderate savings and labor. With limited access to markets and loans, they can partially invest in medium- to high-capacity solar pumps on a PAYOWN basis. Female groups (up to 60 members) can adopt a semi-service model, characterized by informal structures, low savings, and very limited access to markets and loans. They collectively invest in small- to medium-capacity solar pumps on a PAYGO basis. Barriers to collective SBIB investment include high upfront costs, limited finance and O&M services, weak supply chains concentrated in towns, poor linkages, supplier risks, lack of net metering, and reliance on subsidies. Farmer groups also face constraints in land, water, and group dynamics, with female groups particularly excluded. Nonetheless, opportunities exist: SBIBs are highly adaptable, distributors are piloting water-as-a-service models, and scaling collective investment yields strong development outcomes. The supply chain benefits from private sector participation and collaborations with NGOs, research, and government. Additional drivers of investment include rising fuel costs for motor pumps, high profits from dry-season farming, knowledge exchange, and cross-border trade with Burkina Faso. Pathways to scale include multi-actor partnerships, innovative financing, knowledge sharing, and capacity development.

1. Introduction

Solutions for sustainable intensification and irrigation technologies exist but are not widely accessible to smallholder farmers. The International Water Management Institute (IWMI), with various partners, aims to scale solar-based irrigation bundles (SBIBs) through a demand-supply linkage pathway. This involves introducing farmers to solar-powered irrigation pumps (SPIPs), establishing networks for sales and services, and enhancing the supply chain to foster

investment in solar irrigation markets. Since 2020, IWMI has collaborated with private irrigation equipment suppliers and various partners to scale solar-based irrigation bundles (SBIBs) in Northern Ghana. They identified six key demand segments: resource-rich farmers, mobile farmers, resource-limited farmers, farmer groups, out-grower schemes, and institutional clients across several regions. Investments from private and public partners have significantly benefited both resource-rich and resource-limited irrigators and their communities.

Farmers in Northern Ghana collaborate in formal and informal groups to improve their farming activities, offering joint labor for tasks like land preparation, planting, and harvesting. While informal groups are more common, there is a growing trend towards formalizing these groups to access government and financial services. Despite increased investment in irrigation and collective production, the importance of targeting farmer groups and cooperatives in the supply chain has been overlooked. This research explores collective irrigation investment (CI-in) models for small-scale irrigation businesses (SBIBs) in Northern Ghana to address this issue. Specifically, we asked:

1. What are collective irrigation investors and their associated actions in Northern Ghana?
2. What characterizes SBIBs and the SBIB supply chain in the region?
3. What characterizes CI-in models for SBIBs in group-based irrigation?
4. What pathways support the scaling of SBIB CI-in?

This report outlines an analytical framework (Section 2) and details the action research approach (Section 3). Section 4 covers SBIBs and their supply chain in Ghana, while Section 5 explores two demand segments and CI-in models. Section 6 analyzes barriers, opportunities, and pathways for SBIB CI-in in Northern Ghana. Finally, Section 7 concludes with insights into collective investors, their challenges and opportunities, study limitations, and future research recommendations.

2. Analytical framework

Collective action is a "*set of voluntary initiatives and actions undertaken by a group of individuals to achieve shared and mutually beneficial welfare-enhancing activities at social and economic levels"* (Lupi et al. 2021). In this analysis (Figure 1), we define **collective irrigation investment** (CI-in) as a specific type of collective action undertaken by farmer-based organizations with common interests in irrigation, involving voluntary risk-taking and action to achieve their shared interests. CI-in enables cost-sharing, promotes the commercialization of irrigated farming, and improves access to production resources, technical assistance, and market information (Filippi et al. 2022). CI-in involves collective investors, such as farmer groups or cooperatives. Farmer cooperatives are often established by government agencies, non-governmental organizations (NGOs), private organizations, and individuals to meet social, economic, and cultural needs. They operate on the principles of free, voluntary, and open membership; democratic administration; economic participation of partners; autonomy and independence; governance with equal voting rights; and transparency and accountability. Funding sources include entrance fees, share capital, monthly dues, significant contributions, levies, and the cooperative's business activities. Figure 1 presents a framework for analyzing CI-in.

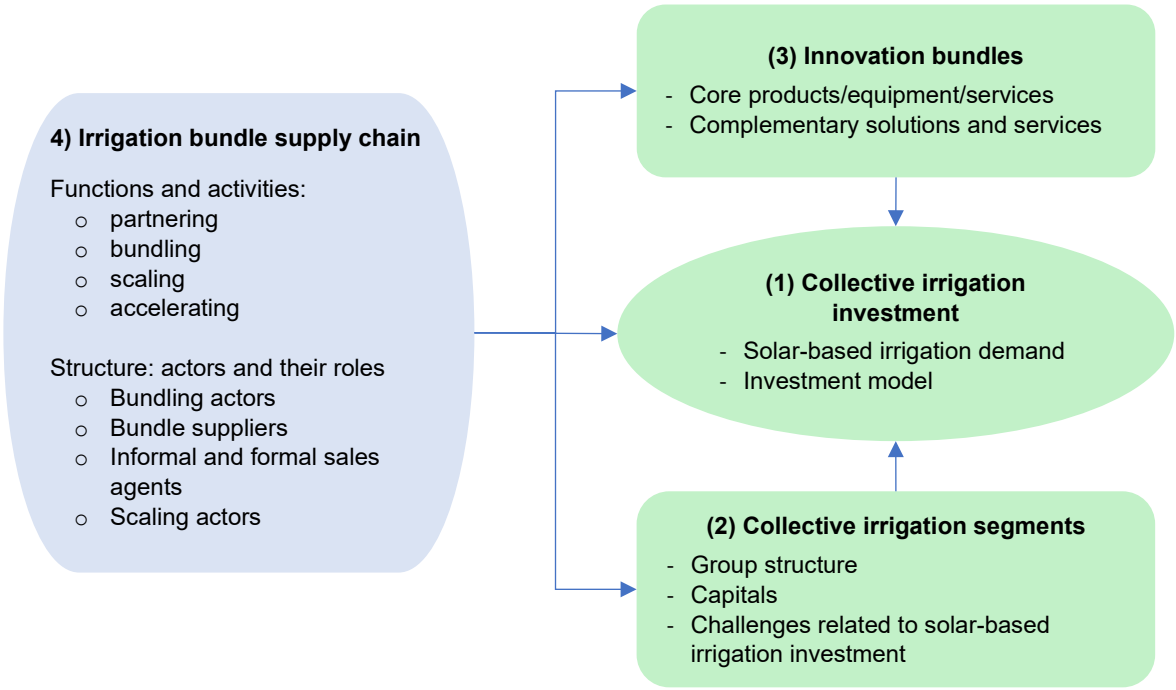

Figure 1. An analytical framework to co-identify collective investment in solar-based irrigation bundles

CI-in depends on internal factors that determine different **CI-in segments**. CI-in segmentation involves identifying specific collective demands for SBIBs by categorizing investors based on characteristics like demographics, interests, and preferences (IWMI 2024). This approach classifies CI-in demands through the integrated business and agricultural value chain perspectives, allowing for tailored segmentation that considers the needs of farmers and companies regarding investment types, available resources, and technology preferences (Aghdaie et al. 2013; 2014). We segmented CI-in based on:

- Group structure and institutional arrangements, such as the number of members, formation, registration, operation, management, leadership, governance structure and shared norms, and group sustainability;
- Challenges related to natural, financial, and human capital, group geographical proximity, and group dynamics (e.g., members' characteristics, economic heterogeneity, and interdependence among members); and,
- SBIB preferences include pump capacity, water application system, and investment models based on financial capital and payment terms.

