Demand-supply linkage pathway to scaling solar-based irrigation along irrigated vegetable value chains in Upper East Region, Ghana

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The Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) program comprises three research-in-development projects supported by the United States Agency for International Development (USAID) as part of the U.S. Government's Feed the Future initiative.

Through action research and development partnerships, Africa RISING is creating opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment.

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Acronyms

AEA	Agricultural extension agents
FLID	Farmer-led irrigation development
IAVC	Irrigated agricultural value chain
IVVC	Irrigated vegetable value chains
IWMI	International Water Management Institute
MOFA	Ministry of Food and Agriculture
PAY-OWN	Pay As You Own
USAID	United States Agency for International Development
WLE	Water, Land and Ecosystems

Summary

There are solutions to sustainable intensification, irrigation technologies and water management under the changing weather and climate conditions; they are just not available to smallholder farmers and vulnerable groups on a large scale. Scaling these solutions, therefore, needs to develop bundles of best-fit solutions to diversify farming and farmer conditions and adapt them to the context of irrigated farming. Furthermore, scaling needs to integrate irrigated agricultural value chains to enhance farmers' re-investment and capitalize on existing public and private sector interventions and businesses. Operationalizing an adaptive, systemic scaling approach along irrigated value chains is essential to co-identify appropriate pathways. This helps understand the micro and macro environments of households and value chains and their influences on the scaling of irrigation technologies and services.

This intervention used an action research process to co-develop the demand-supply linkage scaling pathway to provide contextually relevant and evidence-based knowledge about the potential for irrigation market development. The process involved four steps: analyze, co-design, actualize and reflect. The analyze step investigated potential pathways to scaling and the best-fit bundles of irrigation technologies and services along irrigated agricultural value chains. The co-design step co-identified value chain pathways to scaling best-fit bundles and link farmers with input and output markets. The actualize step jointly implemented the demand-supply linkages pathway in the Upper East Region and beyond. The reflect step assessed the scaling pathway and identified the follow-up actions to adapt the pathways and incorporate lessons learned into new scaling pathways.

Throughout the action research process in Upper East Ghana, PS2 solar-powered irrigation pumps and a pay-as-you-own (PAY-OWN) financing service (PAY-OWN PS2 solar-powered pumps) were identified as the best-fit scalable bundle for the irrigated vegetable value chain in the region. This bundle includes PS2 solar-powered irrigation pumps, a PAY-OWN financial modality, matching services, and installment and monitoring services. To scale this bundle, a demand-supply linkage pathway was co-developed with actors in the irrigated vegetable value chain. The pathway consists of four components: i) establish sales and service networks, ii) increase the private sector's visibility and outreach in the region, iii) capitalize on the sale of PAY-OWN PS2 solar-powered pumps, and iv) facilitate environmental and social sustainability and inclusivity of scaling solar-based irrigation in the region.

Factors enabling a successful scaling pathway include the best-fit of PAY-OWN PS2 solar-powered pumps to the regional context, the existing support to farmer organizations to enhance agricultural production, a functioning village savings and loans mechanism, and the dynamic engagement of irrigated vegetable value chain actors. Factors hindering successful scaling are pump-related technical issues, limited land, water, financial or human capital, group dynamics, and government subsidies and uncoordinated interventions for value chain development. A successful demand-supply linkage pathway, therefore, requires commitment from private sector partners in capitalizing on the partnership's investment and strengthening farmers' collective actions to mobilize land and water resources and financial capital. It also requires the dynamic engagement of actors in the irrigated agricultural value chain to enhance farmers' adoption of solar-based irrigation and multi-stakeholder dialogues and corporations to sustain the partnership's investment and trigger the system transformation.

The demand-supply linkage pathway to scaling PAY-OWN PS2 solar-powered pumps contributes to systemic changes in solar-based irrigation development in Ghana in various ways. First, solar technologies are preferred by women and youth because they reduce the labor needed to provide water for irrigation while increasing the irrigated area and crop yield. Such irrigation can harness the potential young people and women farmers have to do farm work and empower women to be independent investors. Second, companies in Ghana are enabled to capitalize on the market potential for their irrigation equipment and services. By segmenting client groups and providing PAY-OWN financial services in inclusive ways, companies can better target different segments of resource-rich, mobile, and resource-limited farmers and farmer groups. Finally, multi-stakeholder dialogues can bring actors together and provide a space for learning, action, and change while stimulating private sector investments and partnerships, informing public policies and programs and capitalizing on the existing resources and investments to enhance livelihoods and bring about system transformation beyond the scaling partnership.

Introduction

Sustainable transformation in agricultural and food systems can be an entry point in which systemic innovation scaling is necessary. Meaningful impact at a scale rarely occurs within a project lifetime but emerges as new ways of working are accepted by a critical mass of actors in society (Woltering et al. 2019). Two major challenges to stimulate system transformation are identifying the best-fit innovations and innovation bundles and implementing effective strategies to accelerate scaling these innovations to improve the incomes of smallholder farmers while optimizing trade-offs (IWMI 2021). The term 'scaling' is gaining momentum and approaches like stage gating (Cooper 2008), the scaling scan (Jacobs et al. 2018), and scaling readiness (Sartas et al. 2020) are useful ways to assess whether an innovation is ready to scale and which supportive functions are needed to go to scale (IWMI 2021). However, to achieve system transformation with agricultural innovation scaling, there is a need for a mission or vision to drive system transformation (Klerkx and Begemann 2020) and broaden innovation ecosystems by drawing on experiences in business to focus on value creation.

To address these needs, a systemic, adaptive scaling approach has been developed as an organic and integral framework to help analyze, design, and implement scalable bundled technologies and services and collective actions that best fit specific contexts to reach system transformation (IWMI 2021). The adaptive scaling approach has been operationalized in two action research-for-development interventions: The Africa Research in Sustainable Intensification for Next Generation programs (Africa Rising) and the Innovation Laboratory for Small Scale Irrigation. They have shown that adaptive scaling is useful to investigate the existing initiatives and pathways to identify innovation bundles contextually relevant and scalable to the context (Minh and Schmitter in review). However, operationalizing this approach needs to be strengthened, especially from the value chain perspective.

Since 2013, IWMI has been developing and scaling irrigation technologies and water management solutions in Northern Ghana, the agricultural production hub of the country, creating employment for the majority of the adult population. It is confirmed that farmer investment in irrigation conforms to value chain logic as it is dependent on income from the sale of irrigated crops to re-invest to raise productivity and incomes (Adela et al. 2019, de Bont et al. 2019 and 2019a, Minh and Schmitter in review). Farmers often take multiple pathways to capitalize their irrigation investment to improve productivity, generate more household income and increase cash flow for further investment (Beekman et al. 2014, Adela et al. 2019, Kafle et al. 2020). Access to irrigation technologies, inputs, services, and output markets need to merge for farmers to see the value of investing in irrigation. Such access is therefore a major factor determining farmers' investing pathways.

Furthermore, private and public investment have important roles in providing bundles of pre-assessment, installment, and maintenance of irrigation technologies, micro-credit, and market linkages to catalyze farmers' investment (Minh et al. 2020). Their investments are, however, challenged by risks that come from farmers' ability to (re)-invest as well as market competitiveness and value chain linkages. Hence, the relationships, networks, and collaborations between farmers and other value chain actors are essential for farmers' investment and agri-business risk management. These all call for operationalizing the adaptive scaling approach along the irrigated agricultural value chain to co-develop appropriate pathways.

This research aimed to operationalize the adaptive scaling approach to co-develop value chain-based pathways for scaling irrigation technologies and services and water solutions in Northern Ghana. Using an action research approach, this intervention aimed to:

- analyze irrigated vegetable value chains (IVVC), and
- co-identify and implement scaling partnerships with public and private sector entities along the IVVC.

This report starts with a presentation of the framework for the analysis of IVVC (Section II) and the action research approach used in the study (Section III). This is followed by a presentation of the IVVC in the Upper East Region (Section IV), the scalable bundle identified (Section V), and the demand-supply linkage pathway for scaling the bundle (Section VI). The concluding remarks (Section VII) highlight conditions and action research approaches for a successful demand-supply linkage scaling pathway.

Analytical framework

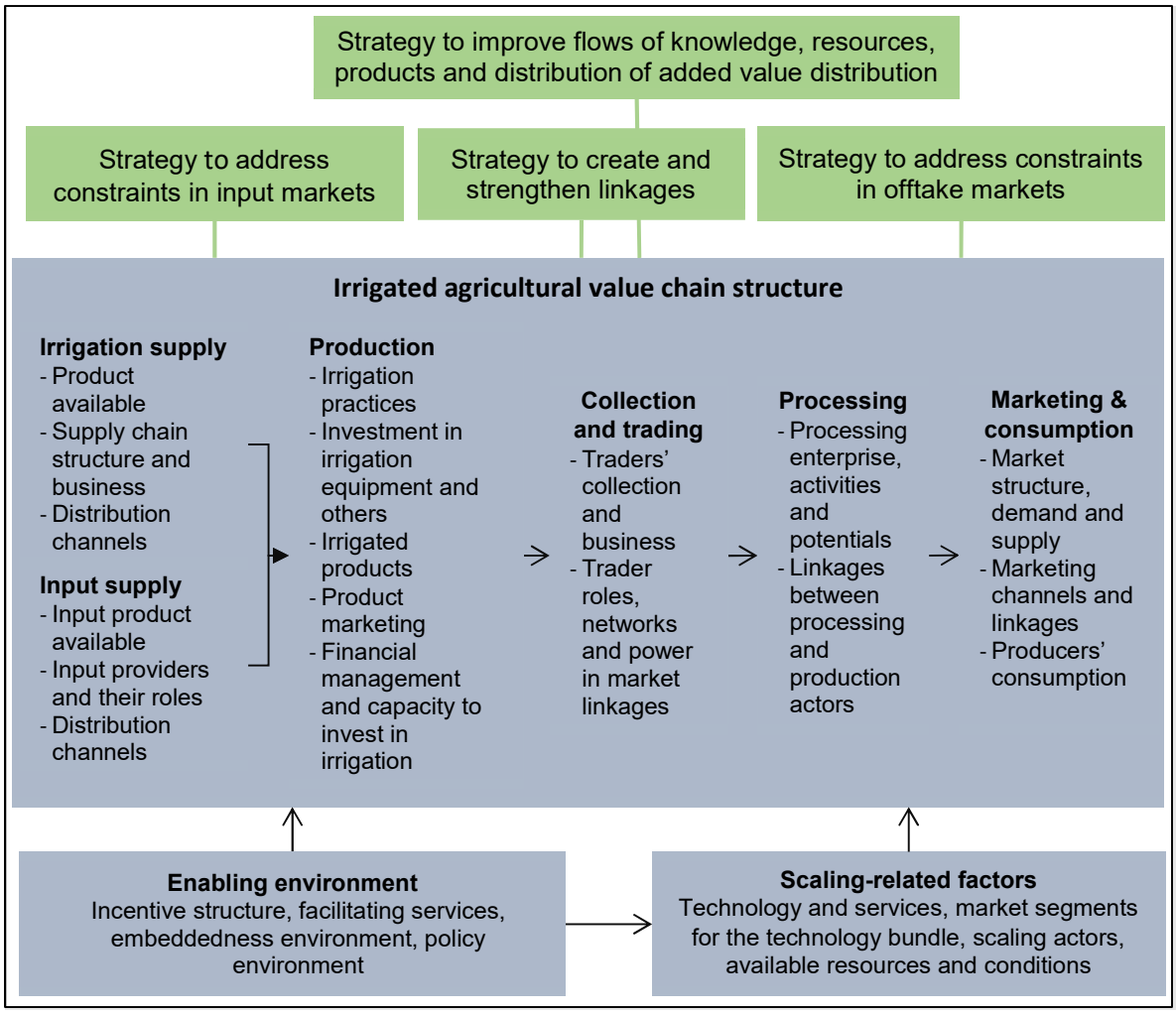
In this analysis, we define an irrigated agricultural value chain (IAVC) as the complex range of activities implemented by various actors, starting from the (pre)-production activities of an irrigated system, and moving irrigated products along the value chain with linkages to enterprises that are engaged in trading, assembling, processing and distribution through to the output markets to consumers. From an IAVC perspective, 'irrigation' includes current practices farmers are using and the supply chain through which farmers access the necessary equipment and services they need to invest in irrigation and the links to input and output markets.

