FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Feed the Future Innovation Lab for SMALL SCALE IRRIGATION

LEGACY REPORT 2013–2023

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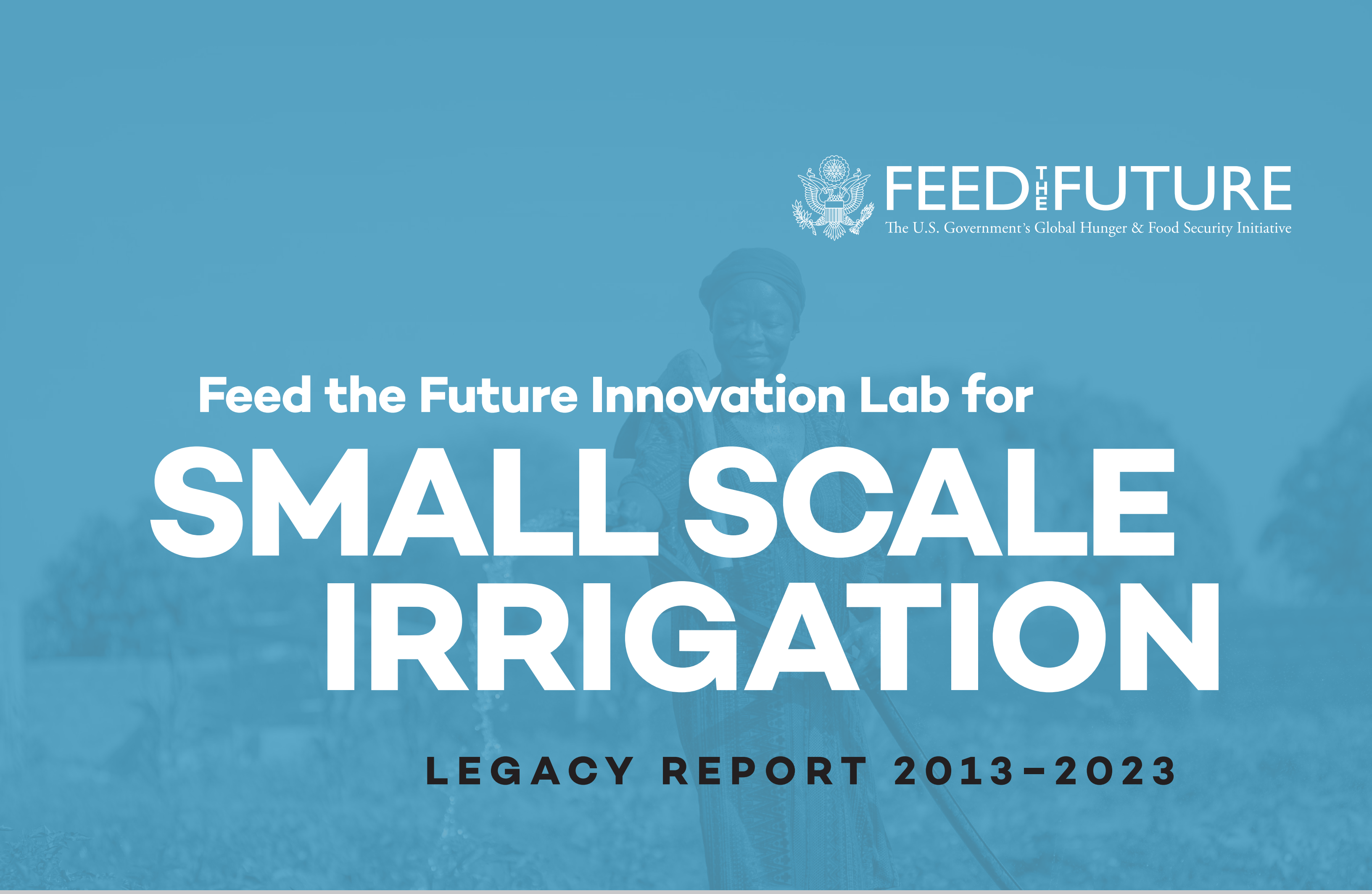

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World Vegetable Center

The Feed the Future Innovation Laboratory for Small Scale Irrigation (ILSSI) is a cooperative agreement between the United States Agency for International Development (USAID) and Texas A&M University (TAMU) AgriLife Research with a consortium of international and national partners. The geographic focus from 2013 to 2023 was Ethiopia, Ghana, Tanzania, Mali, and the West Africa Region.

Executive Summary

Small-scale irrigation (SSI) is expanding with farmers' own investments, often outpacing public investments in irrigation infrastructure across much of the Global South, especially sub-Saharan Africa. However, SSI often develops outside public systems and policies, posing institutional, environmental, and socio-economic issues and potential risks.

Market systems approaches to scale SSI can be effective; farmers are already investing in equipment supplied through the market, and companies are expanding distribution. Targeted interventions are needed to mitigate trade-offs.

ILSSI aimed to contribute to expanding inclusive access to SSI to reach potential benefits for improved nutrition and income and broader agriculture-led economic growth.

More specifically, ILSSI sought to: 1) Strengthen information, tools, and policy and programmatic approaches to support environmentally and economically sustainable scaling of small-scale irrigation while simultaneously reducing and mitigating risks; 2) Generate evidence on trade-offs of SSI technologies and related practices and approaches on the context of climate variability that can inform development investment and planning for resilience; 3) Identify approaches that improve inclusive access for women, men and youth to technology and practice to increase productivity, particularly in irrigated agriculture; 4) Generate knowledge and strengthen capacity to support resilience and gender and nutrition-sensitive policies, planning and programming.

ILSSI research results advanced knowledge on farmer-led, small-scale irrigation (SSI). Research showed that **investments in SSI could substantially contribute to agricultural growth, human well-being, and poverty reduction for millions of smallholder farmers in project countries.** In addition, ILSSI research documented multiple pathways between SSI and improved nutrition, especially for women and children, and potential contributions to women's empowerment. While evidence indicated the potential benefits of SSI investments for rural producers, research also focused on how to support sustainability. The project identified and mapped suitable areas in project countries to sustainably expand SSI with a reduced negative impact on water resource availability under different climate scenarios and to scale field-level practices that can strengthen water productivity. At the same time, the project evaluated market-system approaches to equitably expand access to SSI technologies through local partnerships, including with the private sector. Research was directed primarily at high-value and nutrition-dense crops.

ILSSI supported research, private sector, and public sector engagement processes to generate capacity to innovate, share information, and develop inclusive, market-based approaches to catalyze investment in irrigation.

ILSSI delivered policy and project design guidance to equitably and sustainably increase SSI adoption through bundling socio-technical solutions, such as suitable technologies (e.g., solar-powered pumps, soil-moisture tools, conservation agriculture practices) and scaling innovations (e.g., suitability mapping, business models, finance, tax reforms). The project also produced guidance and provided capacity development. **ILSSI supported research, private sector, and public sector engagement processes to generate capacity to innovate, share information, and develop inclusive, market-based approaches to catalyze investment in irrigation.** Project partners and stakeholders also reflected on knowledge gaps at the time of project closure. The deep engagement and strong partnerships over ten years provided a solid foundation for future work and continued positive outcomes.

Introduction

The Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI) is a USAID cooperative agreement led by the Norman Borlaug Institute for International Agriculture and Development (BIIAD) at Texas A & M University (TAMU) AgriLife Research.

ILSSI sought to contribute to an increase of profitable, sustainable, and gender-sensitive irrigation to support inclusive agricultural growth, resilient food systems, and nutrition and health outcomes, particularly for vulnerable populations in Ethiopia, Tanzania, Ghana, and Mali, as well as other countries in the West Africa region, such as Nigeria. A research consortium conducted collaborative, inter-disciplinary, and multi-method research, and implemented capacity development and stakeholder engagement activities from 2013 to 2023. The project consortium included International Water Management Institute (IWMI), International Livestock Research Institute (ILRI), and International Food Policy Research Institute (IFPRI), and World Vegetable Center, and North Carolina A&T State University (NCA&T).

Small-scale irrigation offers substantial potential to vastly increase access to irrigation for smallholder farmers.

Small-scale irrigation (SSI) is expanding with farmers' investments and outpacing public investments in irrigation infrastructure and schemes across much of the Global South, especially in sub-Saharan Africa. Sometimes referred to as dispersed, individual, self-supply, or farmer-led, small-scale irrigation offers substantial potential to vastly increase access to irrigation for smallholder farmers. Moreover, market systems approaches to support SSI can be effective because farmers are already investing in equipment supplied through the market, while companies are expanding their distribution networks in Global South countries to meet demand. **In addition, SSI offers an opportunity for more flexible and context-specific climate adaptation**. However, the dispersed nature of SSI means the practices and technologies sit outside of public systems and policies, which presents challenges to planning, monitoring, and regulation. The expansion of SSI presents institutional, environmental, and socio-economic issues and risks, such as worsening water depletion and quality and increasing social inequity. Research-based evidence provided through the ILSSI project points to the risks, interventions to mitigate negative impacts, and opportunities to decrease poverty associated with scaling small-scale irrigation.