CI-in is affected by external factors like irrigation equipment, services, and the supply chain. **Irrigation bundles**, particularly SBIBs, include essential products and services for various farmer groups. High-demand items such as solar-powered irrigation pumps (SPIPs) and borehole drilling services support cultivation in both dry and wet seasons. Modern irrigation methods, like drip and sprinkler systems, are increasingly sought after due to climate-induced water stress. Financial services from village savings, microfinance, and banks also play a crucial role in funding irrigation investments. Additionally, input markets provide access to seeds and fertilizers, while harvest storage and processing facilities help reduce post-harvest losses and improve access to markets.

The **irrigation supply chain** includes activities by various actors to provide innovation bundles, which may consist of supply, installation, training, maintenance, and repair (IWMI 2023). Key functions include bundling, partnering, scaling, and accelerating. Partnering encourages collaboration among government, private sector, research organizations, and farmers to share risks and resources for common goals (Smyth et al. 2021). Bundling combines

various innovations and services, requiring collaboration at different levels (Barrett et al. 2022). Scaling aims to promote widespread adoption of innovations, transitioning from pilot projects to broader applications, while allowing diverse actors to engage collectively (Gebreyes et al. 2021; Bohan et al. 2024). Accelerating focuses on deploying financial and non-financial resources to expedite scaling, encompassing both tangible assets and intangible resources like intellectual property.

The supply chain operation involves various **actors**, each with specific roles. Bundling actors collaborate to organize and categorize innovative products and services for farmers. Bundle suppliers provide these products, while formal sales agents are appointed for sales and service tasks. Informal agents, such as extension agents and input dealers, assist farmers in purchasing products for a fee. Scaling actors work to expand innovations, supported by facilitators and enablers like policymakers and community leaders, who aid in policy changes, market linkages, and capacity development.

3. Action research approach

3.1. Research process

Since October 2020, IWMI has employed an action research approach tailored to scaling small-scale irrigation technologies and services, as well as farmer-led irrigation development, in various projects across Northern Ghana (Minh et al. 2020). Specifically, this research was conducted in three interrelated steps: develop, co-design, and reflect (Figure 2).

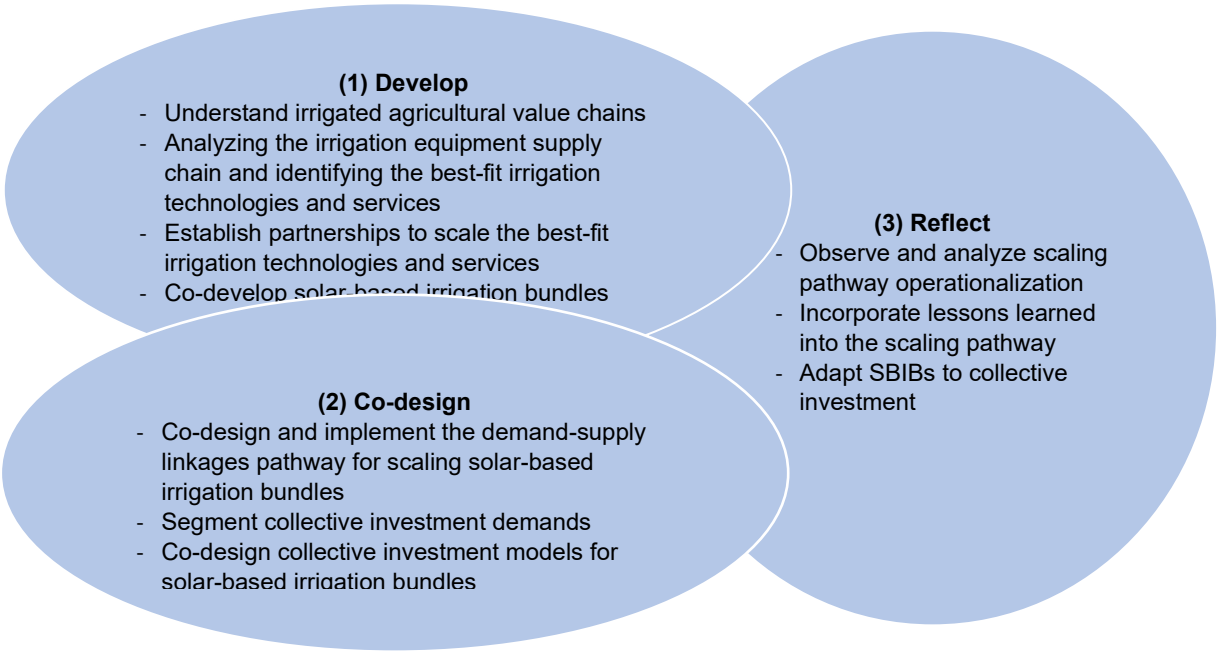

Figure 2. Action research process: Steps and activities (Source: adapted from Minh et al. 2020)

(1) Develop aimed at bundling SBIBs and identifying scaling pathways to facilitate different demand segments in Northern Ghana to adopt/invest in SBIBs. This step included:

- Understanding the irrigated agricultural value chains and different demand segments for irrigation investment in the five regions: We employed a rapid value chain analysis and market segmentation to characterize demand segments for SBIB among resource-rich farmers, mobile farmers, resource-limited individual farmers, farmer groups, out-grower schemes, and institutional clients.

- Analyzing the irrigation equipment supply chain and identifying the irrigation technologies and services best suited to the region: We employed a supply chain analysis approach to map and identify actors and potential partners and their roles in bundling and scaling SBIBs in Northern Ghana.
- Establish partnerships with actors in the irrigation technology and service supply chains: We established and co-invested in three partnerships with Pumptech, Tech2, and Interplast in Ghana to scale SBIBs.
- Co-develop SBIBs: The bundles include SPIPs and accessories, irrigation systems, and jointly supplied financial and information services by the partners (see Section 4.1.1).

(2) Co-design aimed at stimulating investment from partners and stakeholders in scaling SBIBs for collective investments within the five regions of Northern Ghana. It focused on:

- Co-designing and co-investing in the demand-supply linkages pathway to scale SBIBs: During 2020-2024, the established partnerships co-designed and co-invested in the demand-supply linkage pathway to create awareness and facilitate farmers' investment in SBIBs.
- Segmenting CI-in demands: In 2022-2023, 230 farmer groups, 167 in the Upper East Region (UER), 28 in the Upper West Region (UWR), and 35 in the Northern Region (NR), were segmented to understand the different types of farmer groups and the most suitable SBIBs to support their farming activities.
- Co-designing CI-in models for SBIBs: In July 2023, three workshops were organized in Tamale (NR), Jirapa (UWR), and Bolgatanga (UER) with leaders of farmer-based organizations (FBOs) to co-design CI-in options for SBIBs. Collaboration between IWMI and partners fostered cross-learning, cost-sharing, and coordinated efforts to promote SBIBs.

(3) Reflect was undertaken by the IWMI research team and scaling partners to understand the characteristics and governance of farmer groups, their collective activities, financial management, investment, and pathways for catalyzing SBIBs among the groups. This step involved 1) analyzing scaling pathway operationalization among individual farmers and farmer groups, 2) incorporating lessons learned into the scaling pathway, and 3) adapting the SBIBs to CI-in. The partners reflected on how to provide shared products and services for farmer groups that cultivate in a common area and groups with multiple farms near a water source. They discussed the possible challenges of managing assets in a group, repayment options, and actions to minimize repayment defaults. They also identified the best-fit actors and stakeholders to participate in the scaling process.

3.2. Data collection and analysis

We collected a mixed dataset, combining qualitative and quantitative elements, to segment the demands for SBIB CI-in. Initial respondents for focus groups and workshops were identified by extension agents from the Department of Agriculture, followed by additional respondents through the snowball technique across five regions. Oral consent was obtained from all participants. The qualitative data was gathered from 19 focus group discussions and 23 interviews with farmers and value chain actors, including government agents, SBIB providers, NGOs, and researchers, from 2020 to 2023. These discussions explored farming practices, income sources, savings habits, irrigation investments, market linkages, value chain dynamics, and farmers' access to innovations.