Actors engaging in IAVC often establish relationships, networks, and partnerships to enable investment in irrigation. Therefore, analyzing IAVC can generate a better understanding of these relationships and the mechanisms by which scaling appropriate irrigation technologies can be better integrated into value chains. Furthermore, it will provide insights into gender and social inclusion barriers to entrepreneurship to enhance scaling. Figure 1 illustrates the analytical framework for co-identification of value chain pathways to scale irrigation technologies and services with actors in IAVC.

In this study, ***a value chain-based scaling pathway*** is defined as a process of designing and implementing a set of strategies and corresponding activities to enable farmers to invest in irrigated farming and commercialize their investment through value chain engagement. Each pathway has one or more strategies to address constraints that limit actor engagement and benefits from their engagement and the chain's performance, create and strengthen linkages between and among chain actors and functions and improve flows of knowledge, resources, products and distribution of added value. These include improving business linkages and partnerships, strengthening service provision, strengthening the chain's governance structure and improving policies and the business environment.

The value chain analysis includes mapping the chain structure. ***A value chain structure*** maps the chain's functions, potential actor roles and relevant knowledge and experience, value addition and distribution and governance to determine how to organize the chain. The production analysis emphasizes primary resources required for production, environmental consequences of resource exploitation, primary productivity, potential incomes generated for primary producers and factors facilitating and inhibiting production. Specifically, it needs to investigate what and

how irrigated products are produced and farm size, inputs, services and resources are required for cultivation. It also needs to examine current irrigation practices, investments, benefits and profits, interest and willingness to invest, preferences for irrigation equipment and potential financial capital for investment. Finally, it analyses how irrigated products are marketed by investigating market access, marketing, price and volume of the marketed products.



Source: Author's elaboration.

FIGURE 1. Framework to analyse irrigated agricultural value chain for co-identification of a scaling pathway.

The irrigation and input supply analysis investigates activities, information and resources involved in moving irrigation equipment, products and services from input and irrigation suppliers to farmers. It also investigates the main actors such as key players in manufacturing, import, wholesale, distribution and retail and the end-user farmers and their interactions. Farmers largely rely on the private sector to access technological innovations and irrigation services. Therefore, insights into inputs and irrigation equipment supply chains can facilitate farmers' access.

The market analysis provides an understanding of market-related factors and determines conditions for products to be successfully produced and capitalized in the chain. It focuses on

investigating market structure, demand and supply, specifications and prices and future end-user needs, barriers to entry, market options and market demands and requirements for products to be successfully produced and marketed in the chain (Herman and Minh 2020, Minh and Osei-Amponsah 2021). It also studies collection, trading and processing activities and investments needed to leverage the existing local market systems for output market linkages.

The enabling environment analysis provides a foundation and identifies the inputs for the identification of scaling factors. This requires information on incentive structures (value added and benefits for each actor), linkages and power relations in the chain (business practices and relationships among actors, interconnections between chain activities, functions and actors), facilitating services (public sector support to irrigation and agriculture, logistics, transportation, storage, import, export and banking), and the embeddedness environment (informal rules, norms, traditions and cultures, gender and youth roles and involvement) (Minh et al. 2021).

Scaling factor analysis provides insights to better understand i) how public and private sector engagement could be leveraged in favor of smallholder farmers, ii) how equity and inclusion can be achieved in a way farmers have access to resources and services required for technology access and adoption, especially poor, women and marginalized groups who potentially can be involved in the scaling pathway and what roles they undertake, and iii) what resources are available that can be mobilized for scaling. Hence, it identifies technologies and services and the bundles available and suitable to scale for specific demands and client segments. It also identifies the actors involved and their roles in scaling bundles and how to connect actors and involvement in scaling actions and initiatives.

Methodology: Action research approach

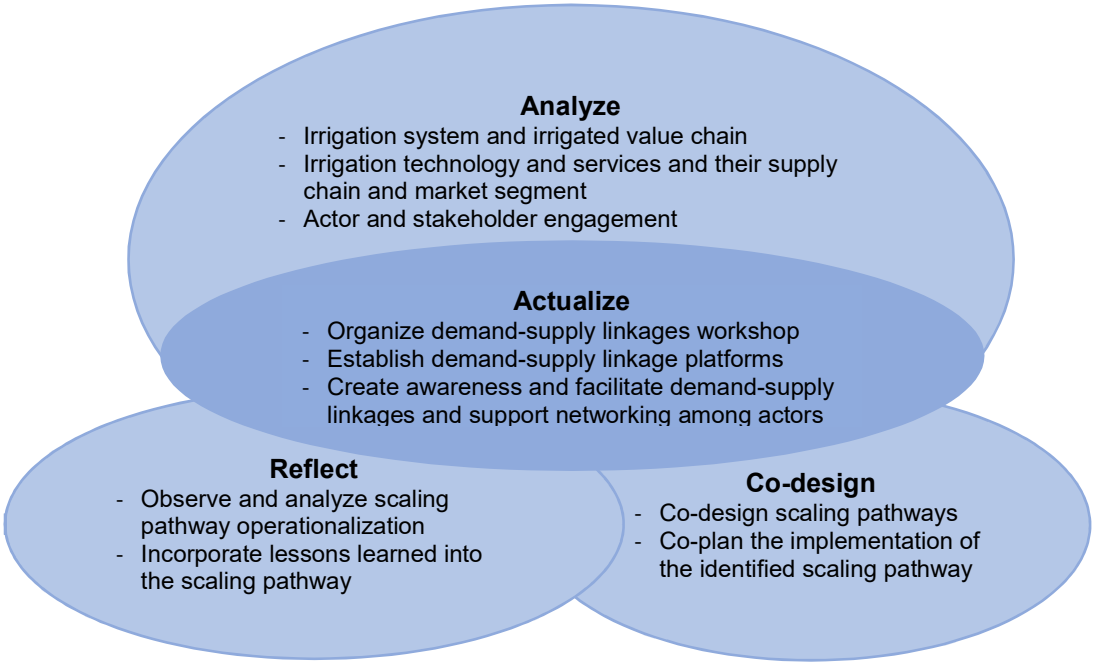
Research process

The research was carried out in the Upper East Region, Ghana in October 2020 by the International Water Management Institute (IWMI) research team. It is an action research approach that has been contextualized to scale irrigation technologies and services in various projects (Minh et al. 2020, Minh and Schmitter 2020). The research involved four steps as illustrated in figure 2: analyze, co-design, actualize and reflect.

The analyze step aimed at understanding the potential pathways to scaling the best-fit irrigation technologies and services along the irrigated agricultural value chains through carrying out interrelated activities and involving a wide range of actors and stakeholders. In this step, 10 group discussion meetings with farmer communities and 28 semi-structured interviews were conducted involving 150 farmers and 33 individuals representing agricultural value chain actors and stakeholders such as agro-input dealers, borehole drillers and pump repairers, solar partners, traders, and market queens, agricultural extension agents and researchers (see details in Table 1).

The research team started with investigating irrigated agriculture and agricultural value chains in the Upper East Region, Ghana to map the IVVC structure. Continuously, the in-depth analysis of irrigated vegetable production and the irrigation equipment supply was carried out to scan the best-fit irrigation technologies and services for the region. The scanning involved analyzing the

collected data to understand the current irrigation equipment, practices, and investment that farmers are applying and the irrigation equipment and services that private sector companies are supplying (see details in Tables 1 and 2). The scanning also looked at the emergent irrigation investment and pointed out the high demand of investing in groundwater and motor pumps for water lifting. Furthermore, the scanning investigated alternative water-lifting technologies that are available in the market and that can reduce irrigation costs for farmers. Finally, the scanning verified the PS2 solar-powered irrigation pumps bundled with pay-as-you-own (PAY-OWN PS2 solar-powered pumps) are the best-fit bundle for the region (See details for the bundle in Section V).



Source: Adapted from Minh et al. 2020; Minh and Schmitter 2020.

FIGURE 2. Action research process to co-identify value chain scaling pathway: Steps and activities.

The in-depth analysis also looked at farmers' needs for water for irrigation, their water, and land available, their preference for irrigation equipment, and their financial capacity to pay for the PAY-OWN PS2 solar-powered pumps. This was to categorize market segments for the PAY-OWN PS2 solar-powered pumps by segmenting farmers as potential investors into smaller groups to enable the irrigation equipment suppliers to target them with the right marketing approaches.

The co-design step aimed at co-identifying value chain pathways to scaling irrigation technologies and services and their bundles and link irrigators with input and output markets in the irrigated vegetable value chains in the Upper East Region. This involved conceptualizing the demand-supply linkage pathway and connecting actors and stakeholders to establish and facilitate the scaling partnership. Conceptualizing the scaling pathway involved interactions with the actors identified from the analysis step. Specifically, follow-up meetings were held with members of the managerial board of the Regional Agricultural Extension Department, Ministry of Food and Agriculture (MOFA), identified as the public partner, and with Pumptech Ltd. Ghana, identified as the private sector partner. The purpose of the meetings was to gather

demand-supply linkage ideas and co-design a plan to actualize the demand-supply linkage pathway for scaling the PAY-OWN PS2 solar-powered irrigation pumps distributed by Pumptech.

The actualize step aimed at jointly implementing the demand-supply linkages pathway in the Upper East Region and beyond. The implementation began with a series of demand-supply linkage workshops to actualize the scaling of solar-powered irrigation supply chain establishment (Annex 1). Based on the results from the first workshop series, Pumptech continues organizing demonstration workshops with farmers and communities showing interest and did a field survey to further discuss contract terms with potential clients. Pumptech has formed and operated three WhatsApp platforms as a communication channel with their sales and service networks established after three workshops.

The reflect step was undertaken by the IWMI research team and scaling partners throughout the scaling process to assess the PS2 solar-powered irrigation pumps and associated financing and scaling pathway, how to continue the scaling pathway, what the local partners and participants think of the pumps and the scaling approach and how they react. IWMI and Pumptech have also been monitoring water use and environmental sustainability by contextualizing the solar suitability map for the Upper East Region and analyzing water use data collected using the PumpScanner App. The IWMI research team has been analyzing and reacting to critical conditions to optimize scaling to reach the identified market scale and exploring the potential to contextualize the pathway for other regions with the same irrigation conditions. The IWMI research team has been gathering and analyzing feedback from farmers and partners participating in scaling pathways and using it to adapt the pathways and incorporate lessons learned into new scaling pathways to be tested in the future and prepare for further stakeholder engagement events.

Data collection and analysis

Guided by the analytical framework, a qualitative dataset on irrigated vegetable value chain was collected in the Upper East Region from November 2020 to January 2021 (Table 1). It involved ten group interviews, 31 individual semi-structured interviews, three participatory market transaction walks, and three demand-supply linkage workshops with actors and stakeholders involved in the irrigated vegetable value chain. Interviews were conducted in the local language, recorded, transcribed, and translated into English for data analysis.

The dataset was analyzed using content analysis. Each transcript was read several times and all texts were examined to identify and categorize emerging concepts based on similarities and differences, then grounding and refining themes from the concepts and discussing and interpreting the themes. This procedure is an open-ended process, moving back and forth between the guiding questions, data, and emerging concepts to refine the themes presented in Table 2.

TABLE 1. Overview of data collected.

Actor	Number	Topic/data collected
Farmers and farmer groups		
Individual Farmers	9	- Interventions to support irrigation development - Farming system and experience, irrigation and technologies applied - Interest to use water-lifting technologies and interventions - Income and expenditure patterns - Input and irrigation equipment supply business
Farmer Groups	10	- Business plan, practices, challenges and opportunities - Demand and supply of vegetables - Market access and marketing channels - Saving practices and access to financial services - Observation: existing crops, irrigation, boreholes, water availability
Other value chain actors		
Solar distributors, and borehole drillers	3	- Manufacturing business: products and market - Challenges and opportunities - Supply of irrigation equipment - Farming systems and irrigation practices, constraints and trends - Well digging business and challenges - Irrigation and water availability in the area - Supply of irrigation equipment
Pump distributor	1	- Motorized pump products and demand - Prices, marketing channels
Input dealers	2	- Business practices, challenges and opportunities - Government intervention: seed and fertilizer subsidies - Supply of irrigation equipment
Vegetable vendor/retailer	5	- Trading business - Opportunities and challenges - Interests in other businesses
Market women	1	
Other value chain actors		
Agricultural officer	3	- Brief discussion about Africa Rising project - Highlights of IWMI's activities - Collaboration between the three offices and IWMI
Agricultural extension agent	3	- Role of extension services - Challenges of extension services - Approaches to engaging farmers and farmer groups
NGOs	3	- NGO interventions in the region - Experience gained from working with farmers in the region - Contacts of value chain actors within the region
Participatory market transaction walk		
Navrongo and Paga	3	- Products and prices - Trading function linkages
Follow-up meetings		
Solar Distributor	1	- Follow-up action plan
Demand-supply linkage workshops		
Navrongo, Bawku, and Bolgatanga workshop	3 (219 participants)	- Irrigation practices and soil management in Upper East Region - Introduction to Pumptech PAYO and PAGO financing model - Establishing demand-supply linkages for solar-powered irrigation pumps - Identify potential clients for Pumptech - Establishing sale and service networks

Source: Authors' data.

