Feed the Future Innovation Lab for Small Scale Irrigation

FINAL REPORT (2013 - 2023)

Submitted to USAID on Behalf of:

Norman Borlaug Institute for International Agriculture and Development,
Texas A&M AgriLife Research

The Texas A&M University System (Lead Institution)

International Food Policy Research Institute (IFPRI)

International Livestock Research Institute (ILRI)

International Water Management Institute (IWMI)

North Carolina A&T State University (NCA&T)

The World Vegetable Center

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Acronyms

BIAAD	Borlaug Institute for International Agriculture and Development
BDU	Bahir Dar University
FTF	Feed the Future
GFSS	Global Food Security Strategy
HDDS	Household Dietary Diversity Score
IDSS	Integrated Decision Support System
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
ILSSI	Innovation Lab for Small Scale Irrigation
IWMI	International Water Management Institute
NARES	National Agricultural Research and Extension Service
NGO	Non-governmental organization
SSA	Sub-Saharan Africa
SSI	Small-Scale Irrigation
TAMU	Texas A&M University
TAMUS	Texas A&M University System
USAID	United States Agency for International Development
WDDS	Women Dietary Diversity Score
WLE	CGIAR Research Program Water, Land, and Ecosystems

Executive Summary

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.

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 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.

1. 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. In addition to core support from the Bureau for Resilience and Food Security, the Bureau for Humanitarian Affairs supported additional 'buy-in' activities in Ethiopia and Mali. The ILSSI research consortium conducted collaborative, inter-disciplinary, and multi-method research, and implemented capacity development and stakeholder engagement activities from 2013 to 2023.

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.

This report[1] highlights key messages from research results and project achievements over ten years, including on the Feed the Future (FtF) indicators. Drawing on peer-reviewed publications and other knowledge products developed through ILSSI-supported research, the report briefly describes significant findings around the high potential for SSI in project countries, the outcomes of small-scale irrigation investments for nutrition, resilience capacities, income, and gender empowerment. At the same time, the report indicates some of the constraints to scaling SSI and potential interventions to overcome barriers. It also emphasizes the risks that SSI poses to water availability, providing direction for groundwater governance and particularly, the types of tools and approaches that need to be strengthened and deployed to safeguard water resources and human health. Finally, the report provides an overview of project achievements toward impact and lessons for future policy and programming.

[1] This report was prepared by Dr Nicole Lefore (ILSSI Director, 2019-2023), Matt Stellbauer (Interim ILSSI Director, 2023), and Abbey Kunkle (ILSSI Program Coordinator) with input from consortium partners.

2. Project Partners

A. Cooperative agreement partners

Led by BIIAD, the project consortium included sub-awarded partners from the Consultative Group on International Agriculture Research (CGIAR), including 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). The consortium of partners jointly designed, implemented, and monitored project activities.

B. National and U.S. sub-awardees

In addition to consortium partners, ILSSI had a strong set of complementary international, national and local partners and a broad network of collaborators. Primary project country national sub-awardees included: Ghana (University of Ghana; Kwame Nkrumah University of Science and Technology ; University for Development Studies); Tanzania (Sokoine University of Agriculture); Ethiopia (Bahir Dar University [BDU], Arba Minch University). ILSSI partnered with four private sector companies including PEG Africa (Ghana), Rensys Engineering & Trading PLC (Ethiopia), EMICOM, and EcoTech (Mali). Prairie View A & M University was also a sub-awardee. A list of key partners for each project country is provided in Annex 1.

3. Project Goals and Objectives

ILSSI sought to contribute to the overarching FtF goal of reducing global poverty and hunger. More specifically, ILSSI research results and activities contributed to advance progress toward the Global Food Security Strategy (GFSS) objectives of inclusive agricultural-led economic growth, improved nutrition and health, and improved resilience in sub-Saharan Africa (SSA). ILSSI's theory of change and country-level impact pathways were designed to guide the project's contribution to the GFSS goals. More specifically, ILSSI's objectives were 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 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.