Contributing to the Feed the Future goals of reducing global poverty and hunger.

ILSSI research results and activities contributed to advance progress toward the Global Food Security Strategy objectives of inclusive agricultural-led economic growth, improved nutrition and health, and improved resilience in sub-Saharan Africa (SSA).

OBJECTIVES:

1. Strengthen information, tools, and policy and programmatic approaches to support environmentally and economically sustainable scaling of small-scale irrigation while simultaneously reducing and mitigating risks.

2. Generate evidence on trade-offs of small-scale irrigation technologies and related practices and approaches in the context of climate variability that can inform development investment and planning for resilience.

3. Identify approaches that improve inclusive access for women, men, and youth to technology and practice to increase productivity, particularly in irrigated agriculture.

4. Generate knowledge and strengthen capacity to support resilience and gender and nutrition-sensitive policies, planning, and programming.

5. Contribute to reducing gender inequality and empowerment of women as essential food producers and market actors.

Evidence on benefits of small-scale irrigation and promising approaches to sustainably reach scale

Through multi-disciplinary research, ILSSI assessed environmentally and socio-economically context-specific potential and approaches to support SSI investments and equitable outcomes. The research results informed investments, policy decisions, community and market-system engagement, and scientific discourse at multiple scales. (See Annex for Publications).

See additional information in the full report

Small-scale irrigation potential for increased income, economic growth, and market opportunities

Previous studies have shown that SSI reaches more smallholder farmers than publicly funded infrastructure schemes, though it tends not to be counted in official statistics on irrigated area. The potential for profitable irrigation development through smallholder technologies is estimated to be significant in SSA (Xie et al., 2014; Worqlul et al., 2017; Worqlul et al., 2019; Xie et al., 2021; Haile et al., 2022). Analysis indicated the extent to which SSI could be adopted profitably in the project countries (Table 1).

TABLE 1: POTENTIAL FOR SMALL-SCALE IRRIGATION DEVELOPMENT

COUNTRY	Area (hectares)	Number of smallholder farmers	Net profit (direct) to producers annually	High potential areas
Ethiopia	1,000,000	5,874,000	USD $2.6 billion	Lake Tana; Ethiopian Great Rift Valley; Amhara, Oromia, Southern Nations, Nationalities, and Peoples' Region
Ghana	115,000	690,000	USD $285 million	Northern Region
Tanzania	750,000	3,000,000	USD $781 million	Across country

As suggested by the potential net profit to producers, increasing small-scale irrigation leads to higher incomes for smallholder farmers and others along the value chain. Farmers, entrepreneurs, and businesses are already leading the way by expanding supplemental and dry-season irrigation in response to insufficient public sector investment in irrigation, climate variability, and growing market demand for vegetables, fruits, and high-value commodities. Increased commercialization of irrigated production creates market opportunities throughout irrigated value chains. However, numerous constraints continue to slow the rate of SSI development (Nakawuka et al., 2017). Moreover, evidence suggests that wealthier farmers are more likely to invest in and benefit from small-scale irrigation (Kafle et al., 2021).

Therefore, ILSSI focused research on scaling interventions to achieve equitable access to equipment and information particularly for resource poor smallholder farmers.

ILSSI research indicated that SSI increases returns to land and labor and reduces risk for smallholder producers, produce buyers, and processors (Balana et al., 2020). Farmers obtain profit across multiple types of small irrigation equipment, particularly pumps (Bizimana and Richardson, 2019). Small-scale irrigators improve the stability and quality of produce and increase profits from farming enterprises. The potential and extent of profit varies depending on crop type, type of water delivery system, and cultivated area. Case study comparisons illustrated that differing combinations of SSI technology and crops result in different profit profiles (Balana and Akudugu, 2022). For example, in Ghana, analysis showed that smallholder adoption of mechanized pumps could increase the net farm profit by 154%–608% (Balana et al., 2020). In Ethiopia, returns from solar-powered irrigation of vegetables enable profit, especially when combined with drip irrigation to reduce labor costs and increase productive land area; farmers could pay back loans taken at 15% interest within two years (Otoo et al., 2018).

Farmers express strong demand for irrigation equipment, including motorized or solar pumps and other agricultural water management tools. However, multiple factors affect farm households' revenue from irrigation and their decisions to invest their resources in irrigation inputs. Labor often makes up a major part of total production costs, and the lack of labor is a major constraint to the expansion of SSI, especially for women farmers (Bryan and Garner, 2022). Labor-saving technologies for lifting, applying, and managing water for irrigation and multiple uses can incentivize investment. Importantly, **labor-saving equipment and practices can enable smallholders to expand area under irrigation in the dry season, especially vegetables that are nutrition-dense crops.**

In addition, increasing seed and other input availability for irrigated crops such as vegetables and fodder is essential to farmer investment decisions. Research showed that irrigation can help to stabilize seed supply, which is often unreliable in SSA, especially during crises or in areas prone to conflict. Analysis conducted by the World Vegetable Center indicated that regulatory reforms in Mali would be needed to increase local vegetable seed production, including under irrigation, creating business opportunities for local seed producers, and improving smallholder access to seed (Dembele et al., 2021; Kuhlmann et al., 2023). Likewise, research and capacity development partnerships with dairy and fodder cooperatives in Ethiopia demonstrated that irrigation helps address significant gaps in fodder seed; increased seed supply through irrigation encouraged hundreds of farmers to invest their resources into irrigated fodder production.

Market and public interventions around complementary inputs are all entry points to catalyze farmers' own investments in irrigation. In one study, farmers in Ethiopia indicated that they would be more likely to invest their own resources in irrigation if there is external support to develop water sources and reduce uncertainties related to water access, for example, assistance for boreholes (Balasubramanya et al., 2023). The study suggests both the priority farmers place on securing water access and the options to stimulate farmers' investment in irrigation equipment beyond subsidies on pumps or drip kits. As discussed below, research also showed that access to affordable and appropriate financing encourages smallholder farmer investment in irrigation equipment and complementary inputs (Merrey and Lefore, 2018).

At the national and sub-national levels, project partners analyzed policies and institutional ecosystems, technology diffusion networks, equipment market margins, and equipment market enablers (Atuobi-Yoboah et al., 2020). Analysis on marketing margins and market ecosystems indicated that the absence of regulatory measures and national manufacturing or assembly contributes to an oligopolistic market structure for irrigation equipment, e.g., equipment importers tend to be wholesale suppliers and retail distributors with little competition (Hagos et al., undated). In addition, informal transaction costs for importing and distributing are high and act as a disincentive for official distributors. Public interventions to increase technology adoption, including through direct distribution, are not necessarily more successful than market-based efforts. Analysis showed that technology diffusion networks vary by country. However, farmers and producer groups are usually on the outside of the public initiatives intended to increase farmer adoption of irrigation technologies. While highly nuanced by context, the studies point to multiple policy and market interventions that could strengthen smallholder access to equipment and information. **Governments and development partners can help to reduce market concentration and increase price competitiveness through improved importation processes and carefully targeted tax reforms.** For example, ILSSI analysis conducted for Ethiopian agencies showed that equipment tariff exemptions could reduce pump prices to end users if importers pass on savings to farmers (Bizimana et al., 2021).

To better understand the specific market dynamics, ILSSI competitively selected solar pump suppliers to partner with in Ethiopia, Ghana, and Mali. These partnerships helped offset the companies' risks of reaching the bottom-of-the-pyramid market segments while generating market information. Through this initiative, ILSSI supported IWMI in developing solar irrigation suitability maps that enabled companies to target high-potential areas based on water availability, irrigable land potential, and socio-economic factors, such as market infrastructure (Schmitter et al., 2018). IWMI also facilitated linkages between partner companies and thousands of potential farmer clients through market segmentation and demand-supply linkage workshops in areas with high SSI concentration. The project co-created multiple approaches to reach bottom-of-the-pyramid clients, especially women, with solar pump distributors.

PROJECT IMPACT:

Around **6,300** producers, practitioners and value chain actors improved their agricultural management practices or technologies through assistance from the Innovation Lab for Small Scale Irrigation between 2013 and 2023 in Ghana, Ethiopia, Mali, and Tanzania.

See additional information in the full report

Small-scale irrigation contributions to nutrition and resilience

As water security continues to worsen amid climate change, it is increasingly critical to understand the relationships between water security, food security, and nutrition (Young et al., 2022). While numerous studies have explored both positive and negative effects of agriculture on nutrition and health, ILSSI partners examined the potential of SSI as a nutrition-sensitive investment (Bizimana et al., 2020). Through this work, more development partners are recognizing the interconnections and beginning to intentionally design irrigation investments for nutritional and health outcomes.