A quantitative dataset was collected in 2023 using a structured questionnaire targeting farmer groups involved in irrigated vegetable production from the Department of Agriculture. Initial respondents were identified, and a snowball approach helped identify additional groups. Community and group leaders were contacted to confirm their interest in SBIBs. A total of 230 farmer groups were surveyed: 167 in the Upper Eastern Region (UER), 28 in the Upper

Western Region (UWR), and 35 in the Northern Region (NR), with UER having significantly more groups due to higher participation in irrigated agriculture. Groups from the Southern Region (SR) and Northern Eastern Region (NER) were excluded due to lower participation and limited water access.

The quantitative data encompasses group details, characteristics, current production arrangements, collective action, financial management, and investment models. Group details include the name, region, key contacts, member gender, total members, and objectives. Characteristics cover membership requirements, individual roles, and responsibilities. The production arrangement details land size, usage, water sources for dry-season farming, irrigation methods, rainfed crops, and farming challenges. Collective action assesses input access, extension services, financial services, marketing of produce, joint activities, and investment plans in collective SBIBs. Financial management looks at group income, saving habits, and access to financial services. Investment models focus on preferences for SBIBs, such as pump type, water systems, production decisions, conflict resolution, and payment methods.

Qualitative and quantitative datasets were collected in English and local languages, then transcribed and translated for analysis. Qualitative data were analyzed by reviewing transcripts to identify key characteristics of SBIBs and their supply chains. Quantitative data were analyzed with descriptive and inferential statistics (Dabas 2024) to segment SBIB demand for CI-in.

In July 2023, we held three workshops with 285 farmer group leaders in Bolgatanga, Jirapa, and Tamale, representing 130 groups. These workshops focused on co-designing CI-in models, exploring financial opportunities for SBIB investments, and discussing challenges in access for farmer groups. Participants engaged with presentations from Pumptech, Tech2, and Interplast about their products and services, seeking clarification on costs and capabilities. The workshops highlighted new insights on the financial opportunities for farmers' investment in SBIBs, barriers and opportunities for promoting SBIB CI-in in Northern Ghana, and various SBIB CI-in options tailored to different farmer groups' conditions and abilities. Participants discussed the process for formalizing farmer groups, financial access through rural and other banks, preferred SBIBs CI-in, and the management of group assets.

4. Solar-based irrigation supply

4.1. Solar-based irrigation bundles

Throughout the action research process, SBIBs have been co-developed and scaled in Northern Ghana since January 2020. This bundle includes various innovations, services, and scaling actions (Figure 3).

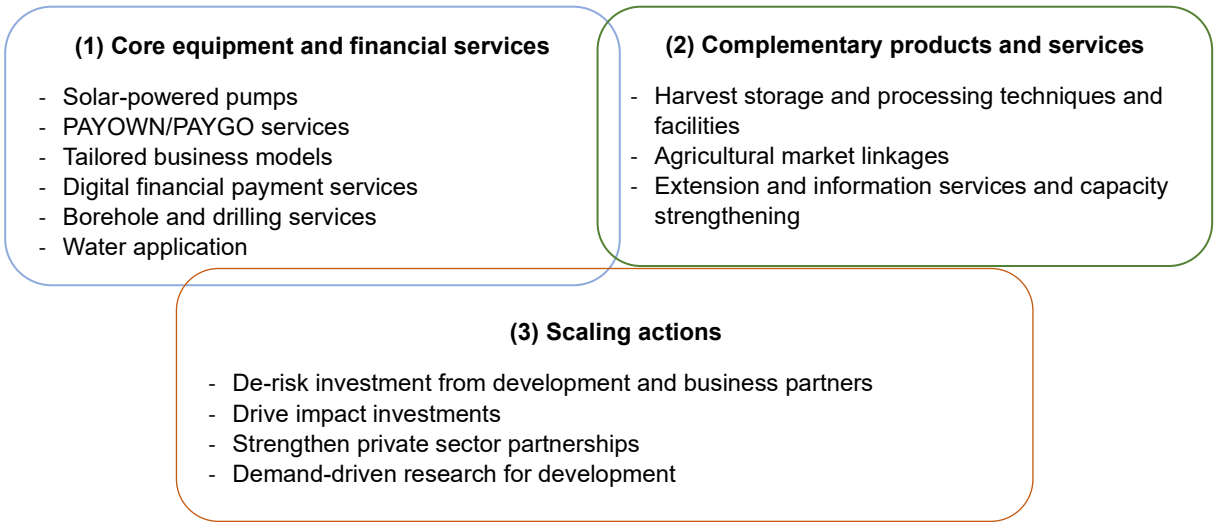

Figure 3. Solar-based irrigation bundles for collective irrigation investment

4.1.1. Core equipment and financial services

Solar-powered irrigation pumps (SPIPs) are available from various suppliers in Ghana, such as Pumptech, which offers Lorentz brand SPIPs with capacities from five cubic meters per day to 800 cubic meters per hour (Table 1). The suitability of these pumps depends on factors like water source, depth, storage tank height, pressure losses, daily water needs, and sunlight exposure. Designed for off-grid water pumping, SPIPs can lift water from both surface and groundwater using mechanical or centrifugal systems, and they support sprinklers, drip, and center pivots. Their remote operation via Android devices or Bluetooth provides farmers with flexibility and saves time for other activities.

PAYGO/PAYOWN are financial services offered by SPIP suppliers to reduce upfront investment costs for farmers. PAYOWN allows farmers to purchase SPIPs with flexible payment plans tailored to their financial situations, while PAYGO offers water access on credit. Payments can be made weekly, monthly, or at harvest times. The initial deposit corresponds to a programmed water amount in the pump. The pump stops working once the water limit is reached unless payments are made. In the PAYOWN model, farmers own the pump after all instalments are paid, but in PAYGO, the provider retains ownership.

Tailored business models cater to different segments (e.g., ability to pay, frequency, and amount), making solar irrigation more accessible and enhancing productivity. The installation-payment model targets resource-rich farmers, while PAYOWN supports resource-limited farmers, and PAYGO is aimed at groups with limited upfront capital. Movable SPIPs are designed for mobile farmers, and partnerships with government and development agencies help introduce these solutions to wider farming communities.

Pump name	Characteristics	Estimated price
PS2-100 pump	- Two 100-watt solar panels - Maximum and minimum depth: 25m and 5m, respectively - Pumping capacity per day: 3,000 litres	**GHS** 25,000 ⁼ USD 1,600
PS2-150 pump	- One 250-watt solar panel - Maximum depth: 40m; Minimum depth: 5m - Pumping capacity per day: 5,000 litres	**GHS** 45,000* ⁼ USD 2,800
PS2-600 pump	- Two 250-watt solar panels - Maximum and minimum depth: 60m and 10m, respectively - Pumping capacity per day: 10,000 litres	**GHS** 45,000* ⁼ USD 2,800

PS2-1800 pump	- Three 250-watt solar panels - Maximum and minimum depth: 140m and 5m, respectively - Pumping capacity per day: 15,000 litres	**GHS** 55,000* ≈ USD 3,400

Table 1.Some Lorentz solar-powered pumps distributed by Pumptech (Source: Pumptech)

** Cost of pump and controller as of November 2024. Solar panels are sold separately*

Digital financial services offered by mobile telephone operators support PAYGO/PAYOWN clients in making repayments for the chosen bundle. These include MTN Mobile Money (MTN MoMo), AirtelTigo Money (AT Money), and Telecel Cash (T-Cash). Farmers' payments are instant, and the cashless system minimizes the risk of transporting cash for service providers and farmers. Farmers also benefit from low transaction costs and the convenience of making payments from their locations without the need to travel to banking facilities.