TABLE 2. Guiding questions for data analysis.

Themes	Guiding questions
Structure of irrigated vegetable value chain	- Who are the actors in IVVC? - What are their roles in the chain? - What are the relationships between these actors?
Irrigated vegetable production and marketing	- Which major vegetables are irrigated? - How is irrigation applied for these vegetables? - How do the farmers market their irrigated products? - Who are the offtake market actors and how do they buy vegetable products from farmers? - What are the market demands and opportunities for these products? - What are the obstacles limiting farmers from marketing their products?
Irrigation equipment and input supply	- What irrigation technologies and services and inputs are provided? - Where can farmers access irrigation technologies and services and input? - Who provides the technologies and services and inputs to farmers and how do they provide these technologies and services and inputs?
Enabling environment	- What services are provided to farmers to enable their investments in IVVC? - Who provides these services? - How are these services provided?
Scaling options	- What irrigation technologies and services are suitable for scaling? - What are the options for bundling these irrigation technologies and services to best fit the IVVC in the Upper East Region?
Value chain-based scaling partnerships and pathways	- Who are the key actors who can enhance scaling and how to involve them? - How could IVVC support scaling these options? - What solutions would enhance farmers' access to scalable bundles? - What partnerships could be established to facilitate scaling bundles? - What factors are influencing scaling partnerships? - What are the conditions for successful scaling partnerships?

Source: Authors' data.

Irrigated vegetable value chains in the Upper East Region

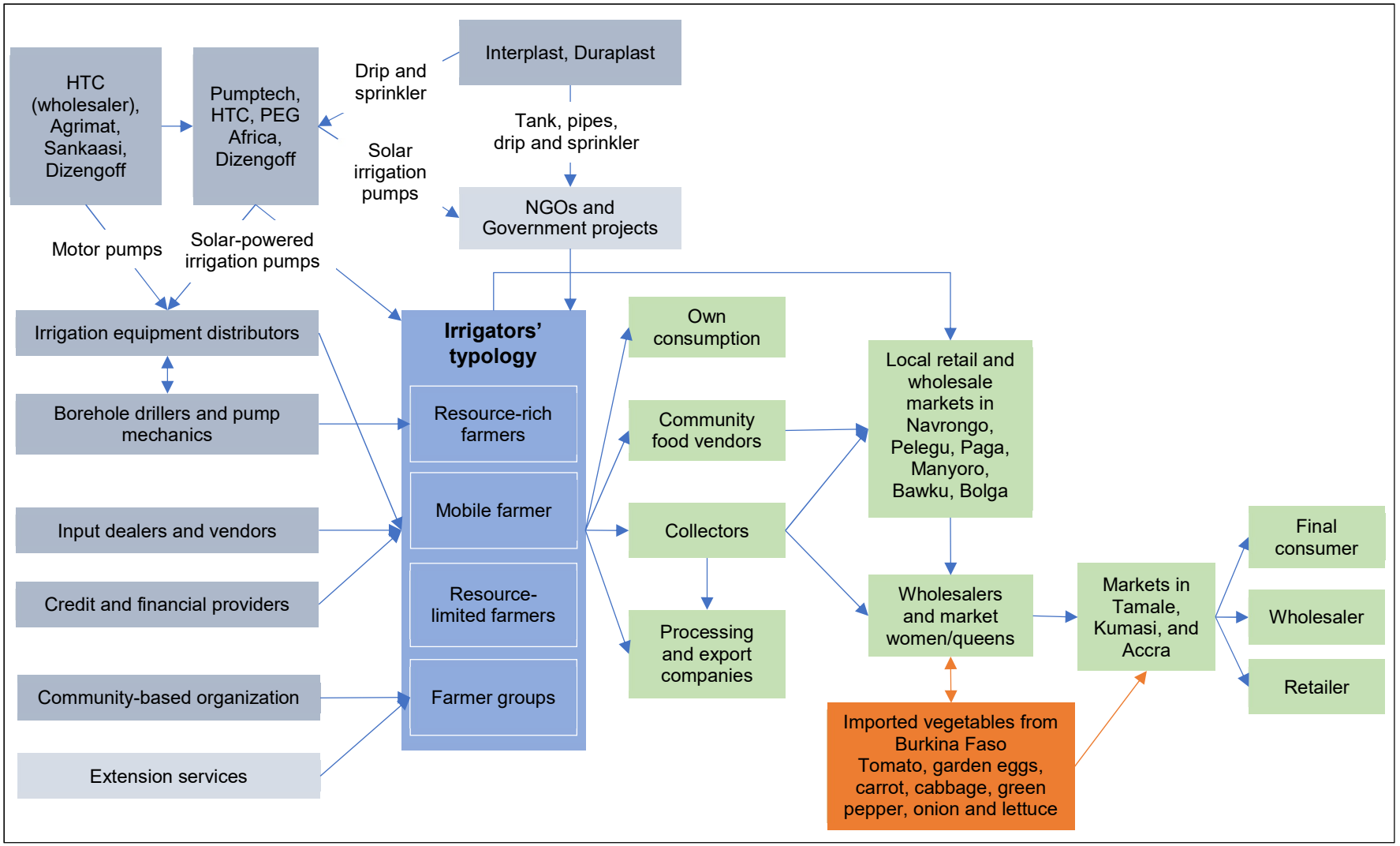
This section presents the structure of the irrigated vegetable value chain in the Upper East Region (Figure 3). It starts with presenting the production and marketing of irrigated vegetable products, followed by irrigation and input supply and service provision for production.

Production and marketing of irrigated vegetable products

Irrigated vegetable production

In the Upper East Region, the common vegetables in the dry season are onion, pepper, eggplant, tomato, water melon, okra and cabbage and green leafy vegetables such as amaranth, bitter leaf, bambara bean leaf and hibiscus. Depending on income generated from marketing these crops, farmers see them as high- and low-value vegetables.

Lower value vegetables are mainly leafy greens such as amaranth, bitter leaf, bambara bean leaf, and hibiscus. Women see these vegetables as 'their crops', including young woman farmers and women's farmer groups. They grow and irrigate small areas in home gardens for home consumption and sell the surplus at local markets.



Source: Authors' elaboration.

FIGURE 3. Structure of irrigated vegetable value chain in the Upper East Region, Ghana.

High-value vegetables include pepper, eggplant, and onion which are considered cash crops in the dry season. In Bawku for example, onions are called *bawku cocoa* as farmers can sell at high prices and earn more income when the supply from Burkina Faso is not yet ready. Men grow these high-value vegetables as cultivating these crops requires a significant investment throughout the cropping season, such as the application of complicated techniques and the high cost of irrigation and inputs and labor. As a woman farmer in the Tekuru community said: "*Most men go in for loans to do pepper farming. Managing pepper and eggplant is very difficult. Pepper demands a lot of inputs and petrol costs for irrigation. We [women farmers] do not have enough money to invest in planting pepper and eggplant. These are men's crops*."

Farmers use different water sources to cultivate irrigated vegetables including dams, small reservoirs, and wells or boreholes (Table 3). Farmers begin cultivation by raising seedlings in nurseries from one to two months usually towards the end of the rainy season in September/October before transplanting in October/November. The common irrigation practices include furrow, hosepipe, and drip irrigation for those using motor pumps for lifting surface and groundwater to cultivate in a larger area and bucket irrigation for those using buckets to lift water from surface sources to cultivate relatively small areas. Farmers irrigate one to two times per week in the morning, afternoon or evening depending on the availability of water. Farmers use a variety of equipment such as buckets and watering cans, treadle pumps, petrol or diesel pumps, solar-powered pumps, open gravity systems, and drip irrigation systems. Buckets, watering cans and treadle pumps are labor and time-intensive and limit the area a farmer can irrigate.

There is increasing use of tanks for storing groundwater for commercial vegetable production in home gardens. Using petrol and diesel pumps helps reduce the labor and time needed for irrigation but comes with a myriad of challenges. Data analysis shows that these challenges include noise and environmental pollution, the high fuel cost of an average of 1,800–2,000 Ghana Cedis/acre/season (USD 290–325), the high routine maintenance and repair cost of an average of 800 Ghana Cedis per season (USD 130) and the need for replacements after three to five years of continuous use.[1]

A challenge for irrigated vegetable production is water availability. By February, there is no water in dams or other surface water reservoirs. Farmers and agricultural officers indicated in the interviews that although groundwater resources are in abundance, the investment cost for drilling and a borehole and mechanization of a pump is often too high for many farmers (see more detail in Box 2). Hence, extending vegetable cultivation beyond February is rare. Poor soil fertility is another challenge. As one farmer said in the group discussion: *"We cultivate on a piece of land for one or two years and then have to change. If we continue to cultivate the third year, the crop dies off. The soil has poor nutrient levels and we are compelled to shift. When we farm tomatoes here, they will not do well."*

Finally, the high cost of inputs is a constraint to irrigated vegetable production. Often, farmers use more chemical fertilizers, pesticides, and insecticides in the dry season to enhance crop growth. Farmers also invest in labor for weeding, spraying, and harvesting, which is hard work. As one farmer said: "*During the rainy season, we can have a good harvest with little or no fertilizer because water is consistent. In the dry season, because all the green is gone, crops need a lot of fertilizer and chemicals to sustain their growth*."

[1] Exchange rates were calculated at the time of manuscript preparation (March 2022).

TABLE 3. Dams and reservoirs in the Upper East Region, Ghana.

Navrongo zone	Bolgatanga zone	Bawku zone
1. Tono dam 2. Saboro dam 3. Dimbasinia dam 4. Nyangua wells 5. Tekuru wells 6. Doba dam 7. Gia dam 8. Uc dam 9. Manyoro stream 10. Nayagnia dam 11. Kajello dam 12. Chiana wells	1. Vea dam 2. Soe dam 3. Anateem wells 4. Sumbrungu reservoir 5. Zuarungu Agric dam 6. Baare dam 7. Zanlerigu dam 8. Pawlugu stream	1. Nakinatinga dug out 2. Wiidi dugout 3. Kuka- Yakin dugout 4. Gumbo dugout 5. Zoogo dugout 6. Zabugu -Natinga dugout 7. Kuka-Natinga dam 8. Kuka- Megogo dam 9. Tambalugu dam 10. Gozesi dam 11. Bador dam 12. Tampizua No.2 dam 13. Zuuku dam 14. Kpalwega dam 15. Arizem dam 16. Zabugu -Zawsi dam 17. Kutanga dam 18. Kolpeingo dam 19. Gumakutari dam

Source: Authors' and MOFA's data.

Note: Attempts were made to obtain information in relation to irrigated areas, however, this information is not recorded officially by regional authorities.

Markets and marketing

Markets for agricultural products including irrigated vegetables are local retail and wholesale markets (Figure 3). Wholesale markets are located in most districts and open weekly. Retail markets are located in district towns and areas with high population densities and are open daily. Retail markets serve mainly local consumers while wholesale markets provide vegetables to domestic markets, for example in Tamale, Kumasi, and Accra.

Market demand for irrigated vegetables is always high, both for low- and high-value vegetables. Local people consume a lot of low-value leafy green vegetables and this raises the demand in the dry season. The high-value vegetables serve both local and domestic markets and the demand is therefore extremely high during the dry season in Burkina Faso. Hence, market prices for most kinds of irrigated vegetables are estimated to be three to five times higher than in the rainy season. As one farmer said: "*Now, a bag of tomatoes around 50 kg costs 45 Cedis (USD 7.3). In the rainy season, I can buy a bag for 15 Ghana Cedis (USD 2.44)*."