With ILSSI support, IFPRI research showed that SSI possesses high potential for improving nutrition and resilience. Studies described several pathways through which irrigation can influence food security, nutrition, and health outcomes, including 1) a production pathway, 2) an income pathway, 3) a water supply pathway, and 4) a women's empowerment pathway (Domènech, 2015). A fifth negative pathway links irrigation to water pollution and disease via the application of fertilizers and pesticides and hosting vector-borne diseases, such as malaria or schistosomiasis, respectively (Passarelli et al., 2018).

ILSSI studies further documented the SSI to nutrition relationships in Ethiopia, Ghana, Tanzania, and Mali. Results from a study on Mali showed that crop income and diversification, market participation, employment, and dietary quality were substantially higher in irrigated farms compared to non-irrigated farms. Likewise, irrigating households had higher food security and higher dietary diversity (Nkonya et al., 2022). **The results show that irrigation is a key entry point for combatting climate variability and change and that small-scale irrigation investments have the potential to benefit women farmers directly.**

Analysis also showed that high seasonal variation in women's diets in Ethiopia can be partly offset by irrigation practices that buffer their seasonal dietary gaps for women (Baye et al., 2021). The study also revealed that compared to non-irrigators, women in irrigating households consume higher vitamin C and calcium during the irrigation season, which helps address important micronutrient deficiencies. In Ethiopia, children in irrigating households have better weight-for-height (WHZ) scores—0.87 standard deviations higher weight-for-height (WHZ) than children in non-irrigating households (Mekonnen et al., 2022).

The results also suggested high potential for SSI to improve resilience to shocks. Water and food insecurity often occur simultaneously, worsening hunger where farmers rely on rainfed production and cannot access irrigation. Droughts cause backsliding from development gains and push people deeper into poverty. However, data suggests SSI is a crucial investment to strengthen resilience to drought. In Ethiopia, researchers showed that among households who reported experience with drought, women in irrigating households had higher dietary diversity scores than women in non-irrigating households (ibid). Analysis further provided evidence of reduced wasting of children in irrigating households in Ethiopia, notably among children who live in households that experienced drought. In Tanzania, irrigating households had higher women's dietary diversity score (WDDS) compared to non-irrigators; the impact of irrigation on WDDS more than doubled among households facing drought. Likewise, among households in Tanzania who reported having faced a drought shock, irrigating households had higher household dietary diversity (HDDS) than non-irrigators. Across multiple studies, ILSSI research results demonstrated that irrigation contributes to climate adaptation and resilience and smoothens nutritional status even during extreme weather shocks.

At the same time, research showed that irrigators are more likely to have sufficient water available for domestic use.

However, the source of water is a key determinant for a household's hygiene. Groundwater is an overall better-quality source for domestic purposes than surface water, though many households use untreated surface water irrigation sources for domestic tasks. Notably, research confirmed that hygiene practices are independent from the water source and do not change merely by introducing new water access points for agriculture. Behavioral change communication needs to be integrated into projects, including irrigation projects that target improved nutrition, to align the development of water sources with health and nutrition goals. Importantly, ILSSI research shows that farmer investments in SSI will require complementary initiatives for public messaging on hygiene and health. Moreover, intentional design of irrigation to support WASH outcomes, such as through multiple-use services, could strengthen the linkages between irrigation investments and improved nutrition (Jepson et al., 2023).

Evidence suggests SSI improves agricultural production, household income, and nutrition, but caution is also needed as irrigated production intensifies. Any form of irrigation is usually accompanied by increased use of agricultural inputs (e.g., fertilizer, pesticides). Stakeholders across countries and regions expressed growing concern that the use of such inputs may cause freshwater pollution, particularly given household reliance on irrigation water sources and shallow groundwater for domestic uses and drinking. Case studies investigated phosphorous and nitrate loads in groundwater and surface water in highland watershed in the Lake Tana Basin (Moges, et al., 2018; Sishu et al., 2021; Sishu et al., 2023). A model-based assessment showed a gentle irrigation-induced risk of nutrient water pollution in four woredas in Ethiopia (Xie et al., 2023). In addition, IDSS analysis showed that SSI in the dry season may affect phosphorus and nitrogen loading through crop consumption; total nitrogen loading may increase if additional fertilizer is used for dry season crops or through fixation of nitrogen, such as irrigated legumes. Together, analysis results showed that an expansion of SSI in Ethiopia may create hotspots with elevated water nutrient pollution risk. As such, irrigation development in Ethiopia and across SSA is likely to have a negative impact on water quality with implications for public health. As nutrient loading is highly varied spatially, broad and urgent efforts are needed to monitor water quality and, where needed, safeguard public health.

PROJECT IMPACT:

IFPRI's work supported by ILSSI on irrigation-nutrition linkages contributed to the evidence-base for a jointly produced IFPRI and World Bank guidance: Nutrition-Sensitive Irrigation and Water Management.

The document provides evidence and guidance on project design and results framework indicators for nutrition-sensitive irrigation and water management investments. It is intended for use by the World Bank to improve the nutritional outcomes of irrigation investments.

See additional information in the full report

Solar-powered irrigation and market system development

Many farmers currently use diesel or petrol pumps for water lifting. However, difficulty getting fuel, increasing and high fluctuating costs of fuel, and high maintenance costs for petrol and diesel pumps are inspiring interest in solar pumps. Shifting towards solar could also help reduce reliance on fossil fuel for irrigated agriculture, partially decoupling energy and food prices and modestly reducing fossil fuel emissions. Given the high potential benefits, ILSSI supported context-specific assessments on technology suitability, energy-related trade-offs, financial feasibility, supply chains, business models, finance ecosystems, and potential for inclusivity. In addition, as solar pumps are becoming less expensive and more available in frontier markets, ILSSI worked with private partners to identify factors that influence market viability.

Given the high interest and anticipated benefits, ILSSI studies identified the most suitable and viable areas within countries for solar irrigation development, including under different climate scenarios. IWMI analyzed solar irradiation, topography, groundwater and surface water availability across seasons, crop selection, land use types, and market-related factors such as road infrastructure and distance or time to markets. The results were encouraging. The suitability assessment for all SSA indicated approximately 120 million hectares (Mha) of potentially suitable land for solar-based irrigation using both groundwater and surface water: East African countries account for 46 Mha, while Southern African countries have the smallest portion, with only 15 Mha. Middle and Western African countries have 34 Mha and 25 Mha solar suitable potential areas, respectively. In Ethiopia, research identified solar-powered irrigation suitability on 9% of currently irrigated land and 18% (approx. 6.6 million hectares) of presently rainfed land (Otoo et al., 2018; Schmitter et al., 2018). While solar pumps may not be suitable in all locations in Ethiopia, solar pumps could provide an alternative water-lifting option to fossil fuel pumps for smallholder farmers in 1.2 million ha when well depths are up to 7 meters and in 3.9 million ha when well depths are up to 25 meters. The area could expand with improved access to surface water sources. In Mali, analysis showed that 4.4 million hectares of land is suitable for solar-powered irrigation (IWMI, 2019). Finally, analysis showed that around 2.3 million hectares of land in Ghana is suitable for solar-powered irrigation (Gebrezgabher et al., 2021). **For solar pump distributors, farmers, and public institutions, information generated on solar irrigation suitability under future scenarios is critical for medium-term agricultural development plans.**