Digital financial services provide mobile telephone operators like MTN Mobile Money, Airtel Tigo Money, and Telecel support PAYGO/PAYOWN clients making repayments for the chosen bundle. These services ensure instant payments for farmers, reducing cash transport risks and lowering transaction costs, allowing payments to be made conveniently from their locations without visiting banks.

Sales and service networks consist of formal and informal agents that enhance the distribution of SBIBs. Suppliers appoint official agents or collaborate with informal ones to sell products and handle installations or repairs. These networks expand through community workshops and digital channels like WhatsApp.

Borehole and drilling services enhance farmers' access to water, especially where surface water is unavailable or inadequate. Dry spells and the increasing demand for surface water for irrigation also drive the high demand for boreholes and drilling services in Northern Ghana.

Water application systems (e.g., drips, sprinklers, and spray tubes) contain all the necessary materials and fittings for smallholder farmers' irrigation. Drip kits and systems include drip pipes, drip tapes, and drip kits for smallholder vegetable farmers. The standard drip kits cover farm sizes ranging from 500 m² to 10,000 m² and are available in both tape and hard-wall pipe configurations. The design may also be customized to the client's request.

4.1.2. Complementary products and services

Agricultural market linkages encourage farmer groups to adopt innovations by providing access to input markets for seeds, fertilizers, and agrochemicals. Farmers acquire these inputs from dealers and agents, including extension officers. High-value vegetable seeds, like cabbage and bell peppers, are mainly imported by select individuals and companies, with prices fluctuating due to foreign exchange rates. Smallholder farmers often demand repackaged seeds in smaller quantities. Fertilizers are imported in bulk from various countries and may be blended or repackaged for local markets. Farmers purchase fertilizers using their funds, sometimes with government subsidies. Output markets include local, district, and regional markets, as well as export markets for crops like peppers in Europe. Sales occur through direct transactions, middlemen, and credit arrangements, such as selling to market queens. Linkages between market actors, government, and development partners can enhance farmers' incomes and reduce post-harvest losses, further motivating investment in innovations.

Harvest storage and processing techniques help minimize post-harvest losses and boost farmer incomes and food access. Key facilities include harvesters, threshers, sorting and packhouses, dryers, refrigerators, and warehouses. While harvesters and threshers are in high demand, their supply is limited, mainly from private investors. Other facilities face supply

constraints due to low yields, seasonal demand, and poor market linkages, affecting their economic viability for the private sector.

Extension and information services support farmers in managing their farms and businesses. This includes physical and electronic services, market information via radio and TV, and weather updates. The Department of Agriculture primarily offers support during the rainfed season, with additional assistance from NGOs, development organizations, and farmer groups. Training in technical and business capacity helps farmers adopt advanced methods and manage their farms effectively through group training, demonstrations, and field schools.

4.1.3. Scaling actions

De-risking investment reduces the risks associated with private sector investment in agriculture, such as climate variability, limited collateral, and poor market linkages. Irrigation equipment suppliers often hesitate to credit smallholders who can't fund the initial costs. Access to low-cost capital and credit guarantees from donors and development organizations enables these suppliers to offer credit for equipment to smallholders and farmer groups.

Impact investments have enabled private sector partners to access funds from organizations like Root Capital, Invest in Africa, Acumen, and GroFin. This funding allows partners to offer farmer groups SBIBs on more flexible terms, which is crucial for resource-limited farmers. ***Strengthening private sector partnerships*** reduces costs and provides mutual benefits, such as cross-referrals, shared outreach expenses, and collaborative bids for irrigation projects. ***Demand-driven research*** helps address business challenges, identifying financing options tailored to the diverse needs of farmer groups for irrigation equipment.

4.2. Solar-based irrigation bundle supply chain

4.2.1 Supply Chain Structure

The SBIB supply chain is led by private suppliers offering various products and services (Figure 4). Key ***SPIP importers and distributors***, like Pumptech, HTC, Aggrico, SunIn, and Deng, operate in towns such as Accra, Tamale, Wa, and Bolgatanga. Pumptech is the main distributor of Lorentz and Grundfos pumps, providing comprehensive irrigation solutions and after-sales support. Their models include PAYGO, allowing farmers to pay for water use, and PAYOWN, which offers installment payments for pump ownership.

Other suppliers, i.e., Interplast, Tech2, Namoo, Fred Ban, and Youno, offer water application systems such as PVC and drilling pipes and drip systems to connect farmers to broader value chains. Based in cities like Accra, Tamale, Wa, and Bolgatanga, they work on various nationwide projects for governments, NGOs, and farmer groups. Interplast manufactures local drip kits, including pipes and tapes for smallholder vegetable farmers while importing accessories mainly from Spain and Italy. Other suppliers, including Dizengoff and Farm Masters, also source products from countries like China and the USA. Interplast distributes its products through agents in Northern Ghana and operates under the brand “InGreen,” providing easy-to-install drip kits for farm sizes from 500 m² to 10,000 m², available in customizable designs.

Drilling contractors take contracts from farmers to identify suitable borehole locations, while rig suppliers, mainly Indian and some Ghanaian companies, rent drilling rigs due to high costs and limited access to financing. Development providers supply pumps for water extraction. Companies like Tech2, established in 2007, drill boreholes, install pumps, and design irrigation systems. Tech2 has expanded its customer base, participated in field demonstrations across Northern Ghana, and collaborates with various companies to execute projects.

The supply chain includes ***formal agents*** like Northern Solar and Tech2, which handle sales and installations for Pumptech and Interplast in the Upper East Region. ***Informal agents***, such as extension agents, input dealers, and pump repairer, connect farmers to equipment and services. They frequently travel between towns and rural areas, assisting farmers in purchasing solar equipment and accessories from suppliers in places like Tamale, Bawku, and Navrongo (IWMI 2024).

Government agencies, notably the Ministry of Food and Agriculture and local assemblies, facilitate farmer group access to SBIBs by implementing irrigation policies and support programs at national, regional, and district levels. **NGOs** such as World Vision, CIKOD, CRS, and GIZ support smallholders with SBIBs through grants and co-financing schemes. While some pumps also serve WASH needs (e.g., World Vision), others are provided mainly for irrigation (e.g., CRS, GIZ).

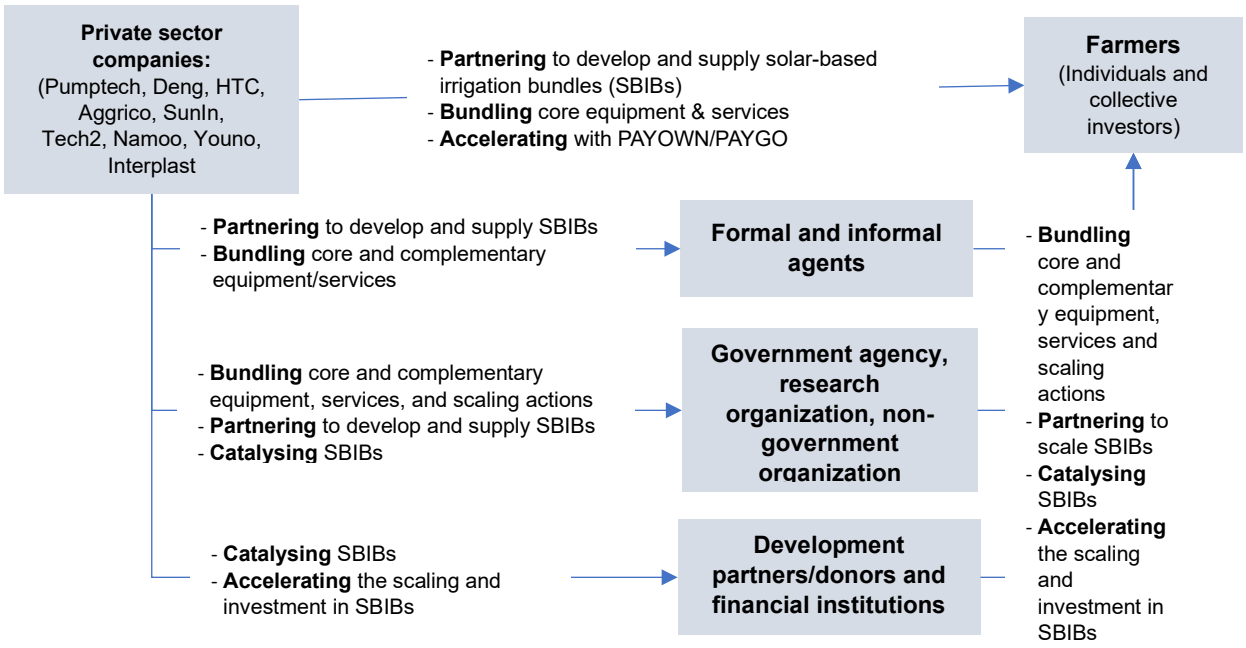

Figure 4. Solar-based irrigation bundle supply chain (Source: Author's illustration)