One ***marketing channel*** is direct sales. Farmers bring their produce to sell to wholesalers and retailers at local markets. This is common when farmers have a small quantity or grow vegetables that cater to local preferences such as leafy green vegetables. This channel is also commonly used by women farmers who cultivate leafy green vegetables in small home gardens. They diversify the types of vegetables in their plots and schedule the transplanting, watering, and harvesting in ways that allow them to sell weekly or biweekly in the local markets. For most women farmers, this provides important nutritional inputs to their diets and cash income to support their families. As one woman in a farmer group interview said: *"I use money from selling green leafy vegetables to buy inputs for the farm and use a half or a quarter of the remaining amount to buy food items from the market, pay school fees and maybe buy things like soap."*

Selling to traders is common when farmers have a regular harvest and a large volume to sell to women traders, who are locally known as 'market queens' (Box 1). These women often buy at the farm gate. This is common practice with the commercial production of high-value vegetables. They might sell their vegetables to the same market woman or another, depending on who offers them a good price. Some farmers have an agreement with market women to buy at an agreed fixed price to reduce the risk of changes in market prices. Sometimes, market women buy on credit and come and pay the farmer after selling the produce.

Hybrid marketing is when farmers use both direct sales and sell to traders. This allows them to choose where and when to sell their products to get higher prices in time for further investment in their crops. Farmers, especially those who know the market demand and market prices well, often apply this type of marketing. As one farmer said: "*I harvest my vegetables once a week, tie the produce behind my motorbike and take it to the Navrongo Market. I also sell to traders and prefer to sell to them when they come here as it reduces transportation costs and saves my time. The price is also better because the traders come to the farm to buy only when the produce is scarce on the market."*

A number of factors influence vegetable marketing in the region. First, ***market access*** is significantly improved with a 'motor king' (Photo 1) available in every community and is the most effective means for transportation. Farmers, especially woman farmers, can save time while the quality of vegetables is maintained during quick transportation to the market. The motor king cost is affordable so the output market is physically accessible to farmers. As one farmer said: "*We used to walk to the market. It is much more convenient now with the motor king taking us and our produce to the market. It costs 2 Cedis (USD 0.32) for the produce and 2 Cedis for me. On a market day, the motor king driver comes around to look for passengers. Once we are ready, we join them and we can arrange a trip home with them."*

Photo 1. Motor King and market linkages

Second, the volume and quality of vegetables produced in the region are not stable, which negatively influences the supply to meet the high market demand. Due to water shortages from February to May, there are not enough locally produced vegetables for the markets. The quality of locally produced vegetables is negatively affected by the over-use of chemicals that farmers use to prevent insect infestations and diseases. To save costs, farmers use cheap pesticides and chemical fertilizers. Coupled with inappropriate application and inadequate irrigation, vegetables can change color, mature too quickly or rot.

Box 1. Market women's vegetable business in the Upper East Region, Ghana

Agricultural trading has been common in the Upper East Region for 30 years. Stating with a group of few market women, such trading business is now carried out by more than 200 market women. They establish associations to collaborate with and support each other in business. They have common loading areas and supporting laborers. Said one trader: *"We support each other. Maybe, if I go to the farm and bring 80 bags and she wants some, I can give 10 bags to her so she can supply them to her customer and vice versa. We also have other people helping us in the business such as those sewing the bags, transporting the produce from the farm and loading the trucks."*

Often, market women buy vegetables from farmers who sell their products at local markets and directly from farmers. In the shortage season, market women buy vegetables from Burkina Faso and Togo. Vegetables are loaded onto trucks and transported daily to big cities like Tamale, Kumasi and Accra. As one market woman said: "*We buy every day except on Fridays because the Friday trucks will get to Accra on Sunday and there is no one there. One truck can take almost 400 bags and we can load 7 to 8 trucks in a day*. *Sometimes, we can provide as many as 1,500 bags.*" I n these big cities, vegetables are sold to retailers and wholesalers in the city markets. The good quality tomatoes and peppers are sold to processing companies and the demand from these companies is increasing.

The local government has currently formalized these businesses by registering and taxing market women's activities and registering and controlling supporting staff. One woman said: *˝Government officers come to register us to start the business. For youngsters who are working with us, we give them some money to buy food, soap, and clothes. They don't pay tax because we register them under our names. When registering, we just need to inform the government that we have ten or twenty supporters and go there with them*."

At the district level, the council issues tickets for loading space to every market woman officially based on the loading unit. However, it can be varied depending on the quantity of bags loaded and the negotiation skill of each market woman. One woman explained: "*We pay council tickets per bag to help our district. On average, the tax is around 4 or 5 Cedis per bag. It can be lower if we have more bags to load. When we go to the bush, we may run out of money so we can negotiate with them to pay half to allow us to load. The council ticket is 1 Cedi per bag but I may have 100 or 200 bags and may not be able to pay for all of them*."

Although vegetable trading is seen as the most profitable in vegetable value chains, market women highlighted some challenges. First, the quality of vegetables varies depending on the farmers' irrigation, farming practices, and harvesting methods. This leads to more time and labor investment to check the vegetable supply to manage the high risk of no buyers in the city markets. Second, loading and transportation are uncertain as trucks are not always available for loading when the vegetables are ready or the truck is damaged on the way. One woman said: "*Sometimes we bring vegetables to the loading centers and there are no vehicles there. Sometimes, the vehicles break down on the way to Accra and we have to throw away most of the decayed produce. If we are not able to get a replacement truck soon enough, vegetables will decay and we have to bear that cost.*"

Finally, there is no guarantee for losses that can happen at any time. For example, there is no guarantee that farmers will sell their products to market women if the farmers do not get support from the market women. The quality of irrigated vegetables depends on farmers' irrigation methods. Said one woman: "*When sprinkler irrigation is used on peppers, it washes them and makes them look very nice and easier to sell in the market. It is the best method for pepper as they are not infested with insects*."

Hence, there is no guarantee of quality when the market women buy vegetables randomly from the local market and this will lead to losses when transporting to the big cities. Finally, the transportation cost is high and adds to the market price.

Source: Interviews with market women in the Upper East Region, Ghana

Third, there is strong competition with the supply of vegetables produced in neighboring Burkina Faso. High-value vegetables such as tomato, garden egg, carrot, cabbage, green pepper, onion, and lettuce are imported from Burkina Faso and Togo during the dry season in Ghana from January to May. A market woman said: "*We have more than 100 buyers from Paga and Navrongo in Ghana who depend on our supply of peppers and tomatoes. We have to go to Ouagadougou, Burkina Faso and Togo to buy when there are no more peppers or tomatoes because there is no water here."* In some cases, vegetables from Burkina Faso are of better quality and size compared to locally produced vegetables. As one market queen said: "*Green peppers and tomatoes we bought from Burkina Faso often have better quality than ones grown in Ghana. Farmers in Burkina Faso use fewer chemicals and more organic fertilizers and this prolongs their shelf life. They also grow good varieties that yield a good quality harvest. Peppers and potatoes from Burkina Faso often stay fresh longer during transportation because farmers there use sprinklers which not only irrigate but wash away the insects*."

Hence, the competitive advantage of vegetables from Burkina Faso over those produced in the Upper East Region is both the better quality and the stable supply during the shortage season.

Irrigation equipment supply

The supply of irrigation equipment and services to the Upper East Region includes three segments along the agricultural water management continuum. ***Water conveyance*** is done with various types of motor pumps (e.g., diesel, petrol pumps and solar-powered). Common motor pumps are Honda, Honday, and Parsun brands. The importer and wholesaler of these pumps is HTC Co. Ltd. and the local distribution system includes local distributors such as Agrimat, Dizengoff and input dealers who have agent contracts and networks with other companies (Figure 2). Honday pumps are in high demand as they are affordable, with the cheapest price at 600–650 Cedis (USD 97 to USD 105) for two-inch pumps. Pumptech, HTC and PEG Africa are currently supplying solar-powered irrigation pumps to the Upper East Region. Retail distributors in the region do not stock these pumps but can order them. Pump rentals, repair and maintenance services are rare in the supply chain.

Water storage involves the use of plastic tanks, wells, ponds and boreholes. Tanks and pipes are manufactured domestically and supplied mainly by Interplast and Duraplast. Ponds and boreholes require local digging/drilling services. Borehole drilling and mechanization services are dynamic as presented in Box 2. Boreholes have been gradually replacing irrigation from dams and dugouts or river bed irrigation where people just follow the flow of the water or dig wells to bring water to their fields. Hence, providing borehole drilling services has become good business in the region and is critical to farmers' investments in irrigation and the benefits they gain.

Water application consists of furrow and gravity, drip, spray-drip, sprinklers and associated services such as pump rentals and repair and maintenance services. The most common irrigation systems are gravity and pumping water for furrow irrigation. Drip irrigation has been introduced to the region but is rarely adopted as it is not appropriate. As one farmer explained: "The t*emperature is too high in the dry season. Water in the pipe heats up and when it reaches our tomatoes, it's like boiling them.*"

Box 2. Borehole drilling services in the Upper East Region, Ghana

Starting from 2009 and 2010, drilling boreholes has become a lucrative business, especially in the dry season. The region has good groundwater at depths of 80 to 100 meters with a success rate of 90% to 95%. Farmers can invest in one or more boreholes if they have access to land and money for drilling. Drilling services involve actors such as drill contractors, rig suppliers and development and mechanization providers.

Drilling contractors provide pre-drilling services such as receiving the orders from farmers, carrying out siting work to identify a location for drilling and contracting the rig providers to come and drill. The contractors carry out siting using either indigenous methods or a combination of indigenous and advanced methods.

Rig suppliers are mainly Indian companies registered as drilling services. In the Upper East Region, only two Ghanaian companies own a drilling rig. The rig suppliers rely on their networks to identify clients.

Development and mechanization providers are pump distributors and supply companies. Many drilling contractors are also development and mechanization providers, especially for electrical pumps. For solar-powered irrigation pumps, distribution companies supply pumps as well. These companies also partner with rig suppliers and contractors to bundle their pumps with borehole drilling as a package. The drilling process was explained by one contractor cum motor pump development and mechanization provider:

"*Farmers contact and show us their sites. We go with our equipment to look for where the water is, get the rig and they give us their money. Mostly, the rigs are owned by Indians. As they are drilling, they sample the rock to find out what the formation is. Sometimes, you get a fracture on top and another fracture below. It is possible to get several fractures. You need to harness all that water so you need to profile the rock formation to know at what level you have water. This way, when we are inserting the casing for the pipe, those blue pipes that we use to protect the well, we know where to put a solid pipe and where to put a screen pipe. A screen pipe has holes in it for water to seep through*. *Once the pipe is in place, we fill it with gravel. This is a special kind of gravel to allow water to seep in and when we are done, we cover it up. The next phase is mechanization. We come with a pump, cable, hose, and other accessories to bring the water up. This aspect of mechanization depends on the type of power available. We can use grid or solar power or a hand pump. Some of the wells are 100 meters deep."*

Total siting, drilling, and lining costs vary from 10,000 to 13,000 Cedis (roughly USD 1,600 to USD 2,000) with 8% for the siting service, 40% for drilling and 40% for development, including pipes, and 12% for mechanization, including the pump. The cost depends on the depth of the drilling, the prices offered by rig suppliers, and the negotiation between farmers and contractors.

There are several risks. For example, the siting determines the success of the borehole but it is very uncertain to do a probe to get the right site. Such probe siting requires a combination of indigenous knowledge to identify the rock structure and siting equipment (e.g., dowsing rod) to enhance the likelihood of reaching a good water level. Second, due to limited knowledge and experience about boreholes, farmers are unaware of the connection between the depth of drilling, the water recharge, and the water yield generated during pumping. To save costs, farmers often ask drillers to stop drilling as soon as the drill hits the water. This can reduce the cost but negatively influence the borehole's sustainable yield. Finally, the risk of having a short borehole lifespan is accompanied by the mechanization and energy supply, especially for the electrical pump. Power fluctuations and surges can take the pump off and the field is reduced. When pumping, the pump needs water around it to reduce the heat. If the yield is not high, it will suck up all the water. If the conditions are good and the yield is good, the farmer can use the pump for a long time.