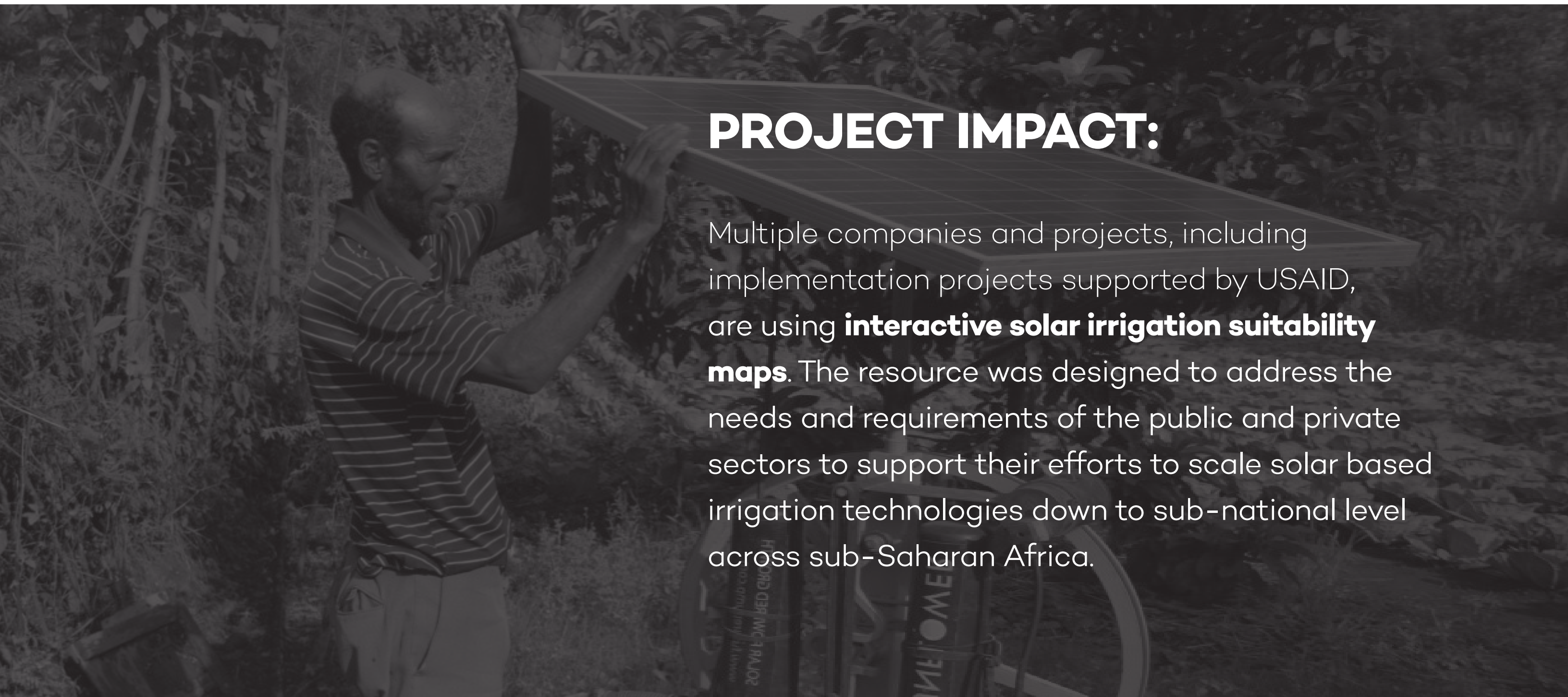
Biophysical suitability aside, cost is a factor in determining smallholder access to solar pumps compared to other types of pumps. In particular, energy cost is important to identify the type of technology suitable for smallholders and, therefore, for a company or development agency to promote. ILSSI conducted multiple assessments that compared costs and returns to solar irrigation at different scales. An IFPRI study partially supported by ILSSI compared the life-cycle costs of groundwater pumping for solar and diesel in SSA (Xie et al., 2021). **The analysis showed that solar energy often provides a more cost-effective energy source for groundwater irrigation.** Diesel fuel constituted the principal cost component of diesel irrigation, accounting for 70%–90% of the life-cycle cost of the whole system, except for a few countries with low diesel fuel prices, mainly where subsidized. In addition, the analysis showed specific areas in SSA where solar power can be more economical than fossil fuel for pumping, such as in West Africa (e.g., Senegal, Guinea, Mali, Burkina Faso, Niger, northern Côte d'Ivoire, and northern Ghana), East Africa (especially South

Sudan, Eritrea, Somalia, and Tanzania) and several countries in southern Africa (Xie et al., 2021). More specifically, assessments indicated solar irrigation is financially feasible in substantial areas in Mali and Ghana using groundwater (Xie and Ringler, 2023a; Xie and Ringler, 2023b). An additional case study in Ethiopia showed that solar-powered irrigation profitability was enhanced when paired with drip irrigation in vegetable production, particularly because the combination of technologies reduced labor requirements and costs, and vegetables garnered higher prices than other crops (Otoo et al., 2018).

Overall, evidence suggests high biophysical and financial feasibility of solar pumps, but smallholders need finance and credit options to address the high capital cost of solar pumps.

In addition to generating information on the potential scope for and co-benefits from solar-powered irrigation, ILSSI partners explored market-based scaling of solar pumps. ILSSI formed several research-private sector partnerships in Ethiopia, Ghana, and Mali to examine the constraints and potential solar pump distribution business models. While most studies indicated promise for profitable, smallholder irrigation with solar pumps, analysis was conducted on the factors that may enable or block scaling (Minh et al., 2021). **Results showed that agricultural producers' access to solar pumps is often hampered by high initial capital costs and distributors' insufficient understanding of local markets and poorly developed supply chains.** Research further outlined the marketing margins for irrigation equipment in Ethiopia and Ghana (Schmitter et al., 2022; Minh et al., 2023). The research identified nuances in market-based approaches to scale solar pump access across countries and, therefore, different options for socio-technical bundles most suitable to specific institutional, policy, and regulatory ecosystem.

Context affects the suitability of business models and, therefore, a company's effectiveness in expanding solar pump distribution. Researchers looked at several business models, including a cost-sharing model, a solar-powered irrigation service provider model, and an individual ownership model that included ways to use solar pumps for non-irrigation purposes. **Studies showed that multiple business models were viable, which would benefit companies and multiple market segments.** ILSSI helped to strengthen business models for distributing solar pumps through the co-development of information on the institutional and regulatory

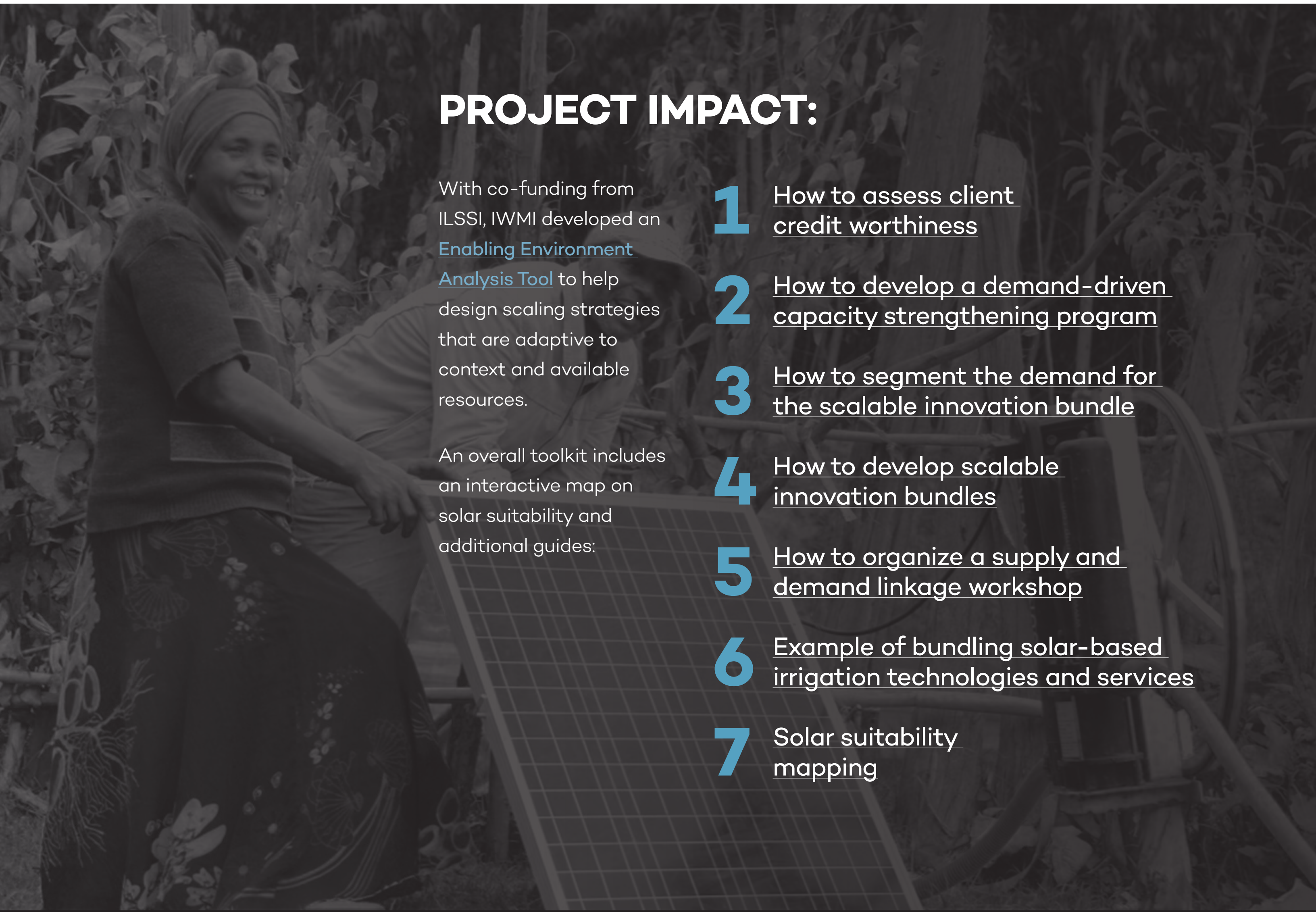


PROJECT IMPACT:

Multiple companies and projects, including implementation projects supported by USAID, are using **interactive solar irrigation suitability maps**. The resource was designed to address the needs and requirements of the public and private sectors to support their efforts to scale solar based irrigation technologies down to sub-national level across sub-Saharan Africa.

landscape, environmental suitability, social barriers that affect demand, and the finance ecosystem. In addition, ILSSI research partners provided technical backstopping to strengthen company capacity by providing information on land suitability and water availability, supporting market segmentation analysis, and jointly testing different modalities for distribution and finance. Researchers worked with companies and identified solar pump market segments among farmers based on varied water needs, pump preferences, access to land, and ability to pay. By helping companies identify and better understand potential customers, companies expanded distribution networks into new areas to meet demand. **Research results showed that because farmers have different irrigation needs and purchasing capacities, and the institutional context and financial system differ, there is no one-size-fits-all business model or financing instrument across countries.**

ILSSI research and stakeholder engagement also revealed that financing mechanisms must be accessible across the irrigation market chain: farmers, manufacturers, distributors, financing organizations, irrigation service providers, and other support services in the market ecosystem all need access to finance. ILSSI research partners worked with private pump distributors to refine "last mile" finance solutions for farmers. Many solar pump companies recognize that farmers cannot obtain loans from finance institutions in often weak finance ecosystems in frontier markets, so they offer a range of consumer credit mechanisms.