Research institutions like IWMI and the International Institute of Tropical Agriculture give farmer groups access to SBIBs at demonstration sites. This increases awareness of improved irrigation technology, helping farmers earn extra income. In Gorogo (UER), for example, farmers use solar technology to grow vegetables, boosting community income and enhancing food security during the dry season.

Development partners and donors like the African Development Bank (AfDB), Agence Française de Développement (AFD), and Global Affairs Canada (GAC) support irrigation projects to boost food security, nutrition, and farmers' incomes. They funded the Small-scale Irrigation Development Project, helping 6,000 farmers cultivate 2,590 hectares under irrigation. Additionally, GAC funded the Hydrogeological Assessment of the Northern Region of Ghana Project to support groundwater management projects.

Financial institutions include commercial banks, microfinance institutions, and rural banks. They offer farmers financial services to support the purchase of SBIBs and other farming inputs. Some commercial banks, such as Access Bank and Ecobank, finance farming activities in collaboration with the Mastercard Foundation. Institutions such as *Girsal* also provide

financial guarantees to financial institutions, thereby de-risking agricultural financing and stimulating increased lending to farmers.

Financial institutions like commercial banks, microfinance institutions, and rural banks provide farmers with financial services for purchasing SBIBs and farming inputs. Banks such as Access Bank and Ecobank collaborate with the Mastercard Foundation to finance agricultural activities. At the same time, *Girsal* offers financial guarantees to reduce risks for lenders and encourage more loans to farmers.

4.2.2. Supply Chain Functions

The SBIB supply chain has four functions, as illustrated in Figure 4. ***Partnering*** established a partnership among IWMI, Pumptech, and the Regional Extension Department (MOFA) in the UER to analyze the irrigated agricultural landscape, and co-developed and scaled SBIBs to increase SBIB availability and accessibility for smallholder farmers. In 2022, Tech2 joined to provide mechanization and borehole drilling services, improving access to water and irrigation technologies. Collaboration with GIZ aimed to reduce risks for private sector investments in PAYOWN SPIP bundles. In 2023, partnerships expanded to include Interplast, which offers drip systems as part of the product bundle. Various products and services were co-developed with farmers and value chain actors.

Bundling co-identified SBIB components involved collaborating with individual farmers, farmer groups, cooperatives, irrigation suppliers, community leaders, government services, research organizations, and market actors. This process included leveraging existing products, services, and market links by considering farmers' practices, irrigation needs, savings culture, and group dynamics. The resulting bundles were co-created based on identified core and complementary innovations, along with the reflections shared.

Catalyzing scaled SBIBs through implementing demonstrations, workshops, and results-based financing schemes with partners like GIZ. These activities increased farmer awareness and connected demand and supply actors. Companies like Pumptech, Tech2, and Interplast showcased solar pumps, while joint investments and international forums boosted private sector visibility. Under the Green People's Energy project, GIZ offered subsidies of 50% for women's groups and 40% for men's and mixed groups.

Accelerating encourages financial institutions to offer credit for farmers to invest in SBIBs. To boost uptake, partnerships with institutions like GIRSAL, Access Bank, ARB Apex Bank, Naara Rural Bank, and Nandom Rural Bank have been formed to provide flexible payment options. IWMI is collaborating with Pumptech to pilot PAYGO and PAYOWN financing, allowing farmers to make manageable initial deposits and repay over 18 months.

5. Collective investment in solar-based irrigation bundles

Farmer groups in Northern Ghana have varying demands for Smallholder Business Investment Budgets (SBIBs), influenced by several factors. These factors include economic activities and power dynamics, gender composition, willingness to invest in SBIBs, and specific irrigation needs. In this section, we present two investment models tailored for different segments of farmer-based organizations, as shown in Table 2.

Character	Male and mixed-gender groups and the ownership investment model	Female groups and the (Semi-) service investment model
Structure and characteristics		
No. of member	- Up to 50 members	- Up to 60 members

Formation	- By farmers, government agencies, and NGOs	- By farmers, government agencies, and NGOs
Registration	- Largely informal - Some groups registered with NGO assistance	- Largely informal - Some groups registered with NGO assistance
Operation	- Collective labor arrangements - Formalized village savings and loans	- Collective labor arrangements - Informal village savings and loans
Management	- Farmer managed by elected officials	- Farmer managed with NGO support
Sustainability	- Capacity development by NGO and government agencies to improve governance and sustainability	- Capacity development by NGO and government agencies to improve governance, sustainability, and family nutrition
Challenges related to solar-based irrigation investment		
Capital	- Limited access to water in the dry season (*Natural*) - Low access to commercial loans; limited financial literacy, low collective investment, and business ventures (*Financial*) - Low access to extension support in the dry season (*Human*)	- Limited access to land and water in the rainfed and dry seasons (*Natural*) - Low access to commercial loans, low financial literacy, and low value of savings (*Financial*) - Low access to extension support in the dry season (*Human*)
Group dynamics	- The dominance of informal groups - Poor leadership - Lack of transparency	- The dominance of informal groups - Better leadership due to fewer power struggles - Lower cases of lack of transparency
Value chain dynamics	- Limited collective access to input and output markets - Poor bargaining power for prices	- Limited collective access to markets - Poor bargaining power for prices - Limited access to markets
Investment ability	- Low ability to fund SBIB purchase entirely from own funds - Possible funding for investment: 30,000 – GHS 50,000 (~USD 1,936 – USD 3,227)	- Minimal ability to fund SBIB purchase entirely from own funds - Possible funding for investment: GHS 1,000 – 5,000 (~USD 65 – USD 323)
SBIB need		
Pump capacity	- Medium to high capacity (e.g., PS-1800 pump or higher)	- Small to medium capacity (e.g., PS2-100 to PS2-1800 pumps)
Water application	- Sprinklers, spray tubes, drips, furrow	- Furrow, bucket, watering cans, water hoses
Financial service	- Medium to long-term soft loans, financial planning, and advisory services - Farm business investments	- Medium to long-term soft loans, financial planning, and advisory services - Farm business investments
Market information	- Price information and market demand	- Price information and market demand
Investment model		
Land and water resources required	- Rented, community, and government land - Surface water - Groundwater	- Family and community land - Surface water - Groundwater
Financial capital	- 30% to 50 % of the initial capital outlay	- 5% to 20% of the initial capital outlay
Payment term	- Part payment + PAYOWN	- PAYGO for water use - Part payment + PAYOWN - Part payment + PAYOWN +PAYGO

Collective action	- Village savings and loans - Collective labor arrangements and marketing	- Village savings and loans - Collective labor arrangements
Services	- Government extension - NGO extension support	- Government extension - NGO extension support

Table 2. Collective investment segments and models (Source: Author's analysis)

5.1. Male and mixed-gender groups and the ownership investment model

Male and mixed-gender groups, consisting of 10-50 members, are formed by farmers, government agencies, and NGOs like Catholic Relief Services and GIZ. Most groups are informal, with some registered through NGOs. They are managed by elected officials, providing mutual support during tasks such as weeding, planting, and harvesting. Many groups have a village savings and loans (VSLA) scheme, which includes passbooks, a secured metal box for funds, select keyholders, and sometimes a group bank account. Contributions can be weekly, monthly, or seasonal, typically ranging from 20 to 100 GHS (~USD 2 to US $ 10). Access to loans from financial institutions is often limited due to high interest rates, though some groups obtain loans up to GHS 10,000 (~USD 643) from rural banks for purchasing equipment or inputs.