Source: Interviews with borehole contractors and development and mechanization providers.

Spray-drip irrigation is found where farmers have access to surface water and use motor pumps. Due to limited financial capital, demand for sprinklers is low. Interplast and Duraplast are well-known suppliers for drip lines and sprinklers. These companies have local distributors in the region. They also partner with pump supply companies to provide packages of pumps and irrigation systems to mainly large-scale farmers. They also collaborate with government projects and NGOs to supply drip lines and sprinklers to farmers involved in the projects.

As one NGO representative explained: *"For smallholder farmers, irrigation systems have largely been around drip irrigation. We have quite a large project funded by Global Affairs Canada where we tried to promote irrigation, particularly for smallholder farmers along river beds and dams and targeting a number of women as well. We introduce the pumps to Water User Associations and Farmer Associations. We partner with Interplast and Duraplast, but have an agreement only with Duraplast. We used to buy from Interplast with cash but with Duraplast we can buy on credit."*

Although 'know the customer' is arguably the first rule of marketing, irrigation equipment companies often see farmers as a homogenous group with similar water resources, farming land conditions and financial capacity to invest in irrigation. This leads to an underestimation of local market demand and potential, resulting in limited business investment in the region. A managing director of Pumptech said: "*We have a distribution office in Tamale, just next door to the Upper East. However, we have underestimated this region's potential and have almost no share of the market. When we visited farmers here with IWMI, we saw a huge market potential and before the end of this year, we will have an office here to address this high demand."*

Input supply

Input dealers have shops in towns and vendors have stalls in the local markets. Input dealers sell multiple products such as organic and chemical fertilizers, seeds, pesticides, pumps and other irrigation equipment. Many input dealers also sell pumps, especially motor pumps. National policy and programs such as *Planting for Food and Jobs* promote local input supply through the formalization of input dealers at the district level. However, these programs target only rain-fed agriculture. The government registers and certifies input dealers' businesses. The registered dealers are connected to the formal service provider network and are involved in implementing the government's input subsidy program. The dealers are contracted by the agricultural office to supply inputs, mainly fertilizers, at government-subsidized prices. As explained by an AEA: *"The dealers may come to the government office and register with a voter ID card to provide subsidized fertilizers to a farmer. After-sales, returns are sent to the office. The government officers check before sending the claims to Accra for payment*."

Government subsidies are a factor influencing the price of subsidized inputs. One dealer explained how they use two pricing schemes: "*In the rainy season, the prices are lower due to the subsidies from the government. We sell at normal prices after the rainy season. In the dry season, inputs are more expensive and farmers have to buy more. Only a few wealthy farmers can buy more inputs during the rainy season to use for the dry season*."

Input vendors have stalls at local markets and mainly sell seeds, pesticides and insecticides at retail prices. For many smallholder farmers, it is convenient to buy inputs from these stalls. As one farmer said: "*I go to the Navrongo market to buy seed from the seed stall. I*

don't have a particular shop which I buy from but I know vendors who often sell good quality seeds at good prices."

Many input dealers and vendors also act as technical advisors for their clients. As the dealers have been doing business for many years, they can recommend what product will meet a farmer's needs or solve their problem. As one dealer said: *"I have been in this business for years and I know what a fungicide does and what an insecticide does. So when farmers come, I discuss with them how their field is and I know what to recommend. Most of the time, they want to come and meet me at the shop*." Input dealers also collaborate with NGOs and development projects to supply inputs to farmers. One dealer explained: *"I sell Honda pumps of 2, 3, and 5 horsepower. Some NGOs ask me to supply pumps to some farmer groups. Another dealer was given the supply contract for another district. When the pumps were compared, mine were better quality because I get my pumps from Dizengoff and Agrimat while the other gets his stock from Sankaasi.*"

Service provision

Our data analysis shows that ***agricultural extension services*** focus on promoting rain-fed agriculture and irrigation schemes or irrigated farmer groups. Agricultural extension agents (AEA) make an annual plan and submit it to the regional Agriculture Extension Department to obtain funding and resources for their activities including training farmers on mainly cereal crops such as rice, millet, maize, and beans. AEAs use demonstration plots for training farmers. An AEA explained:

"*I work with eight communities. I do demonstration plots in my areas depending on the problem the farmers identify. Ideally, I am supposed to do demonstration plots in all my areas but the resources are not there to buy seed and fertilizer. Because the resources are not there, I do two demonstrations, sometimes one, even none. We use the demonstration plots as a farmer training school. This means when we are doing a demonstration, we make sure farmers in the community can come. We want a sizable number of farmers to see every activity."*

AEAs also facilitate the formation of farmer organizations and farmer groups. One AEA can handle about six communities with at least four groups in each community. Each group has a purpose, such as raising livestock, cultivating crops, or credit savings. One farmer can join different groups. This structure is the most effective way to sensitize and educate farmers given the limited funding. As one AEA said: "*The surest way of getting to farmers is through groups. When you get them in a group, they spread the message faster than when you do field and home visits."*

AEAs also implement government policy and strategies defined for the region such as Planting for Food and Jobs and value chain development. They do the latter by connecting farmer groups to output and input markets and other service providers such as input dealers, tractor rental providers, and traders. As one AEA said: *"When organizing a meeting with farmers, I say I am looking for bullock farmers or those who have tractors and link them with these service providers if they have the need. I also get the total number of farmers who want to sell their products to buyers, especially to the buyers who can pre-finance them with fertilizers and seeds. Sometimes when you are lucky and there are willing sellers, you can link them with the farmer and the farmer can benefit from it."*

AEAs collaborate with NGOs and development projects to coordinate project activities in their respective domains. They introduce innovations like agronomic practices and livestock

rearing. They also organize and coordinate farmer group participation in the innovation piloting and monitoring activities. However, AEA activities and services rarely cover farmer-led irrigation. In the dry season, AEAs conduct mainly monitoring and backstopping activities such as data collection to service policy implementation, farmer registration for the coming activities and programs from the government and preparation and planning for rainfed extension. As one AEA said: "*Farmers irrigate by themselves because they know that there is money in it. I don't know any NGO or individual enterprise seriously investing in irrigation. At the Pusinamon Dam, for instance, the market queens from Kumasi come to buy tomatoes and build relationships with farmers there but there is no coordinated effort in irrigation that I know of*."

Financial services are formal and informal forms of credit. Formal credit is provided by the banking system and individual farmers and farmer groups can access it if they meet the requirement. This form of credit is obtained mainly by men farmers who invest in high-value crop cultivation. As expressed by one farmer in the group: "*Most of the men go in for loans to do pepper farming. If the pepper yields well, it is profitable and men can save money at the bank and mobile money units. Some men contribute to the village savings and loan scheme but most prefer to save using mobile money as they have easy access to their money to buy inputs without a tedious process*."

Informal credit is commonly found with village savings and loans or '*Susus'* by which farmers save money as part of a self-organized group scheme. Farmers organize themselves in groups of women, men or mixed-gender groups and agree with each other on the terms of reference for saving and governance, appoint box keepers and a manager and hold regular meetings to generate savings. In many villages, *Susus* are formed in a semi-formal setting with support from an AEA. The *Susu* is the most effective credit scheme in the Upper East Region to supplement the limited outreach of formal credit schemes. As expressed by farmers in the group interview: *"Normally, we buy boxes and books and do common accounting entries. The box costs about 200 or 250 Ghana Cedis (USD 32 to USD 41). When we get the box, we start our Susu saving. Our Susu is one of the most effective ones and it is doing very well here. Sometime we can save up to 30,000 or 40,000 Cedis* (USD 4,871 to USD 6,495)."

Solar-based irrigation bundle and market segments for scaling

The best-fit bundle of solar-powered irrigation pumps and financial services

The analyze and co-identify steps (Methodology Section) singled out PAY-OWN PS2 solar-powered pumps as the best-fit bundle for irrigated agriculture in the region. The bundle includes i) PS2 solar-powered irrigation pumps, ii) a pay-as-you-own financial modality, iii) matching services and iv) installment and monitoring services.

PS2 solar-powered irrigation pumps manufactured by Lorentz are supplied by Pumptech (Table 4). The pumps are built specifically for off-grid water pumping and sold as a complete package including the pump, the motor and the solar panels. With 20 years of experience, Lorentz's solar-focused team designs these pumps with high quality materials ensuring excellent load handling and suitability for rural environments. They are designed to be easily serviced to give more water to farmers because of the DC brushless motor technology and

efficient electronics. The pumps also have a customer-friendly LED display and can be linked to the interactive PumpScanner app to collect data on pump use. This enables the farmer to monitor water use and reduce waste. The ability to operate the pump remotely using a mobile device also gives the farmer flexibility and helps save time for other farm activities. The PS2-100 pump, for example, can be used to pump surface and groundwater. Its plug-and-play function does not require any form of wiring, making it easy for self-installation. This puts the farmer in charge, eliminating the need for frequent visits from solar technology experts. Farmers can move the pump away for safety after use or from farm to farm due to the lightweight and foldable nature of the solar panel. It can function even with a damaged solar panel although there may be a loss of efficiency due to the damage. The pump is designed to allow the farmer to increase the amount of water pumped in the future by adding more solar panels instead of changing the whole pump.

TABLE 4. Lorentz solar-powered pumps distributed by Pumptech.

Pump Name	**Characteristics***	**Estimated Price (Cedis)****
PS2-100	- Two 100-watts solar panels - Maximum depth: 25 m - Minimum depth: 5 m - Pumping capacity per day: 3,000 liters	7,000 (USD 1,137)
PS 150	- One 250-watts solar panel - Maximum depth: 40 m - Minimum depth: 5 m - Pumping capacity per day: 5,000 liters	15,000 (USD 2,436)
PS 600	- Two 250-watts solar panels - Maximum depth: 60 m - Minimum depth: 10 m - Pumping capacity per day: 10,000 liters	20,000 (USD 3,247)
PS 1800	- Three 250-watts solar panels - Maximum depth: 140 m - Minimum depth: 5 m - Pumping capacity per day: 15,000 liters	25,000 (USD 4,059)

Source: Pumptech.

*All types of pumps can be sold under the PAY-OWN financing modality.

** Price is subject to change based on the source of water, depth of water source, the height of storage tank, pressure losses, daily water requirement, and location that determines the number of sunlight hours/irradiation and corresponding solar panels.

The PS2-100 pump is designed for off-grid water pumping with the smallholder farmer in mind (Figure 4). The pump has three main components: the panel, the pump and its controller and the hose. All components fit into one box with a handle. This helps to address the challenge of pumps and panels being stolen by giving the farmer the option to move the pump for safety after use or from farm to farm due to the lightweight and foldable nature of the solar panel. The PS2-100 pump is plug-and-play and does not require any form of wiring, making it easy for self-installation. This puts the farmer in charge, eliminating the need for frequent visits from solar technology experts. The PS2-100 pump comes in three variants.

i. The first type has more power but gives a small quantity of water at any one time and is recommended for very deep wells with low water yields.
ii. The second type has moderate power and gives a moderate flow of water and is recommended for water sources that are not too deep and not too shallow.
iii. The third type has low power but gives a large flow of water. It is recommended for surface or shallow water sources like ponds which require little force to pump but can give the farmer a high flow of water.

Small 100 W system to fit mass market low-cost systems

- High quality
- Engineering polymer PE
- Mini controller
- Very portable
- Typically, 200 Wp solar
- 24–50 V operating range
- Plug and play for self-install
- Motor cable with plug, fixed by screws (exchangeable)

Technical performance efficiency

- Provides over 20,000 liters of water per day
- Pumps up to 40 meter head
- Global LEAP Awards by a significant margin, at 25% more efficient than the closest competitor

Financial service for maximum flexibility for smallholder farmers

- Pay- to- use or Pay- to-own
- Controller and pump are paired for asset protection
- Uses same keypad solution as other products
- Codes entered via PayGO App
- Usage data can be configured from the App

PumpScanner

- Simple system configuration: Setup, Register, Analyze
- Performance: real time, historic data and diagnostics
- Unlimited licenses included
- High customer and partner value

Source: www.lorentz.de/ps2-100.

FIGURE 4. Features of the Lorentz PS2-100 solar-powered irrigation pump.