PROJECT IMPACT:

With co-funding from ILSSI, IWMI developed an Enabling Environment Analysis Tool to help design scaling strategies that are adaptive to context and available resources.

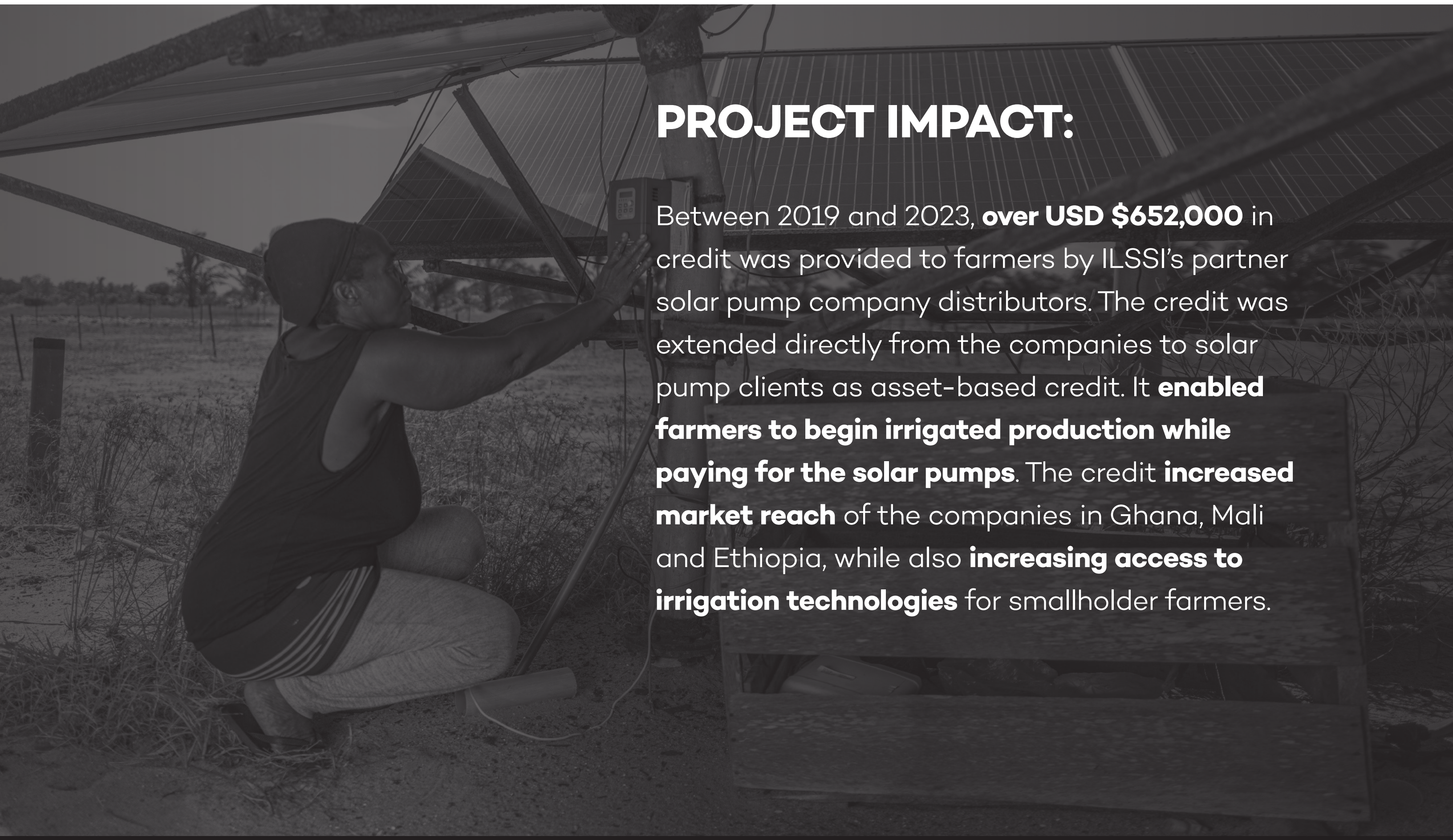
An overall toolkit includes an interactive map on solar suitability and additional guides:

1. How to assess client credit worthiness
2. How to develop a demand-driven capacity strengthening program
3. How to segment the demand for the scalable innovation bundle
4. How to develop scalable innovation bundles
5. How to organize a supply and demand linkage workshop
6. Example of bundling solar-based irrigation technologies and services
7. Solar suitability mapping

Together with the companies, ILSSI researchers helped to identify the highest potential forms of non-collateral, asset-based finance for farmers, such as more inclusive pay-as-you-go financing instruments.

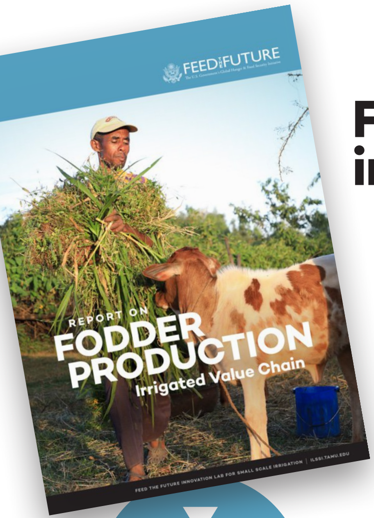
Research also highlighted that solar pump companies that provide consumer-based finance may have to limit sales based on PAYGO or credit due to a lack of company finance. While addressing company finance was largely outside the scope of ILSSI, the project contributed to the dialogue on climate funds and carbon credits for solar pump manufacturers and distributors that could be used to reduce retail prices for smallholders. ILSSI also supported research to document and evaluate irrigation service provision as a business model (Minh et al., 2022).

Again, ILSSI research indicated that large areas of irrigable land in SSA are suitable for solar irrigation and that solar irrigation is financially feasible. Solar-powered irrigation is a promising piece of climate adaptation and mitigation. Evidence showed the effectiveness of various business models distribution and asset-based finance for clients, including reaching the bottom-of-the-pyramid market segments. **While investments are needed to strengthen the irrigation equipment market, investments are equally important to expand knowledge and learning partnerships.** Governments, public agencies, private companies, farmer cooperatives, and research organizations need to participate in the co-design of context-specific, suitable socio-technical bundles of solar pumps combined with other tools and inputs. However, solar pump expansion may pose risks to water scarcity, as with any form of irrigation. Robust information on water quality, quantity, demand, and changing production and socio-economic factors are critical to ensure smallholder climate resilience and avoid maladaptation as solar irrigation grows across SSA.



PROJECT IMPACT:

Between 2019 and 2023, **over USD $652,000** in credit was provided to farmers by ILSSI's partner solar pump company distributors. The credit was extended directly from the companies to solar pump clients as asset-based credit. It **enabled farmers to begin irrigated production while paying for the solar pumps**. The credit **increased market reach** of the companies in Ghana, Mali and Ethiopia, while also **increasing access to irrigation technologies** for smallholder farmers.

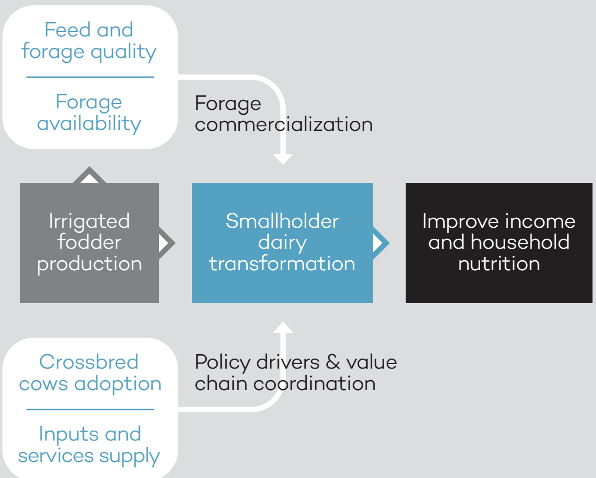


See additional information in the full report

Fodder production as a promising irrigated value chain

Livestock contributes to socio-economic and nutritional well-being in many countries in SSA, but low productivity limits sectoral growth. A key constraint is the lack of reliable and quality feed, particularly during dry seasons and droughts. Currently, climate change is negatively impacting fodder and dairy value chain actors. Unreliable rainfall causes feed shortages, drives input costs up, and reduces milk supply by about half. Extreme weather events push many small enterprises out of business. Primary dairy suppliers — often women — lose out the most. Moreover, smallholder households reduce dairy consumption, worsening nutrition, especially for women and children. For these reasons, ILSSI selected fodder as an irrigated value chain case study. **The research considered the potential for irrigated fodder to fill the feed gaps, increase productivity for animal-source foods, and improve smallholder climate adaptation.**

FEED AND DAIRY TECHNOLOGY DRIVERS CAN SHAPE AND INFLUENCE TRANSFORMATION OF THE SECTOR.