Male and mixed-gender groups face challenges related to capital, group dynamics, and investment capabilities. They struggle with limited access to water from February to May due to scattered plots, which complicates irrigation. Financial service access is low, and informal group structures hinder support from the government and NGOs. Poor leadership and transparency reduce trust and conflict resolution. Limited collective actions for purchasing inputs and seeking agricultural services decrease the benefits of bulk purchases. Bargaining power for selling produce is weak due to low volumes and individual decision-making. High initial costs make it difficult to finance Small Business Investment in Agriculture (SBIBs), and some groups can't even raise the necessary capital due to low fees, limited activities, and lack of access to loans. Savings often aren't invested for further income generation. Additionally, low awareness of SBIBs and inefficient farming practices significantly affect productivity and income, limiting investment potential.

Male and mixed-gender groups typically work around the same water source or village savings group, managing 12 to 20 hectares in total, with individual farmers cultivating 0.4 to 2 hectares. They grow high-value crops like peppers, onions, cabbage, lettuce, and tomatoes, often sharing irrigation infrastructure powered by petrol or diesel. Farmers access water from rivers, streams, dams, boreholes, dugouts, and occasionally pipe-borne water from the Ghana Water Company.

Groups need SBIBs that lower fuel costs and irrigation time. Some require SBIB bundles to apply fertilizer through fertigation, conserve water, and enable flexible acquisitions. Women in mixed groups often access land and irrigation from male relatives in exchange for labor, managing the entire farm, weeding, protecting crops, and harvesting. SBIBs include high-capacity SPIPs (like PS-1800 pumps) and improved water application tools such as drip irrigation and sprinklers, along with financial services and market access.

The modality for such solar-based irrigation investment by the male and mixed farmer groups is the **ownership investment model**. This applies to those renting land, using community land informally, or cultivating government land. Groups contribute an initial deposit of 30% to 50% for the SBIBs on a PAYOWN basis. They operate pumps on a rotational schedule of 3-5 days based on group size. Down payments are funded through membership dues, special levies, and possibly village savings schemes. Group leaders or extension agents handle payments directly to product and service providers in major towns in Northern Ghana. To succeed with

the ownership investment model, groups may use village savings and loans to buy inputs, make minor repairs to shared assets like PVC pipes, and assist each other with labor and market output. They should receive government extension services, particularly during the wet season, with occasional support in the dry season, complemented by NGO assistance.

5.2. Female farmer groups and (semi-) service investment model

Female farmer groups consist of 20 to 60 members and are formed by the farmers themselves or with support from NGOs and the government. Some are informal, while others are registered. Group management may be led by elected leaders or supported by NGOs initially. Members assist each other in farming activities like weeding, planting, and harvesting, and partake in village savings and loans for farm inputs. Female farmer groups often operate more informal VLSAs due to their inability to buy metal boxes, which cost approximately GHS 300 to GHS 600 (~USD 20 to USD 40), and limited access to financial institutions. They record contributions in a notebook, which is kept by a designated group member, while another trusted member keeps the group's money at home. The member responsible for keeping the group's money brings the full amount to each meeting to reassure the other members that their contributions are safe. Group contributions are often made weekly, ranging from GHS 2 to GHS 10 (~US$0.13 to US$0.64). NGOs and the Department of Agriculture support some female farmer groups in formalizing their VSLA activities.

Female farmer groups face several challenges, including limited access to land and water, particularly during the dry season, due to competition for irrigable land. Cultural norms often restrict women from owning land, requiring them to rely on male relatives, which limits their cultivation potential. They also struggle with access to financial services due to poor record-keeping, lack of collateral, and social norms inhibiting interactions with men. Additionally, they have limited bargaining power and access to markets beyond their local communities. Their investment ability is hindered by low yields and a focus on low-value crops primarily for home consumption.

Many groups have a common fenced area for cultivation to enhance economic empowerment and nutrition. They irrigate using surface water sources like the White and Black Volta rivers and use methods such as manually lifting water with metal basins, cans, and buckets, or using motor or solar pumps from boreholes. Irrigation can be done individually or collectively through scheduled turns. Groups focusing on economic empowerment typically grow high-value crops like cabbage and lettuce for sale, while others aim to improve nutrition by growing a variety of vegetables, including green leafy options such as amaranth and pumpkin leaves, as well as okra, tomatoes, and onions for home use. Some groups balance between economic and nutritional goals, adapting their crops to market demands.

Female farmer groups need SBIBs that minimize irrigation time, allowing them to focus on other farm activities. With sufficient land, they can expand cultivation, enhancing production and income. Depending on their size, these groups require P2-100 or PS2-1800 SPIPs, along with financial services, to address capital shortages and access markets for necessary cash flow.

The identified modality for female farmer groups is a **(semi-)service investment model** based on their demand for SBIBs and financial capabilities. This model includes three options. The PAYGO option allows the group to pay a service provider for water without owning the equipment. The PAYOWN option allows the group to purchase SBIBs on credit and own the equipment after repayment. The combined PAYOWN and PAYGO allows the group member to buy an SBIB on PAYOWN and sell water to other members to cover the investment.

To manage SPIP usage, groups in a common area pump water into overhead tanks during peak hours. Leaders schedule irrigation for fields in the mornings and evenings, rotating every

3-5 days based on tank capacity and membership. Groups without storage irrigate directly from pipes using hoses or cans. To save for a down payment, members contribute weekly, monthly, or at harvest time, and a special levy may also be collected. Male relatives or extension agents make the down payments, which are paid directly to providers in major towns in Northern Ghana. To enhance the (semi-)service investment model, groups should diversify production towards high-value crops. Collaborating with the Department of Agriculture to train female extension agents will improve access to support year-round. Additionally, investing in low-tech communication devices like feature phones will boost access to markets and market information.

6. Pathways to scale collective investments in solar-based irrigation bundles

6.1. Barriers and opportunities for scaling collective investments in solar-based irrigation bundles

Several factors influence the sustainable and inclusive acceleration of collective SBIB investment. This section presents these factors as barriers and opportunities (Table 3).

Theme	Barriers	Opportunities
Solar-based irrigation bundle	- High initial investment cost - Limited access to financial services - Limited technology suitability for users (credit metering, level of sophistication) - Limited access to operation and maintenance services - Low SBIB adoption	- Scaling readiness at level 9 - High adaptability to collective investments - Water as a service business opportunity - Excellent development outcomes when scaling SBIBs to farmer groups
Supply chain	- Dominance of free-gift and subsidy business models - High business and investment risks for the SBIB suppliers - Limited supply of SBIBs to the main towns - Poor market linkages - Lack of net metering	- The established supply chain of SBIBs - Existing initiatives and investments from the private sector suppliers for SBIBs - Collaboration opportunities with research, NGOs, and government
Context	- Limited access to irrigable land - Limited access to irrigation water and uncertainties with groundwater access - Group-based challenges - Exclusivity of female farmer groups	- Challenges with the use of motor pumps - Profitable dry-season farming - Research opportunities to address knowledge gaps - Learning from Burkina Faso

Table 3. Barriers and opportunities for accelerating collective investments

6.1.1. Barriers to catalyzing collective investments in solar-based irrigation bundles

Bundle-related barriers

High initial investment cost is for most CI-in models. Even with subsidies and PAYOWN financing models, a Lorentz PS2-1800 SPIP still costs GHS 139,000 (~USD 8,942). Drip irrigation is limited due to the high costs of materials, labor, and time required for land preparation, planting at the correct drip distances, and removing and storing drips during rainfed cultivation (IWMI, 2024). A drip irrigation system set up for one hectare of irrigated land can cost up to GHS 41,000 (~USD 2,638)

Limited access to financial services is due to high financial illiteracy, a poor savings culture, inadequate record-keeping, and a lack of collateral. These factors may hinder farmers from fully utilizing solar-based irrigation bundles, which could enhance production, improve incomes, and bolster family nutrition. To cultivate effectively during the dry season, farmers require various inputs, including irrigable land, seeds, fertilizers, insecticides, pesticides, labor, and extension support.