The PS2-100 meets the needs of both surface and groundwater. It allows farmers to collect data on pump performance in real time using Android technology. This enables farmers to monitor water use and reduce waste. The ability to operate the pump remotely using a mobile device also gives the farmer flexibility and helps save time for other farm activities. It can function even with a damaged solar panel although there may be loss of efficiency due to the damage. The pump is designed to allow the farmer to increase the amount of water it produces in future by adding more solar panels instead of changing the whole pump. The PS2-100 and other PS2 pumps should be operated to maximize benefits. As explained by Pumptech's Managing Director:

The pump will continue to run as long as it is under water and as long as you have switched it on. For solar, we don't turn off the pump because turning it off is wasting energy. The solar-powered irrigation pump wants to work when the sun is out until the sun goes down. It is a lot of waste of the farmer's investment if they are not pumping water. So when they install it, the farmers have to work hard to use more of the water. They can do a rotation or expand to optimize the use of the pump."

Pay-as-you-own (PAY-OWN) financing service includes various technical and financial services that the scaling partnership provides to farmers. PAY-OWN is a credit system that

allows farmers to make use of equipment while paying instalments to own it. Farmers differ in their financial abilities to make a deposit for a pump from Pumptech and in their ability to pay. Pumps sold under a PAY-OWN arrangement contain a chip and are connected to the PumpScanner app which tracks payments. Pumptech uses the PumpScanner as a credit control mechanism for defaulters. Pumptech offers the PAY-OWN option for farmers who cannot afford to buy a pump in one payment. The PAY-OWN offer includes an initial deposit depending on the terms agreed with Pumptech.

Pre-installment services and business advice are provided by Pumptech as part of the sales contract. Pumptech conducts a farm survey with a potential client to identify the best-fit pump for the farming conditions and financial capacity. This allows for customization of the pump and PAY-OWN terms of reference for each farmer. PAY-OWN allows more farmers to overcome the initial capital barrier to acquire solar technology. Farmers will then regularly pay Pumptech as agreed until the total cost of the pump has been paid for. The payment may be weekly, monthly, quarterly, or scheduled around the farmer's harvest times. Pumptech offers the PAY-OWN option for farmers who cannot make full upfront payments to acquire their pumps. Pumptech's Managing Director said:

"*For farmers who can't pay upfront, we have a system called pay-as-you-own. It means we will meter the water over time that we all agree on. Once clients finish clearing their bill, the pump is for them and the more deposit they have, the more it quickens their payoff time. Pay-as-you-own is initiated by Angaza company to help farmers acquire a pump without them knowing their payment for the pump. With pay-as-you-own, it is possible to negotiate for 0% deposit, 10% deposit or 90% deposit, depending on the individual profile and how he can measure his income. A farmer is making a profit but instead of 20% profit, he is making 5%. This is a person we can be sure that if we give it to him at no deposit, he can still pay because we already know what he paid on his diesel pump*."

Success about the initial beneficiaries of the PAY-OWN pumps is expected to encourage more farmers to take up the technology and increase demand for solar-powered irrigation pumps.

Matching services come with the provision of a PS2 solar-powered irrigation pump and PAY-OWN finances to help customize the type of pump and accessories to fit farmers' land size, water access, and financial capital. The matching services for individuals or groups of clients include field investigation to identify the land size and irrigated crops, water source and water field, existing irrigation investment, and application and irrigation plan. The services also include introducing and demonstrating different pump technologies (e.g., PS2 solar-powered irrigation pumps) and PAY-OWN services, identifying a client's irrigation needs and financial capacity to invest, and discuss the terms of reference for the pump technology and pay-own options which can be recommended to the client.

Installment and monitoring services include different activities by which the company installs a pump package and PAY-OWN, training on pump operation and maintenance, advice on the farmer's irrigation system, and monitoring pump performance. The installation includes checking the borehole to measure its yield and calculate the amount of water needed for the farm size, placing solar panels to ensure the optimum harvest of power, mechanizing the pump and laying out pipes to allow the water to flow and installing tanks for water storage. The company also provides training and advice on the type of irrigation system, water storage options, operation and maintenance of the pump and solar panels.

With PS2 pumps, the monitoring can be done remotely as explained by Pumptech's technician:

"*All PS2 pumps have a data log connected to the controller that stores data on the pump including water usage. You can connect your phone via Bluetooth to download all the data and performance records of the pump at any point. It is like the brain of the pump. It records every five minutes for five years and stores the data for about a year and then it starts over-writing the data from the oldest one stored. After five years, it only overrides the earlier records. Even when we have larger installations like the one we have in Ada, we have what we call an ePS2 communicator. That one also takes the information from the pump and uploads it to cloud storage so you can see the live performance of the pump at any point, anywhere, once you can connect.*"

Market segments for PS2 solar-powered irrigation pumps and pay-as-you-own services

The analyze and co-identify steps also indicated different farmer segments who stand to benefit from solar-powered irrigation pumps distributed by Pumptech. These segments include resource-rich farmers, mobile farmers, resource-limited farmers, and farmer groups (Table 5).

Resource-rich farmers own a large area of land, have control over one or more water sources, manage an advanced irrigation system including water storage facilities, and need a high capacity solar-powered irrigation pump. These farmers have the financial capacity to make a deposit for a pump and to pay the difference using a payment schedule.

Mobile farmers migrate seasonally to be closer to surface water sources to farm during the dry season. They cultivate on rented land or government land close to formal irrigation systems and irrigate their farms on an individual or group basis. There is a water source where they normally go to cultivate but the water does not last. By February, March, or April, all the surface water is gone so they have to come home and prepare for rain-fed farming. Individual mobile farmers or an informal group of farmers need a movable, low-capacity solar-powered irrigation pump since their farming activities can be in different locations each season. Mobile farmers can buy a PS2-100 or a bigger capacity solar-powered irrigation pump as individuals or as a group using the pay-to-own option.

Resource-limited farmers have permanent access to cultivated land. Their water source is mainly groundwater from dugouts and wells. They need low to medium capacity solar-powered irrigation pumps for both farming and domestic uses. Some individual farmers have relatively good financial capacity to invest in solar technology on a PAY-OWN basis while others, especially women farmers, have limited financial capacity. These individual farmers may invest in solar technology on their own or may join farmer organizations to invest as a group.

Farmer groups have the collective capacity to invest in a medium to high capacity solar-powered pump for both farming and domestic purposes. Land is individually owned but some groups have access to a common cultivation area. These farmer groups might have funds generated from monthly or seasonal dues paid by members, village savings and loans schemes (e.g., *Susu* schemes), savings from harvests in rural banks or mobile money wallets or a combination of these. Group members also sometimes sell some of their livestock when there is an urgent need for money. As a group, the challenges for expanding or investing

more in irrigation is water access and governing the group's use of water and irrigation facilities. According to one farmer group:

"*Although we have a watering schedule so that every member of our group will be able to water their crops, water is not enough and many times we need to spend more money to buy fuel to pump water and it is very expensive. If one person waters her crops, she buys a gallon of fuel which is about 30 Cedis (USD 5) or as much as 50 (USD 8.2) Cedis for one week. If they want to water the whole area as a group, they put their money together and buy fuel worth about 200 Cedis (USD 33.3) to water for one week. So for the whole group, they spend 800 Cedis (USD 133) on fuel in a month. In six months, that is almost 5,000 Cedis (USD 800).*"

TABLE 5. Farmer segments for Pumptech distributed solar-powered irrigation pumps.

Characteristics	**Resource-rich farmer**	**Mobile farmer**	**Resource-limited farmer**	**Farmer group**
Land and water access	- Owns a relatively large land area - Able to control water sources	- No ownership of irrigated land - Access mainly to surface water	- Permanent access to cultivated land - Access mainly to groundwater	- Individual ownership to cultivated land with possible access to common land for collective production - Access mainly to groundwater
Arrangement of irrigation, production, and marketing of irrigated vegetables	- Advanced irrigation system managed by individual farmers - Focus on high-value vegetables - Diverse marketing and access to market information to manage price-related risk	- Individual or informal group management - Flexible in terms of irrigation and irrigated crops - Direct sale at farms	- Individual/group management - Potential to expand production - Mainly cultivate leafy green vegetables - Direct sale at markets and farm gate	- Individual or collective management of irrigation - Cultivate mainly leafy green vegetables for regular cash income - Direct sale at market and farm gate
Financial capital and potential	- High potential to invest in solar-powered irrigation as an individual	- Relatively high potential to invest in solar-powered pumps - An individual or group investment	- Very limited financial capital, especially women farmers - Limited potential to invest in solar-powered pumps	- Limited financial capacity to invest in solar-powered pumps - Potential to invest collectively in relatively high capacity solar-powered pumps
Pump product preferences	- High capacity pump with payment schedule	- Low capacity and movable solar pump - Solar-power irrigation pump with or without payment schedule	- Low/medium capacity of solar-powered irrigation pump and multiple uses	- Medium/high capacity of a pump - Multiple uses depending on collective financial management and mobilization

Source: Ofosu and Minh, 2021.

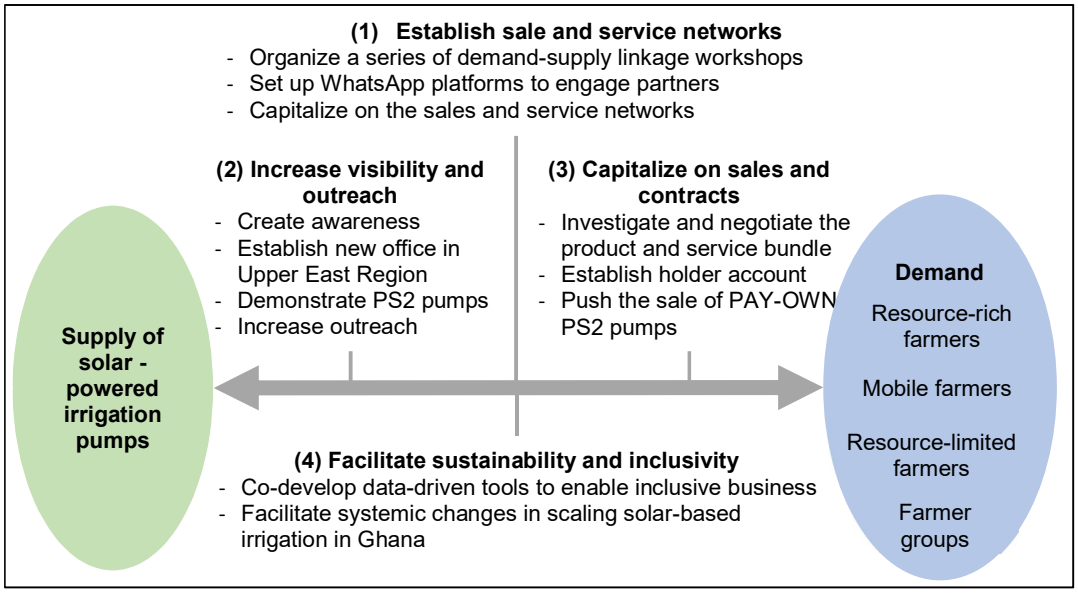
Capturing market segments is critical for the company to develop a business plan to expand and diversify its supply models to reach different groups of clients in the Upper East Region. According to Pumptech's Managing Director: "*We have been trying to set up an office in the Upper East but have not yet done that. But with the potential that we explored with IWMI, I think by the end of the year, we will have a physical presence here. IWMI has created this opportunity to bring us together. We would also like to encourage you to bring more of us together again to realize our potential.*"

Demand-supply linkage pathway to scaling solar-based irrigation bundle

Demand-supply linkage pathway for scaling of PS2 and PAY-OWN bundle

Based on the results from the co-identify step, a demand-supply linkage partnership has been established among partners to facilitate the scaling of solar-powered pumps for irrigated agriculture in the region. In this scaling partnership, IWMI partners with Pumptech and the Regional Extension Department, Ministry of Food and Agriculture (MOFA) to design a demand-supply linkage pathway to scale a bundle of PAY-OWN solar-powered irrigation pumps and co-implement the pathway with other partners. The scaling partnership aims to:

- Establish sales and service networks,
- Increase the private company's visibility and outreach in the region,
- Capitalize the sale of PAY-OWN PS2 solar-powered pumps,
- Facilitate sustainability and inclusivity of scaling solar-based irrigation (Figure 5)



Source: Author's elaboration.