Source: ILRI Discussion Paper — Economic analysis and trade-offs of irrigated fodder production in Ethiopia: Implications for smallholder dairy transformation

Initial studies on markets for fodder in Tanzania, Ghana, and Ethiopia pointed to Ethiopia as having the highest potential for irrigated fodder development. In-depth market studies in Ethiopia showed growing demand for reliable, good-quality animal feed (Abera et al., 2022). The analysis also showed a range of benefits: irrigated fodder production is profitable, lends to improved nutrition for livestock and households, and offers business opportunities in the value chain. Fodder produced under irrigation improved dairy productivity, particularly when other constraints were addressed. Regarding scaling potential, analysis revealed that significant areas of Ethiopia are suitable for producing fodder, including under irrigation (Worqlul et al., 2021). **Multiple studies showed that water resources can be used sustainably for fodder production to ease major livestock production constraints.**

Ex-ante analysis of economic gains from plot-level experiments on 100 m2 irrigated land showed that productivity gains from oat-vetch mixture could reach as high as 184 kg of milk or 30 kg of meat, assuming maintenance requirements are met from other local feed resources. The productivity gains from Desho and Napier grasses during the first season of establishment were lower than the oat-vetch mixture but gained in subsequent years as they reached their maximum biomass yield potentials.

On-farm feeding trials with local and cross-bred lactating cows showed that daily supplementation of 2kg of oat-vetch mixture hay increases milk yield by 50% and 70%, respectively. Moreover, oat-vetch mixture hay as a replacement for commercial concentrates in the diet of fattening sheep indicated that oat-vetch mixture hay can effectively replace costly commercial concentrate needs by about 67% while providing optimal body weight gain of 110 g/day/head and increasing the income of farmers.

ILRI assessed numerous fodder varieties (Worku et al., 2021). In particular, ILRI analyzed ten forage genotypes to identify the forage varieties that perform well under minimal irrigation and nutrient input. Napier grass 16791 had the highest dry matter yield (DMY) (9.82 ton ha-1), water use efficiency (WUE) (39 Kg ha-1), livestock water productivity (0.28, 1.32 USD m-3) and net revenue (852 USD ha-1) at full irrigation. However, other Napier grass varieties performed acceptably under irrigation deficit providing options for water scarce areas. Selected varieties are in the national registration process.

Generally, evidence showed that irrigated fodder promotes increased resilience to climate variability, smoothing access to nutritionally important animal source foods (Bizimana et al., 2023).

More broadly, research demonstrates the economic and nutritional benefits of irrigating fodder for the green fodder market, especially the dairy sector. **Smallholders that produce fodder under irrigation gain net profits and improve their household nutrition. Linking the fodder and dairy value chains allows multiple actors to benefit.**

Given this growing body of evidence, ILSSI supported research partnerships between ILRI and fodder and dairy cooperatives to understand further how to strengthen the market system and the capacity to expand fodder markets in "milk sheds" in Ethiopia. While smallholder dairy farms are the backbone of the dairy sector, multiple studies have indicated that they require a regular fodder supply to become efficient in dairy production. ILSSI sought to understand if small-scale irrigation investments could be viable enterprises for both fodder producers and dairy and meat producers.

PROJECT IMPACT:

The number of farmers growing forages under irrigation in the Robit-Bata kebele **grew from only 17 farmers in 2015 to 1,060 in 2023**. The number of irrigated forage producers is higher when other areas outside the kebele are included. More farmers were reached on irrigated fodder opportunities and practices through field days and experience sharing events, as well as farmer-to-farmer technology sharing. As evidence of the high interest from farmers, the plot area assigned to irrigated forages by individual farmers **grew from 100m2 to 1000m2** on average over the life of the project.

Farmers and government agencies in the Amhara Region continued to scale irrigated fodder production to more communities. Some farmers began to remove khat and plant forages, stating that changing from khat to forages eliminated the use of pesticides and reduced water use for irrigation.

Field studies in the Bahir Dar "milk shed" indicated that irrigated green fodder can be commercialized profitably. Production for own dairy cows can also increase income for smallholder dairy farmers (ibid). For example, in a comparative study, irrigated fodder had higher annual net returns (USD 482; 2021) than irrigated vegetable farming (USD 296; 2021) but lower than khat (USD 564; 2021) on one hectare of production. However, given the lower pesticide and labor requirements and the concerns over negative socio-cultural and health impacts, many farmers are converting farms from khat to fodder.

While fodder producers and dairy smallholder farmers point to constraints, such as poor feed storage and bulkiness of feed, problems in the dairy markets, and insufficient extension support, more and more farmers are making investments in water lifting equipment, land, and fodder seed to produce fodder.

PROJECT IMPACT:

ILSSI partnered with dairy cooperatives and **strengthened their capacity to drive fodder commercialization and increase dairy production**. The support **enhanced the ability to collect, process and market fluid milk, and pulled more producers into fodder development**. Cooperatives diversified into forage seeds and other farm inputs, in addition to dairy. In addition, cooperatives significantly boosted organizational capacity. **Membership and daily milk supply to the local market both doubled**. They now supply commercial market off-takers — a first in their operations.

As a reflection of the success, the Government of Ethiopia adopted the dairy cooperative at Robit Bata as a **model and learning center** on the development of fodder and dairy value chains. In addition, ILRI established a **forage technology park** at Bahir Dar University for learning and research for students and faculty and to serve as a source of seeds and planting materials.

See additional information in the full report

Gender inclusive small-scale irrigation and water governance

Improving smallholder women farmers' participation in small-scale irrigation enhances the resilience of households, enables climate adaptation, and bolsters nutrition and health. Indeed, focusing resources on women and girls will be important for easing food crises (Bryan et al., 2022). However, most projects and actors aiming to increase irrigation fail to take a gender- and youth-sensitive approach, thus increasing the access gap. Reaching women and enabling equitable participation requires additional interventions. ILSSI elevated gender as a central theme of all research and engagement activities (c.f. Theis et al., 2016 and 2017).

Women's level of empowerment depends on the context within which they live, the resources they have access to, and their ability to make strategic life choices resulting in well-being improvements — factors that change throughout women's lives. Indeed, research showed that women's empowerment is one of the four main pathways that link small-scale irrigation to improved nutrition for entire households (Bryan et al., 2019). ILSSI research in Ethiopia indicated that empowerment may lead to more household resources allocated to nutritious foods and healthcare. **When women are able to make decisions about irrigation technology, irrigated produce, and proceeds, or when women no longer have to spend time collecting water, then SSI can be a route to women's empowerment.** However, research in Ghana showed that giving women motorized pumps did not increase empowerment (Bryan, 2023). Rather, the study found that benefits of a motor pump intervention for women were indirect, including increasing household asset holdings. Along with other research, this indicated that more careful planning and implementation of irrigation interventions are needed to facilitate women's empowerment.

Introducing small-scale irrigation can bring opportunities for empowerment but also exclusion. Despite the rapid expansion of farmer-led SSI, most irrigation pumps are being acquired by relatively wealthy male farmers, exacerbating already high levels of inequality in rural communities (Lefore et al., 2019). **ILSSI research also showed that policies and programs must go beyond technology supply alone to ensure benefits to women farmers and women in smallholder households.** Women and men have different priorities and preferences regarding irrigation equipment, practices, and crops. In addition, women face specific barriers compared to men, such as more limited access to information, finance, fewer assets, and gender norms (Bryan and Garner, 2022). Furthermore, even with efforts to support women in obtaining equipment, men might well take over the use or benefits (Theis et al., 2018a).

Contexts vary, but all too often, the opportunity structure is stacked against women, and interventions fail to address the fundamental social, economic, and political inequities characterizing most rural societies. Despite this structural reality, women do benefit by directly participating in irrigation or more indirectly. In many rural areas where men migrate for labor, women are gaining more access to land and water resources and are better able to make decisions and participate in community decision-making.