Limited access to operation and maintenance services is a challenge for solar-based irrigation, which is still relatively new compared to traditional methods such as manual irrigation and motorized pumps. Only a small number of trained technicians are available to provide quick support for solar-powered irrigation systems. This situation puts farmers at risk of losing their harvests if they cannot adequately irrigate their crops due to malfunctioning solar equipment.

Inappropriate technology for farmer groups is a result of varying SBIB needs (SBIB) across regions, communities, and different groups of farmers. The needs often depend on factors such as size, production preferences, and resource availability. As a result, the available SBIBs may not be suitable for all farmer groups. For example, some female farmers in Northern Ghana face difficulties operating the Lorentz PS2-1800 pump because they have a limited understanding of the messages displayed on the control board.

Low adoption rates are particularly evident among resource-poor farmers and women farmers, primarily due to limited awareness, financing, and support throughout the value chain. Women's groups encounter additional challenges, including restricted access to land and necessary inputs. Data on collective investments is also scarce, largely due to inadequate information sharing. To enhance access, it is essential to implement actions such as demonstrations, tailored business models, stronger market linkages, and flexible PAYGO/PAYOWN financing, all of which should be supported by mobile money services.

Supply chain barriers

The prevalence of free-gift and subsidy business models for solar pumps, especially in groundwater irrigation, stems from donor funding and NGO support. Consequently, few farmers invest in solar-powered irrigation because they expect assistance. Additionally, many farmer groups view their farms as non-business ventures and rely on significant subsidies for irrigation, which discourages them from purchasing solar pumps at full price from private providers.

The limited availability of SBIBs is mainly in towns like Accra, Kumasi, Tamale, and Wa, limiting farmers' access to services and innovations. High transaction costs for suppliers when dealing with farmers further restrict market expansion for SBIBs.

High business and investment risks exist for SBIB suppliers. Bundling SPIPs with PAYOWN/PAYGO services is especially risky due to low down payments, poor client management, and a high chance of credit default from agricultural uncertainties and foreign exchange fluctuations, which can erode profits on loans to farmer groups.

Poor market linkages hinder farmers' access to essential inputs like seeds and fertilizers, primarily due to financial constraints, inadequate planning for dry-season cultivation, and supply irregularities caused by government bureaucracy and political instability in countries like Russia and Ukraine. Additionally, limited road networks and access to market information and storage facilities decrease farmers' motivation to invest in sustainable agricultural practices.

The lack of net metering restricts SPIBs from connecting to the grid, limiting farmers' ability to sell excess capacity, especially during the rainy season. Since SPIBs are capital-intensive,

farmers may struggle with loan repayments needed for investment, reducing their motivation to invest further.

Contextual barriers

Limited access to irrigable land is common, as farmers rely on family, community, or informal rentals. Urban land scarcity pushes cultivation near settlements or in unfinished buildings (Wang et al. 2020). Increased demand for irrigable land from population growth and dry-season farming has intensified competition, restricting farmer groups' expansion with SBIBs.

Limited irrigation access stems from climate variability, weak aquifer recharge, and insufficient groundwater investment. Farmers depend on rivers, dams, and wells, with furrow irrigation still prevalent, while sprinklers are gaining use among market-oriented farmers. Increased water competition can lead to conflicts, plot abandonment, greywater use, and damage to unprotected SBIB equipment.

Groundwater uncertainties arise from increasing demand as surface water resources decline. UER farmers benefit from lower drilling costs due to multiple service providers and good aquifers. Borehole demand varies by region, with challenges in areas like the Savannah and NER facing rock structure and water quality issues, while NR's complex geology and saline water increase drilling costs.

Group-related challenges abound. Low energy costs of solar technology can result in overexploitation of groundwater and the use of wasteful irrigation methods like furrow systems. Additionally, shared SBIB resources may suffer from poor management without effective leadership, and limited joint activities can weaken group cohesion and reduce synergies.

The exclusivity of female farmer groups arises from their limited access to land and production resources, leading to small-scale cultivation primarily for home use. Low savings and restricted access to financial services, market information, and linkages hinder their investment in SBIBs.

6.1.2. Opportunities for catalyzing collective investments in solar-based irrigation bundles

Bundle-related opportunities

Level 9 of scaling readiness has been demonstrated for SBIBs in Ghana, with successful impacts that have expanded to Ethiopia and Mali (Minh & Ofosu 2022). In 2021, a private sector partner in Ghana increased their smallholder producer investment product (SPIP) sales by 80 percent. In 2022, private sector partners invested an estimated USD 500,000, with USD 250,000 dedicated to smallholder farmers. Notably, USD 1 million for impact investment in smallholder solar-based irrigation has been mobilized by Shell and Lorentz Foundations, alongside UK Aid, focusing on Lorentz's distributors in Sub-Saharan Africa. Since 2023, the Kwame Nkrumah University of Science and Technology (KNUST), in partnership with UK Aid and the Shell Foundation, has aimed to enhance capacity in clean energy strategies. Additionally, Ghanaian universities received support from the Shell Foundation and UK Aid from 2019 to 2021 to develop energy sector postgraduate curricula through the Transforming Energy Access – Learning Partnership project.

The SBIBs' adaptability to farmer groups considers various factors like purchasing power, the financing ecosystem, natural resources, energy sources, and social norms. Their context-specific components make them flexible for different groups, including men-only, women-only, and mixed farmer groups. Innovations can be bundled and scaled for irrigable lands in Northern Ghana, utilizing available surface and groundwater resources.

Water as a service business opportunity is in high demand, especially during the dry season. Combined with limited access to financial resources for purchasing SBIBs, this makes the water-as-a-service business model viable in Northern Ghana. Entrepreneurs may invest in SBIBs, enabling them to irrigate their farms and sell excess water to farmers within their communities.

The *water-as-a-service business model* is in high demand during the dry season in Northern Ghana. With limited access to financial resources for purchasing SBIBs, entrepreneurs can invest in these systems to irrigate their farms and sell excess water to local farmers.

Significantly improving development outcomes can be achieved by scaling SBIBs to farmer groups in Northern Ghana. Enabling year-round cultivation and raising incomes helps combat extreme poverty. Expanded access to irrigation innovations could enhance employment, nutrition, and food security. With increased crop production, beneficiaries can afford healthier diets while SBIB adoption cuts CO_2 emissions from water pumping by 97–98% compared to diesel pumps (Minh & Ofosu 2022).

Supply chain opportunities

The established SBIB supply chain to provide solar-based and drip irrigation, spray tubes, and sprinklers is gaining popularity in the region, particularly among market-oriented vegetable producers. This is driving agricultural input dealers, borehole drillers, SPIP suppliers, and agents in major towns in northern Ghana to stock equipment in anticipation of demand. This enhances access for farmer groups interested in utilizing efficient water application systems.

The SBIB supply chain for solar-based irrigation systems, including drip irrigation, spray tubes, and sprinklers, is gaining popularity among vegetable producers in northern Ghana. This trend is prompting agricultural input dealers and borehole drillers to stock equipment, improving access for farmer groups interested in efficient water application systems.