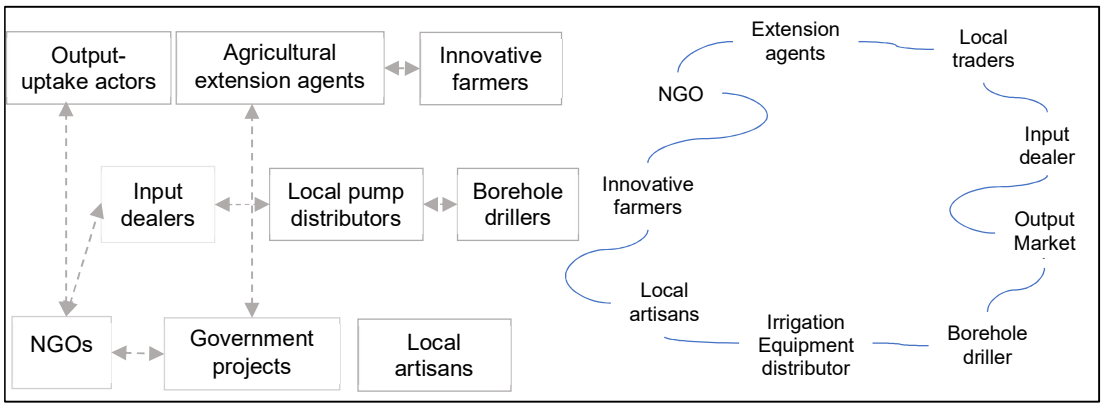
FIGURE 5. Demand-supply linkage pathway to scaling PAY-OWN PS2 solar-powered irrigation pumps.

As a private sector partner, Pumptech supplies the PAY-OWN PS2 solar-powered irrigation pumps to farmers and establishes its sales and service networks to expand its market in the Upper East Region. As a public sector partner, the Regional Agricultural Department facilitates increasing Pumptech visibility and establishing sales and service networks by mobilizing AEAs and other actors in the irrigated vegetable value chains. As the research

partner, IWMI provides knowledge, expertise, tools and services to de-risk investment for the private sector partner and develop inclusive business models for solar-based irrigation to target marginalized market segments at the bottom of the pyramid and boost the sustainable market development for solar-based irrigation. The demand-supply linkage pathway consists of four components as discussed below.

(1) Establish sales and service networks

This is a core component in the demand-supply linkage scaling pathway. It aims to upgrade the existing network of actors and stakeholders involved in solar-powered irrigation pump supply in the Upper East Region to the ideal form of the network as illustrated in Figure 6. In current networks, linkages among different actors are weak and fragmented. Projects undertaken by NGOs link the demand and supply side by making use of a local pump and borehole distributors for the installation of solar-powered pump systems for beneficiary communities. Local input dealers, output-uptake companies, and AEAs may also be involved depending on the project. Government-funded projects often establish a link between the beneficiary communities and the solar-powered irrigation pump suppliers by using AEAs. The ideal network that Pumptech and IWMI are seeking to build involves the active participation of all actors such as artisans, pump distributors, borehole drillers, input dealers, AEAs, innovative resource-rich farmers, and output-uptake companies. These actors help Pumptech identify farmers and farmer groups interested in acquiring solar-based irrigation technology and their preferences. NGO and government-funded projects will complement the activities of these actors.



Source: Author's elaboration.

FIGURE 6. Left: Existing network of actors. Right: Sales and service network.

Organizing demand-supply linkage workshops aims to establish the networks (as presented in Section III and Annex 1) by which Pumptech can potentially use participants as sales and service agents and actualize and activate the networks with digital platforms such as WhatsApp. The demand-supply linkage workshops were organized in Navrongo, Bawku, and Bolgatanga townships in the Upper East Region of Ghana from 12 to 14 January 2021. Workshops involved 49 farmers and representatives from farmer groups and 170 individuals representing value chain actors. The workshops organized breakout groups to discuss one of the potential client categories identified (resource-rich farmers, mobile farmers, resource-limited farmers, and farmer group) to respond to three questions: i) Who are the farmers or farmer groups who could become Pumptech customers in your community? ii) What resources do these farmers or farmer groups have? iii) In what ways could farmers or farmer groups connect with Pumptech? Participants suggested 144 individuals and 15 farmer groups with contact numbers for Pumptech as potential customers from their communities.

Pumptech has established three WhatsApp platforms for sales and service networks. Sustaining such networks needs to:

- Expand newly established networks from zone to district and community level. To do so, Pumptech and MOFA are collaborating to lead the organization of district-level demand-supply linkage workshops in the region. The workshop participants can further identify new people to join the sales and service networks. MOFA officials can serve as group administrators for the WhatsApp group to be established.
- Capitalize on the established networks with commissions or finder's fees to serve as an incentive from suppliers of solar technology for these actors. Pumptech is applying the company's commission scheme for its distributors to incentivize the sales and service networks.
- Organize follow-up workshops to strengthen the identified sales and service partnerships. The workshops can be organized annually to strengthen collaboration and interaction between network members and Pumptech.

(2) Increase private sector visibility and outreach

This component aims at presenting Pumptech services in the Upper East Region and tailoring the company's supply models to target market segments. To achieve this, Pumptech is preparing to connect farmers and farmer groups with Pumptech to:

- Create awareness about PAY-OWN PS2 solar-powered irrigation pumps for Upper East Region farmers. This can be achieved by organizing farmer meetings, home and farm visits, radio advertising, advertising through text messages, extension delivery, use of lead farmers within target communities, communication and advertising through WhatsApp and community forums and demonstrations.
- Establish a new distribution office in the Upper East Region to tailor Pumptech's solutions and business models to market segments to boost the high potential market for solar-power irrigation pumps in the region. Pumptech aims to reach smallholder farmers including resource-limited farmers and farmer groups with complete packages of technology and services using smart, flexible and sustainable financing mechanisms. Pumptech, in collaboration with MOFA, established the new branch in September 2021 in the MOFA building.
- Directly demonstrate PS2 pumps on farms. This includes organizing demonstrations to farming communities and mobile farmers farming around the Tono Irrigation site in Kajelo (Aliabolo, in Naaga, close to the White Volta) and in Kologo (close to the Kologo River). In February 2021, Pumptech organized three field demonstrations to introduce the PS2 pumps to 50 individual farmers and representatives from three farmer groups. At these demonstrations, Pumptech sold seven PS2 100 W pumps.
- Increase Pumptech's outreach to different market segments. This includes a mobile service providing water for farmers as and when needed without the need for the farmer to invest any capital into acquiring a solar-powered irrigation pump. This also includes offering landlords who rent land to mobile farmers the option of buying solar-powered irrigation pumps and offering water as a service to mobile farmers.

(3) Capitalize on sales and contracts

This component aims to increase the sale of PAY-OWN PS2 solar-powered irrigation pumps in the region and Ghana in general. To do so, Pumptech is investigating and negotiating the supply of PAY-OWN PS2 solar-powered irrigation pumps with potential clients identified during the demand-supply linkage workshops and beyond. The opening of the distribution office in the region enables Pumptech to tailor the best-fit bundle of solar-powered irrigation pumps and financial services to diverse farmer clients and engage more closely with high potential individuals and groups. For example, in September 2021, two new clients

had signed and paid for their solar facilities from Pumptech. One client bought a pump worth 20,000 Cedis (USD 3,248) with a first payment of 18,000 Cedis (USD 2,923) and a second payment of 2,000 Cedis (USD 325) after one year from installation. Another client bought a pump worth 15,000 Cedis (2,436) with a first payment of 5,000 Cedis (USD 812) before installation and at least 3,000 Cedis (USD 487) after every harvesting season for three years after installation.

Pumptech is also establishing holder accounts and a PAY-OWN client management platform. Pumptech is investigating possibilities for establishing a PAY-OWN platform. This includes discussions with MTN Ghana on Angaza integration.[2] The company is pushing the sale of PAY-OWN PS2 solar-powered irrigation pumps together with other services for contracted farmers. Pumptech reported an increase of 80% in pump sales in 2021 compared to 2020. Pumptech has also partnered with Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) to de-risk the company's investment in the supply of PAY-OWN PS2 solar-powered irrigation pumps. Specifically, GIZ subsidizes 40–50% of the pumps sold under the PAY-OWN scheme to ensure the company's investment in financing services to smallholder farmers.

(4) Facilitate sustainability and inclusivity in scaling solar-based irrigation

This component aims to enhance the sustainable and inclusive scaling of solar-based irrigation within the scaling partnership and beyond. To achieve this, IWMI and Pumptech carry out a set of activities to facilitate stakeholders and actors sustainable and inclusive businesses and interventions to scaling irrigation in Ghana. One set of these activities is the co-development of data-driven tools to enable private-sector partners to target their products and services to the right people in the right way. These tools include client segmentation, digital marketing and data management, and customization of solar suitability mapping.

Client segmentation has resulted in tailoring business models for four segments of resource-rich, mobile, and resource-limited farmers and farmer groups in the Upper East Region as discussed in Section V.2. Market segmentation means dividing the PAY-OWN PS2 solar-powered irrigation pump market into smaller, more defined categories. Farmer clients were segmented into groups based on land ownership and land tenure system, irrigation water source, the structure of irrigation scheme, access to credit and inputs, extension services, intelligent communication technologies, market infrastructure and needs of special groups, and climate change factors (Ofosu and Minh 2021). Ways to segment the market include the use of existing data from government agencies such as demographic data focus group discussions, field surveys, and analysis of past projects and interventions, and the use of digital innovations and appropriate technology in terms of ease of use considering the educational level of the users. By segmenting client groups in gender-sensitive ways, businesses can better target a range of farmers, including women. This is helping accelerate the adoption of solar-powered irrigation technologies in frontier markets while promoting women's equitable participation in irrigated agricultural value chains. Women farmers are more likely to face difficulties accessing resources such as land, credit, and information that

[2] The two parties are yet come to an agreement due to concerns from MTN that the integration may compromise the security of the company's system. Pumptech has also held discussions with another payment platform called Beyonic which is based in Uganda and operates largely in East Africa. The possibility of merging Pumptech's system with Angaza using Beyonic has not yet been explored because it will add additional costs to the end user. It will require payment of fees to Angaza and Beyonic for each transaction that occurs on the joint platform.

would enable them to invest in irrigation. Businesses essentially provide farmers with a loan to buy a pump, with the pump itself serving as security. The model is especially beneficial for resource-limited farmers and farmer groups who lack the collateral or credit history usually required for a loan.

A digital marketing and data management system aims to improve the efficiency of the marketing system and business management. The system helps the company market its products and services better, especially to the more challenging but promising small-scale irrigation market. It also reduces errors in capturing customer information, improves retrieval time, and allows for comparative analysis across products, market segments and businesses. Pumptech, with help from IWMI, has developed this system to address challenges of poor filing, analysis and usage of customer data, limited leveraging of online technologies and low company branding. An expected outcome is Pumptech's new website that will present an extensive product catalogue, highlight the company's partnerships in developing its inclusive business and solar-based irrigation market and generate social media attention on projects. Other positive changes have been achieved in Pumptech's business management. These include a better virtual communication tool and reliable telecommunications and the development of business and partner networks.

Customization of solar suitability mapping. IWMI has developed an interactive solar-suitability online mapping tool to assess land suitability for using solar energy.[3] IWMI developed this tool to help users identify suitable areas for solar-based irrigation depending on water sources and pump characteristics. Marketing initiatives and interactions with other actors within the irrigation supply chain have also been guided by the maps.
Another group of activities is the facilitation of systemic changes in scaling solar-based irrigation. This includes the facilitation of the local scaling ecosystem and multi-stakeholder dialogues and institutional capacity building to support sustainable transformation.

Facilitating local scaling ecosystem aims to enhance the demand-supply linkage scaling pathway by engaging local scaling ecosystem actors such as community leaders, local authorities, and microfinance institutions to open up interactions and collaborations to co-develop and scale bundles of solutions that strengthen the adoption of PAY-OWN PS2 solar-powered irrigation pumps. The facilitation also includes expanding the scaling PAY-OWN PS2 solar-powered pumps to other regions in Ghana.

Facilitating multi-stakeholder dialogues aims to create open organizational and institutional spaces which can bring actors together and provide them with a space for learning, action and change while stimulating private sector investments and partnerships. These include establishing scaling partnerships to reach more target groups, innovation platforms to scale up innovation in the field, learning alliances to influence policy at the national level and multi-stakeholder dialogues to accelerate innovation scaling and system transformation.