With SSI situated outside of official public programs, companies, and organizations must design market or public interventions to reach women through their preferred information sources, offering technologies suitable for multiple purposes, providing relevant financial tools and credit products, and facilitating market linkages. In addition, intra-household cooperation can help women turn a profit and benefit from irrigation.

Opportunities for women in irrigated production and value chains can significantly increase the overall number of people adopting and benefitting from small-scale irrigation.

Again, small-scale irrigation can be an entry point for women's empowerment, but only if public agencies, organizations, and companies intentionally target women. Therefore, ILSSI developed tools such as the "Guidance for inclusive irrigation interventions" and open access training videos to help public agencies and development organizations identify the main constraints to inclusion and then design actions to make small-scale irrigation more equitable (Theis et al., 2018b). **Many of the actions to support inclusion in access to SSI technologies and other inputs differ from publicly funded communal irrigation schemes, so ILSSI's knowledge products have been used across SSA as governments and development partners roll out SSI projects.**

Research activities also indicated strong demand from women in project countries to acquire solar pumps for multiple agricultural productive activities, including irrigation and commercial poultry and livestock production. In addition, women often use irrigation pumps for other household needs, such as cooking, washing, and household livestock watering. Women preferred solar pumps that are mobile or installed near the homestead compared to fossil fuel or manual water lifting pumps. However, many pump distributors and sales agents in SSA ignore women producers as a viable market segment. **ILSSI's partnerships with private companies helped to demonstrate to solar pump distributors that women producers form an important target market.**

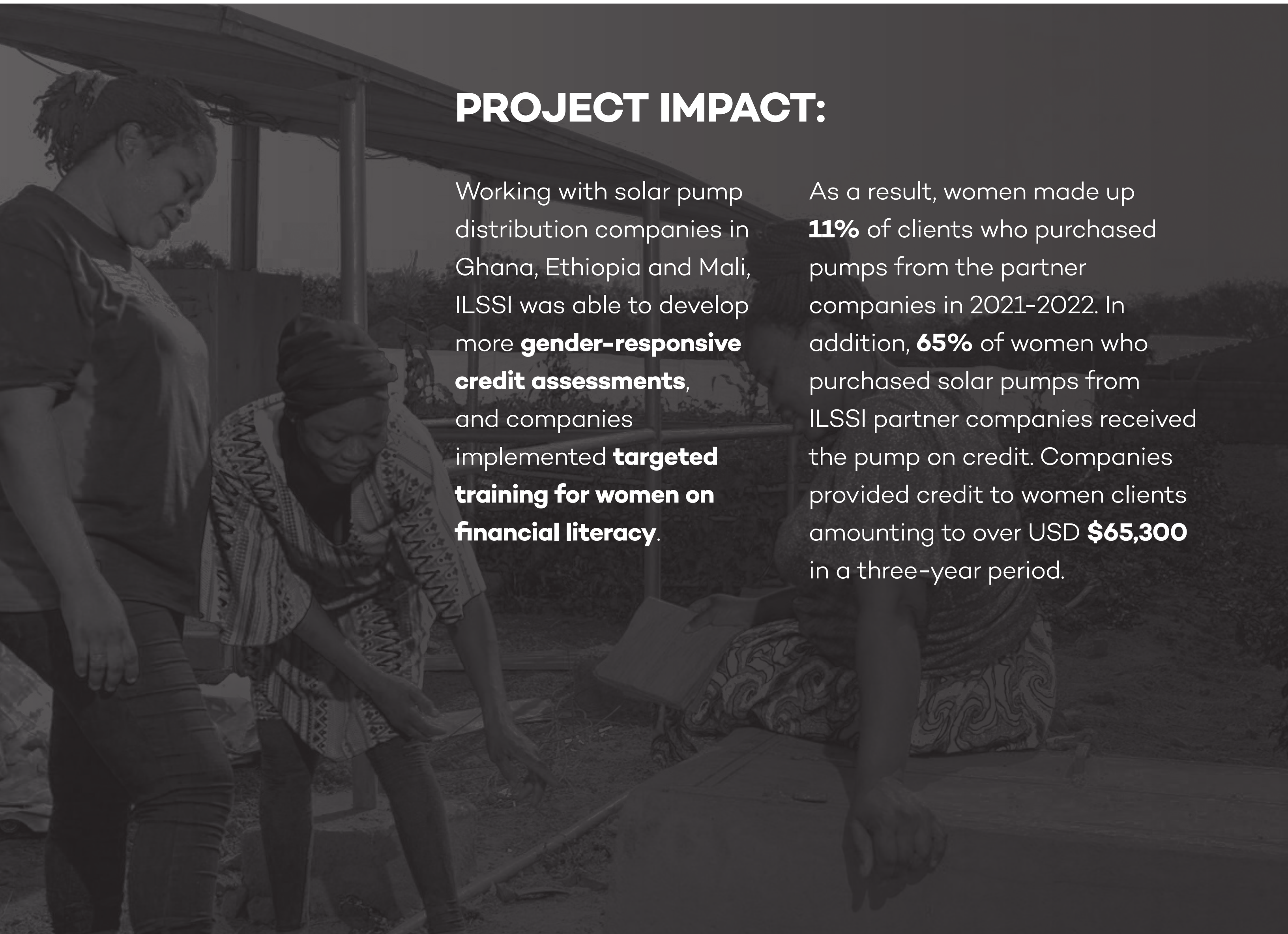
In addition, credit is critical to increase capital investments in agriculture, but access is nearly always insufficient to meet the need. Improving smallholder women farmers' access to finance is central to ensuring participation in irrigated production. Research showed that it is not only a problem of credit availability, though that is important. Smallholder farmers — especially women — are understandably risk-averse: they are reluctant to take on debt that could become a burden if crops fail (Balana et al., 2022). Furthermore, the design of credit products and the criteria used for assessing creditworthiness tend to reinforce gender disparities. Poor smallholders, especially women, cannot meet the required credit checks and, therefore, cannot purchase pumps on credit (Merrey and Lefore, 2018). Nor do they have access to finance to purchase complementary inputs such as fertilizer or seeds.

ILSSI worked with irrigation equipment companies, financial service providers, and produce off-takers to develop a more inclusive credit supply. Solar pump distributors are innovating their own farmer finance models, such as asset-based finance, pay-as-you-go, seasonal repayment, and group loans. ILSSI research partners worked with the companies to prioritize inclusivity. For example, researchers and private-sector solar irrigation equipment suppliers co-developed more inclusive, gender-sensitive credit assessment criteria in Ghana, benefitting both women farmers and equipment suppliers. ILSSI research indicated that carefully designed financial products and credit assessment processes show promise but that there is no single solution.

The challenge is to scale out gender-responsive products and practices in context-specific bundles based on the lessons learned.

ILSSI research identified the benefits of gender-equitable access to irrigation, including women's empowerment, reduced time poverty, improved income, and household nutrition. Research showed that while women's participation in irrigated production and value chains can contribute to the global food security strategy, overcoming constraints requires both public and private sector actors to take intentional, gender-responsive approaches beyond technology adoption. In addition, governance efforts to reduce water scarcity risks must also intentionally include women.

From the household and community levels to the national scale, women's voices need to be heard to build resilient markets that enable access to irrigation and its benefits and to govern water resources equitably and sustainably. For example, where groundwater use for irrigation is expanding in Ethiopia and Ghana, ILSSI researchers ensured that women were provided opportunities to participate and express their voices in experiential learning games to improve water resource governance. For gender inclusion in small-scale irrigation, a key priority should be ensuring that women's voices are heard when decisions are made about using and accessing water resources from household to community to national levels.



PROJECT IMPACT:

Working with solar pump distribution companies in Ghana, Ethiopia and Mali, ILSSI was able to develop more **gender-responsive credit assessments**, and companies implemented **targeted training for women on financial literacy**.

As a result, women made up **11%** of clients who purchased pumps from the partner companies in 2021-2022. In addition, **65%** of women who purchased solar pumps from ILSSI partner companies received the pump on credit. Companies provided credit to women clients amounting to over USD **$65,300** in a three-year period.