Private sector initiatives enhance community engagement and understanding of farmer needs for SBIBs. By tailoring business models to the financial capacities of farmer groups and strengthening market linkages, access improves. However, the affordability of innovations may be an issue for many groups. PAYGO and PAYOWN financing models especially benefit resource-poor and women-dominated groups, though repayment periods can vary. Digital financial services like MTN Mobile Money, AirtelTigo Cash, and Telecel Cash reduce the costs and time associated with payments for these services.

Collaboration opportunities exist for research, NGOs, and the government in Northern Ghana, focusing on irrigation. The IWMI partners with the Department of Agriculture, private firms, and GIZ to scale SBIBs and test farmer-led irrigation business models. These efforts improved access to irrigation technologies for smallholders and enhanced SBIB visibility through awareness campaigns and workshops.

Contextual opportunities

Challenges with the use of motor pumps include their rising cost, short lifespan, and high fuel and maintenance expenses push demand for alternatives, including solar pumps. Fuel alone costs about 1,800–2,000 Ghana Cedis (~USD 290–325) per acre per season, with maintenance averaging 800 Cedis (~USD 130). Pumps typically last only three to five years. Farmers are seeking cheaper energy sources for water lifting, including connecting liquified petroleum gas cylinders to motor pumps to reduce expenditure on petrol and diesel.

Challenges with motor pumps include high costs, short lifespans, and significant fuel and maintenance expenses. Fuel costs about 1,800–2,000 Ghana Cedis (~USD 290–325) per acre per season, with maintenance averaging 800 Cedis (~USD 130). Since pumps last only three

to five years, farmers are exploring alternatives like solar pumps and using liquified petroleum gas to lower their fuel expenditures.

Dry-season farming is profitable as farmers grow high-value vegetables like onions, peppers, and cabbage when supplies from Burkina Faso are low. Onions, known as 'Bawku cocoa,' generate significant income, supporting wet season farming afterward. Farmers earn about two and a half times more in the dry season compared to the wet season (Ofosu et al. 2025). Additional benefits include breaking disease cycles, enhancing family nutrition, and reducing youth migration from Northern to Southern Ghana due to limited job opportunities.

Research opportunities to address knowledge gaps exist as solar-based irrigation remains in a niche stage in Ghana, with several knowledge gaps remaining. These include establishing and maintaining market linkages and scaling strategies to foster gender equality and social inclusion. Other gaps include assessing groundwater quantities, water quality, sustainable use, and the effects of solar-based irrigation on groundwater sources. This offers opportunities for research and the private sector to provide farmers with relevant information on the sustainable use of SBIBs.

Research opportunities exist in Ghana as solar-based irrigation is still in a niche stage, with notable knowledge gaps. Key areas include establishing market linkages, scaling strategies for gender equality and social inclusion, and assessing groundwater quantities and quality. These gaps present opportunities for research and the private sector to inform farmers on the sustainable use of SBIBs.

Learning from Burkina Faso offers valuable opportunities for risk management, as Northern Ghana shares a border with it. Cross-border interactions include the exchange of inputs and vegetables, enabling Ghanaian farmers to gain insights from Burkina Faso's vibrant, government-supported vegetable value chain, which supplies local and neighboring markets.

6.2. Pathways to accelerate collective investments in solar-based irrigation bundles

Multiple pathways may be deployed to accelerate SBIB CI-in in Northern Ghana, focusing on overcoming barriers and leveraging opportunities. These include 1) fostering multi-actor partnerships, 2) innovating inclusive finance, and 3) sharing knowledge and strengthening investment capacity.

Multi-actor partnerships, both formal and informal, involve collaborations among organizations and individuals to overcome barriers to catalyzing SBIB CI-in (Ofosu et al. 2025). These partnerships provide bundled resources—products, services, knowledge, and investments—while minimizing risks for PAYOWN/PAYGO SBIBs in diverse markets. Private sector, government, and research collaborations have developed tailored offerings for collective investors, with impact investors like Shell and Lorentz Foundations supporting smallholder irrigation (Minh and Ofosu 2022). By strengthening partnerships that enable joint bids, project collaboration, and capacity development, transaction costs for farmers can be reduced, business synergy improved, and easier access to necessary products and services facilitated for farmer groups.

Innovative financing engages various financial ecosystem actors to boost farmers' investments and reduce risks for private sector businesses (Minh et al. 2024). While farmers are willing to pool resources for SBIBs, their contributions remain limited due to low savings and membership fees between 10-100 Ghana Cedis (~USD 0.65 – USD 7) per person annually. Access to commercial bank capital is hindered by high interest rates of over 20%, a lack of credit history, and banks' risk aversion towards agriculture. Innovative financing models, such as PAYGO, results-based financing, and performance-based grants, can support farmer group

investments and make private sector engagement less risky. For effective implementation, it's crucial to co-develop group-based loans with finance actors to lower the financial barriers faced by farmer groups. Such financing improves liquidity for private sector irrigation suppliers by expanding lending to farmers. It also promotes inclusivity for female farmer groups by addressing their specific barriers to resources and financial capital. This includes co-designing SBIBs that meet women's needs and providing financial support like grants and low-interest loans. Collaborations among farmers, researchers, the government, the private sector, NGOs, and development partners can facilitate women farmer groups' access to SBIBs.

Knowledge Sharing and Capacity Development are crucial for farmers in Northern Ghana, as solar-based irrigation is relatively new to them. Providing information on crop water needs, irrigation scheduling, and sustainable groundwater use can aid in their decision-making regarding SBIB investment. Joint training programs involving government, research institutions, and private partners aim to equip farmers with the necessary skills to utilize SBIBs effectively, enhancing production. For instance, the Department of Agriculture collaborates with initiatives like the MAG and MOAP programs to train extension agents in irrigated practices and organizes additional training based on current agricultural needs. Innovation platforms facilitate information sharing, joint learning, and problem-solving, while multistakeholder dialogues (MSDs) enable interactive knowledge exchange and networking among various actors, focusing on common interests in the agricultural value chain.

7. Conclusions and recommendations

This study used action research to identify investment models, barriers, and pathways for scaling solar-based irrigation in Northern Ghana. The ownership investment model, suitable for male and mixed gender groups of up to 50 members, allows farmers to collectively manage labor and invest 30%-50% of the initial capital through dues, levies, and loans for medium to large capacity SBIBs. The semi-service model, designed for female groups of up to 60 members, is managed with NGO support, enabling them to invest 5%-20% of the capital for small capacity SBIBs or pay-as-you-go services.

Catalysing collective SBIB investments faces barriers, including high initial costs, unsuitable technologies, limited financial services, and low adoption rates. Additionally, supply chain issues arise from farmers' reliance on subsidies, few SBIB outlets, poor market ties, and the lack of net metering. Contextual challenges include restricted access to land and water, groundwater uncertainties, group dynamics, and the risk of excluding female farmers. However, opportunities for scaling SBIBs exist due to their high readiness, adaptability, strong farmer interest, and potential to reduce poverty. Supply chain advantages include an established network in Ghana, supplier investments, and collaboration opportunities among various stakeholders. Rising demand for alternative energy, profit incentives for dry season farming, research to bridge knowledge gaps, and insights from Burkina Faso's successful horticulture industry further drive investment.

This study had limitations, primarily due to its focus on the Upper East Region for quantitative data. To enhance the analysis and scalability of collective SBIB investment, we recommend including more farmer groups from the Upper West, Northern, Northeast, and Savannah Regions. Additionally, exploring ways to accelerate this investment is vital for contextualizing the innovation bundle. The analytical framework developed can also be applied to segment collective investment in other bundled innovations and regions for verification.

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Contact
Petra Schmitter, Research Group Leader – Climate Mitigation & Adaptation Pathways, IWMI, Colombo, Sri Lanka (p.schmitter@cgiar.org)

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