Institutional capacity building aims to build greater trust, knowledge sharing and collaboration between the private sector, public sector and research institutions that contribute to an enabling environment to scale solar-based irrigation in an economically and environmentally sustainable way. For example, with Pumptech and other private partners in Ghana, IWMI has supported young entrepreneurs and young professionals through private

[3] http://sip.africa.iwmi.org/ This tool was first piloted in Ethiopia in 2018 and currently covers several countries in Sub-Saharan Africa and beyond, including Ghana. The tool was developed with funding from GIZ and WLE.

sector working experience and demand-driven innovation development, strengthening systemic capacity to be responsive and inclusive while scaling solar-based irrigation.

Factors influencing the demand-supply linkage pathway

Several factors potentially enable or hinder the scaling of PAY-OWN PS2 solar-powered pumps. One enabling factor is that ***PAY-OWN PS2 solar-powered pumps*** are the best-fit bundle to reduce high fuel costs while optimizing solar radiation in the region. Introducing solar-powered pumps needs to address the high initial investment challenge that farmers often face when acquiring the technology. Another enabling factor is the ***existing support to farmer organization***s to enhance agricultural production. Policies and programs have supported farmer group access to inputs, credit and extension services through the facilitation of AEAs as discussed in Section IV.4. There are many farmer groups led by women The importance of women's leadership is widely acknowledged in the region as essential for supplying PAY-OWN PS2 solar-powered pumps to farmer groups. As one AEA said: "*Everyone knows that when it comes to groups, women leaders are better. Ask women to contribute something and they will contribute it and account for it diligently*."

The ***Susu credit system*** is another factor that enables farmers, especially farmer groups, to mobilize their financial capital to invest in PAY-OWN PS2 pumps. This enables women and young farmers to invest in solar-based irrigation for vegetable farming to produce food for households and serves as a source of income, reducing unemployment and poverty levels and empowering women and youth to be independent as women are believed to be better managers of a business, including vegetable farming. Finally, there is a ***dynamic engagement*** of irrigated agricultural value chain actors, especially irrigation equipment suppliers as discussed in section IV.2. The success of irrigation depends significantly on access to irrigation equipment, getting information and training on water resource management and access to loans for initial capital. The key actors within the irrigated vegetable value chain in the Upper East Region are irrigation equipment suppliers, extension agents, improved seed providers, fertilizer providers, market women as intermediaries, microfinance groups, well drillers, group formation trainers, and chiefs and traditional authorities.

Hindering factors include technical issues such as product lifespan, solar panel maintenance, theft, and gender-friendliness. The misconception of solar systems for home consumption is they have short lifespans and this has negatively influenced the reputation of solar pumps. The short lifespans of some home solar systems were attributed to users overloading the system with gadgets and lighting points beyond the stated capacity. There is also the issue of limited land, water, financial and human capital. For example, dry season farming is difficult as the water dries up before the end of the cropping season. Investment in solar technology is often extensive and the initial cost is high for many farmers. Farmers do not have adequate finances to invest in both solar-based irrigation and inputs for irrigated farming.

Group dynamics such as leadership style, transparency, and social and cultural norms may also influence the effective management of group-acquired solar technology. Social norms in the community control the degree to which group members and leadership can be punitive, making group management very difficult. Accountability of the group leader and members affect group ownership and management of collective assets. Farmers' poor bargaining power may lead to low selling prices for irrigated vegetables and limited access to agricultural inputs and services.

Government subsidies and uncoordinated interventions for value chain development led to duplication of effort and a reduction in the benefits that may have accrued to farmers. The

introduction of solar technologies may fail to consider the social and economic dynamics of the target group and government interventions influenced by political interests and a lack of an established rural distribution network for solar-powered irrigation pumps and accessories. The government's subsidy for fertilizers and seeds for farmers mainly target rain-fed production and come at a time when farmers do not have cash on hand. Government agencies and public service providers have been embedded in supply-driven approaches and collaboration and coordination among these agencies is limited.

The successful demand-supply linkages pathway lays out a set of actions to respond to these enabling and hindering factors. First, commitment and investment from Pumptech is key to capitalizing on the partnership. Sustaining the sales and service networks and platforms requires capital that can enable Pumptech to expand its business to the region. Obtaining investments to de-risk the PAY-OWN financing services is essential to manage the risk of clients who are unable to fulfill their payment obligations and potential failures in Pumptech's supply chain and capacity to supply the scaling package in time. These measures will ensure Pumptech can tailor its business and financing models to target market segments in the most effective way.

Second, strengthening farmers' collective action is key to farmers organizing their input and output market access and managing the *Susu* credit scheme to mobilize land and water access and financial capital for solar-based irrigation. Farmer groups have been formed to support members' access to inputs such as seed and fertilizers and extension services. However, these mainly focus on providing inputs and services to major rain-fed crops. Many established farmer groups have not been based on farmer demand but on AEA's needs for fulfilling their mandate. Hence, promoting collective action in farmer groups is a challenge. One promising form of organization to promote collective action is farmer groups established by farmers in the same village to address their needs for input access and land, water, and financial capital mobilization. With many villages in the region, farmer group *Susu* credit schemes can be strengthened to mobilize financial capital for investment in solar-based irrigation.

Third, the dynamic engagement of actors in the irrigated agricultural value chain is key for farmers' adoption of solar-based irrigation. These actors include private and public service and input providers who can provide irrigators with inputs such as good quality seed, irrigation knowledge, and organization of production and collective actions. With the engagement of these actors, existing interventions supporting farmers' adoption of irrigation and agronomic techniques and inputs and market linkages can be leveraged in the demand-supply linkage scaling pathway. Regional MOFA departments can act as local operational hubs connecting farmers with most services and resources required for irrigated agriculture and Pumptech's distribution and services.

Finally, multi-stakeholder dialogues and cooperation on scaling solar-based irrigation and market development can bring actors together to stimulate private sector investments and partnerships, inform public policies and programs and trigger system transformation beyond the scaling partnership. Research organizations undertaking knowledge brokering roles are a necessary condition for the sustainability and inclusivity of the demand-supply linkage scaling pathway, the capitalization of private sector inclusive businesses to target market segments, and de-risking private sector investment.

Conclusion

Throughout the action research process in Upper East Region, Ghana, PS2 solar-powered irrigation pumps and pay-as-you-own (PAY-OWN) financing services were identified as scalable bundles for irrigated vegetable value chains. The scalable bundle comprises PS2 solar-powered irrigation pumps, PAY-OWN financial modality, matching services, and installment and monitoring services. To scale this bundle, a demand-supply linkage scaling pathway has been co-developed with actors in the irrigated vegetable value chain. The pathway consists of sales and service partner networks, increasing the private sector partner's visibility and outreach in the region, capitalizing on the sale of PAY-OWN PS2 solar-powered pumps, and facilitating sustainability and inclusivity of scaling solar-based irrigation.

To operationalize the demand-supply linkage scaling pathway, a demand-supply linkage partnership has been established that includes the International Water Management Institute, Pumptech Ltd., Ghana and the Agricultural Extension Department, Ministry of Food and Agriculture. In this scaling partnership, Pumptech supplies the PAY-OWN PS2 solar-powered irrigation pumps to farmers, established and capitalized its sales and service partner networks, opened a new office in the Upper East Region to create awareness about and demonstrate the scalable bundle and is pushing the sale of PAY-OWN PS2 pumps. The Ministry of Food and Agriculture supports Pumptech's visibility and establishment of sales and service partner networks by mobilizing the engagement of agricultural extension agents and other actors in the irrigated vegetable value chains in the supply platforms. IWMI provides knowledge, expertise, data-driven tools and facilitation services to de-risk the private sector partner's investment and enables the partner's inclusive business model to target marginalized market segments at the bottom of the pyramid.

Factors enabling successful scaling are the best-fit of PAY-OWN PS2 solar-powered irrigation pumps to the regional context, the existing support to farmer organizations to enhance agricultural production, the functioning Susu credit scheme, and the dynamic engagement of irrigated agricultural value chain actors. Factors hindering successful scaling are technical issues related to product lifespan, solar panel maintenance, theft and a lack of gender-friendliness, limited land, water, financial and human capital, group dynamics and government subsidies and uncoordinated interventions for value chain development.
A successful demand-supply linkages pathway, therefore, requires the commitment and investment of private sector partners in capitalizing the partnership's investment and strengthening farmers' collective action to mobilize land and water access and financial capital. It also requires the dynamic engagement of actors in the irrigated agricultural value chain to enhance farmers' adoption of solar-based irrigation and multi-stakeholder dialogues and corporations to sustain the partnership's investment and trigger system transformation.

The demand-supply linkage pathway for scaling PAY-OWN PS2 solar-powered pumps contributes to systemic changes in developing solar-based irrigation in Ghana in several ways. First, women prefer solar technologies which reduce labor in providing water for irrigation while increasing irrigated crops and crop yields. Women and youth are encouraged to invest in PAY-OWN solar-powered pumps for irrigated farming as irrigation provides food for households and serves as a source of income, reduces unemployment and poverty levels, harnesses the strength the youth have to do farm work, empowers women to be independent, and limits north-south migration and reduces illegal mining activities in the Upper East Region.

Second, private sector solar-powered irrigation companies in Ghana are enabled to determine and capitalize on the market potential for their irrigation equipment and services. By segmenting customer groups and providing PAY-OWN financial services in inclusive ways, companies can better target client segments such as the resource-rich, resource-limited, mobile farmers, and farmer groups. This is helping accelerate the adoption of solar-based irrigation in frontier markets while promoting women's equitable participation in irrigated agricultural value chains.

Third, corporations among pump manufacturers and distributors, public and research sectors and other value chain actors and ongoing multi-stakeholder dialogues at different levels continuously trigger changes in solar market development. Multi-stakeholder dialogues and corporations can i) bring actors together, ii) provide them with a space for interactive learning and collective action while stimulating private sector investments and partnerships, iii) inform public policies and programs, and iv) capitalize on the existing resources and investments to enhance system transformation beyond the scaling partnership.

Using an action research process to co-develop the demand-supply linkage scaling pathway provides contextually relevant evidence-based knowledge on the potential of solar irrigation market development. Specifically, the approach facilitates identifying the best-fit bundle and the right-fit actors and stakeholders to form the scaling partnership, thereby enabling inclusive irrigated value chains for smallholder farmers. How to connect the right-fit actors and stakeholders in a specific scaling pathway remains critical to designing the pathway. Hence, it is essential to identify the roles of actors involved in the different components and facilitate them as they play their role in the scaling process.

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Annex 1. Demand-supply linkage workshop agenda

Demand and supply linkages workshop:
Solar-powered pump for irrigated agricultural value chains
12–14 January 2021

Workshop series: Navrongo, Bawku and Bolgatanga, Upper East Region Ghana

Objectives:

- Share knowledge about irrigation in the Upper East Region.
- Share new insights on irrigation technologies, products and services.
- Develop a plan to establish and facilitate demand-supply linkages for solar based irrigation.
- Network and explore collaboration for business opportunities.

Time	**Activity**	Remarks
08.00 – 08.30	Arrival registration	
08.30 – 09.00	Welcome by - IWMI and Africa Rising - Regional Agriculture Department	Zimi Alhassan, MOFA Olufunke Cofie, IWMI; Fred Kizito, Alliance Bioversity-CIAT
09.00 – 09.45	Share knowledge about irrigation in the Upper East Region	Obed Tuabu and Prof. Abdul-Ganiyu Shaibu
09.45 – 10.30	Share the new insights about irrigation technologies, products and services	Osman Kulendi (Managing Director), Timothy Mensah and Ivy Konadu, Pumptech
10.30 – 10.45	Market segments and demand-supply linkages for solar-powered irrigation pumps	Thai Thi Minh and Desire Dickson-Naab, IWMI
10.45 – 11.00	**Coffee break and networking**	
11.00 – 12.00	Interest group discussion to: - Develop a plan to establish and facilitate demand-supply linkages for solar-powered irrigation pumps; and - Explore collaboration and business opportunities.	All participants
12.00 – 12.30	Follow-up action	All participants
12.30 – 12.45	Closure	IWMI

Source: Ofosu and Minh 2021.