See additional information in the full report

Capacity strengthening for sustainable expansion of small-scale irrigation

Human and institutional capacity development was a core mandate of ILSSI. As farmer investment in irrigation increases, public institutions are adapting to the changing approaches to irrigation development, and private sector companies are building broader distribution networks for equipment. Likewise, tertiary education institutes and National Agricultural Research and Extension Services (NARES) are adjusting their programs to meet the growing needs on technologies and information. **With relevant capacity across the food system, local institutions, organizations, and individuals across sectors can contribute to the sustainable expansion of small-scale irrigation.**

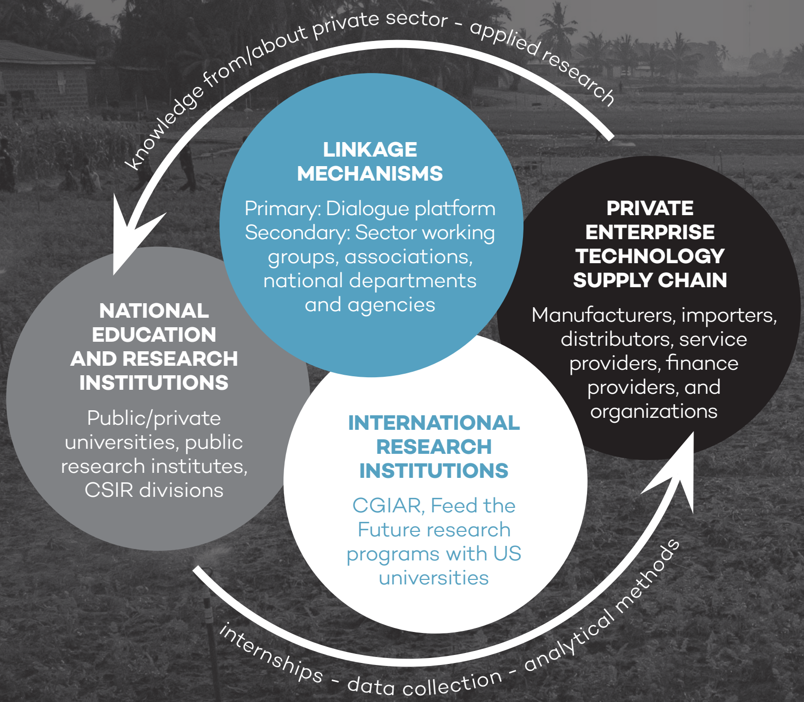
ILSSI developed capacities across the spectrum of key actors, including scientists who generate evidence, decision-makers who use scientific evidence for monitoring, planning, and investing, practitioners and advisory service providers, and producers who apply practices and methods. This included training on the Integrated Decision Support System suite of models: **1295 men and women were trained from basin authorities, irrigation agencies, donors and non-government organizations, companies in the water sector, research institutions, and national universities, in Ethiopia, Ghana, Ivory Coast, Nepal, Rwanda, and Tanzania.** In addition, ILSSI supported 145 students, graduate students and post-doctoral fellows, including graduate students at eight national universities in Ethiopia, Ghana, and Tanzania, and various U.S. and European universities.

As more and more farmers rely on irrigation to adapt to climate change and to meet the growing demand for nutritious foods, capacity for continued innovation is essential.

To sustain innovation and a more resilient market system, ILSSI engaged across sectors and actors to generate trust, share knowledge and information, and build lasting collaboration between private companies, public agencies, and research and scientific institutions across sectors.

For example, IWMI and ILRI partnered with Bahir Dar University and private companies to provide competitive internships that placed students with companies. Students and recent graduates gained hands-on experience conducting market studies, adapting technologies to local conditions, and in-app development for managing sales, after-sales services, and inventory.

These partnerships led to solid results, advanced marketing strategies, and opportunities for young scientists to network in agricultural careers and create their own technology start-ups. Moreover, ILSSI created systemic linkages in irrigated value chains and irrigation equipment supply chains through field-level workshops and events. Finally, IWMI facilitated multi-stakeholder dialogue platforms to create a space for networking, exchanging information, and catalyzing innovation in Ghana, Ethiopia, and Mali (Minh et al., 2020). Local stakeholders set the agendas based on high-priority learning areas. Producers, entrepreneurs, and companies identified partners and investment opportunities through these platforms. **Across the various engagement approaches, ILSSI enabled a range of actors, institutions, and companies to access information on water for agriculture and irrigated production.**



SYSTEMS APPROACH TO CAPACITY DEVELOPMENT

Smallholder investment in irrigation relies on a robust market system. Based on an understanding of market constraints and capacity gaps, ILSSI project partners sought to integrate private companies into all project activities, from research to capacity development and outreach.

Capacity strengthening aims to facilitate linkages, enhance trust, and co-create knowledge across sectors and actors.

Looking forward: Knowledge gaps and future research

Sufficient water quantity, quality, and stability is required to transform food systems and meet global goals for food security (Ringler et al., 2022). Official policies and programs increasingly recognize small-scale irrigation as a strategy to ensure adequate water for food production. Investment in research has enabled this shift.

Evidence on the extent of SSI development, the potential to sustainably expand SSI, and significant economic and nutritional benefits has contributed to re-positioning SSI as a viable alternative or complement to infrastructure-based, communal irrigation schemes. **A broader range of development partners and private sector actors have increased investment toward SSI.** More specifically, ILSSI and other projects open new scaling pathways by testing commercially available technologies and documenting the viability of multiple business models and finance instruments to reach various market segments, including the bottom-of-the-pyramid producers. The wider availability of information for investment decisions has also led to changes at the farm level. More irrigation equipment and tools are becoming accessible to farmers directly through the market, and some farmers are better able to get finance for irrigation and complementary inputs. **Dialogue is now firmly centered on how to accelerate SSI at scale.**

However, stakeholders, researchers, and practitioners have also suggested that some things have NOT changed despite evidence that a new direction is needed. To begin, piecemeal projects and lack of sectoral coordination persist, placing constraints on the pace of scaling. Equally important, stakeholders shared their perception that donors and public agencies continue to be technology-centric, i.e., preoccupied with finding a piece of singular equipment that can be pushed into smallholder adoption. The stakeholders pointed to public projects that primarily procure and distribute technology as examples of attempts to impose top-down control over the growth of SSI. That said, agencies and civil servants in some countries have requested guidance on programming for SSI and related technical advice because the public sector's role in SSI scaling is unclear compared to historical roles in developing irrigation infrastructure and large-scale schemes. Moreover, minimal progress has been observed in inclusion to avoid deepening social inequities. Stakeholders largely agreed that smallholder farmers are frequently sidelined, and more effort is needed to reinforce farmers as leaders in irrigation development.

After ten years of research under ILSSI, new knowledge gaps emerged, and others still needed to be answered. Stakeholders gathered at several events in the final year of ILSSI to outline their priorities.

First, stakeholders prioritized more information on groundwater and water governance generally. Stakeholders pointed out that data continues to be insufficient for research and decision-making, and costs to access some data sources are too high for local partners. They noted very little progress on localized groundwater management and, more so, national planning on strategic water use. In addition, they highlighted the lack of approaches for governance, lack of governance institutions at multiple levels, and missing linkages of mechanisms across levels. **Second**, stakeholders across regions and sectors agreed that there needs to be more information or action on water quality. Indeed, stakeholders strongly expressed the need for future research to elevate attention to surface and groundwater quality to safeguard public health and the environment. **Third**, new market and economic questions surfaced with SSI expansion, including the impact of various types of investments and investors, viable market size across countries, rising risks to farmers from rising debt burdens from increased credit, and broader economic implications from the growth of SSI. Some market and economic questions still needed to be answered from the research, such as the feasibility and benefits of service provision models, approaches to strengthen supply chains from global to local, and linkages between irrigated production and post-harvest management. **Fourth**, as alluded to above, stakeholders observed that SSI expansion is disrupting previous roles in the irrigation sector, which is not always smooth for either public or private sector actors. Stakeholders noted the need for more information and support to operationalize the investor and facilitator roles along different pathways to SSI expansion, natural resource stewardship, and planning and monitoring. On a related note, digital technologies arose as potential tools to be deployed by various actors to enable sustainable SSI scaling. **Fifth**, stakeholders noted numerous questions around SSI, climate change, and mitigation, from field adaptation to carbon to green funds, carbon credits, and maladaptation risks. **Finally**, stakeholders highly ranked investment in approaches for inclusivity and equity in scale-scale irrigation, particularly for youth and women.

Beyond knowledge gaps, stakeholders joined in an urgent call to increase local capacity. Public agencies noted the need for more skilled staff to take on new roles required to scale SSI through different pathways and ensure sustainability. Private companies frequently bemoaned the lack of relevant skills for a range of positions needed for market expansion and maintenance. Likewise, university and tertiary research institutes commonly recognized that curriculum and institutional infrastructure have not kept pace with the shifting demands related to small-scale irrigation or climate change, leaving them unable to supply a suitable, skilled human resource pipeline. Stakeholders and partners stated that unsuitable and insufficient capacity is a central constraint to scaling SSI sustainably.

ILSSI's research results and interventions contributed to the growing recognition that SSI can help to achieve the Global Food Security Strategy objectives and the Sustainable Development Goals. The ten-year project cycle enabled both longitudinal and in-depth applied research and learning across countries and regions. The timeline further allowed for the formation of critical multi-disciplinary and multi-sectoral partner networks and dialogue processes. Through these interconnections, ILSSI will continue to inform research and practice beyond project closure.

ANNEX

Publications and knowledge products

108 Peer-reviewed publications
81 Discussion/Working papers
45 Briefs and technical reports
130 Conference papers, posters, and/or presentations
108 Student Thesis Papers

Numbers as of June 30, 2023.

Additional publications and student thesis papers are anticipated after project closure.

PEER-REVIEWED PUBLICATIONS

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