In addition, ILSSI aimed to contribute to GFSS cross-cutting outcomes, notably gender and nutrition. The project recognized women as essential food producers and market actors and sought to reduce gender inequality toward achieving global food security. ILSSI integrated a gender-responsive approach to research design and implementation and expanded evidence on the links between irrigation and gender, as well as between irrigation, gender, and nutrition.

Through 10 years of research, ILSSI identified and provided evidence on the high potential of SSI 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. Research results contributed to approaches to support sustainability of natural resources and resilience capacities of the people whose livelihoods depend upon them. In addition, ILSSI provided evidence on ways to increase inclusively increase access to and use of small-scale irrigation.

4. Overview of Activities: Research-based evidence on benefits of small-scale irrigation and promising approaches to 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. As noted above, SSI investments can advance progress toward the GFSS goals. Country-level summaries are provided in Annex 2, and more detailed reports, publications, and knowledge products are listed in Annex 3.

A. Small-scale irrigation contributions to 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. ILSSI research indicated the extent to which SSI could be adopted and profitable in the specific 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 million	5,874,000	US$ 2.6 billion	Lake Tana; Ethiopian Great Rift Valley; Amhara, Oromia, Southern Nations, Nationalities, and Peoples' Region
Ghana	115,000	690,000	US$ 285 million	Northern Region
Tanzania	750,000	3,000,000	US$ 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.

Project Impact:

Around 6,300 producers, practitioners and value chain actors applied 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.

ILSSI research indicated that SSI increases returns to land and labor and reduces risk for smallholder producers, produce buyers, and processors. 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. For example, in Ghana, analysis showed that smallholder adoption of mechanized pumps could increase the net farm profit by 154%–608%. 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.

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. 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 could increase local vegetable seed production, including under irrigation, creating business opportunities for local seed producers, and improving smallholder access to seed. 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. 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.

At the national and sub-national levels, project partners analyzed policies and institutional ecosystems, technology diffusion networks, equipment market margins, and equipment market enablers. Analysis 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. 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. For example, 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.

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. IIWMI 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.

B. 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. 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. Through this work, more development partners are recognizing the interconnections and beginning to intentionally design irrigation investments for nutritional and health outcomes.

ILSSI supported IFPRI research that showed 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. 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.

ILSSI studies further documented the SSI to nutrition relationships in Ethiopia, Ghana, Tanzania, and Mali. Analysis 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. 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.

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.

The results 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. 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.

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. An ILSSI-supported assessment showed a gentle irrigation-induced risk of nutrient water pollution in four woredas in Ethiopia. In addition, IDSS model analysis showed that SSI in the dry season may affect phosphorus and nitrogen loading through crop consumption. However, total nitrogen loading may increase if additional fertilizer is used for dry season crops or through fixation of nitrogen, e.g. irrigated legumes. The additional 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:

ILSSI researchers at IFPRI, IWMI and TAMU participate in the Global Framework on Water Scarcity in Agriculture (WASAG), particularly the Working Group on Water & Nutrition. Through this platform, evidence has been shared from ILSSI research on the linkages between irrigation and nutrition, and broader health implications for irrigators compared to non-irrigators. The work also touches on the importance of targeting technologies and interventions for multiple uses and to be gender responsive.

Through such global engagement, ILSSI research influences the design of future investments in irrigation.

C. Small-scale irrigation's contributions to climate adaptation and addressing climate change, water resources, and irrigation sustainability to avoid maladaptation

Water resources are currently underutilized in agricultural production in much of Sub-Saharan Africa, with significant scope for irrigation development. Small-scale irrigation enables farmers to adapt to climate change and build resilience based on local context, filling an immense gap in public investments in irrigation. Development of SSI outside of public systems offers opportunities for acceleration and flexibility, but it also creates challenges. Water depletion and declining water quality globally and in some areas of SSA suggest the need for more careful monitoring of SSI to support resilience and avoid maladaptation.

ILSSI research partners supported decision-makers to understand where and how small-scale irrigators can sustainably use water. In addition to sharing research results and data, ILSSI also strengthened local capacity to use tools and evidence in planning to effectively manage competing demands for water and mitigate the risks to water security. In addition, ILSSI partnerships guided organizations and companies to target their markets for solar pump distribution based on biophysical suitability and sustainability. Furthermore, working with farmers, water users, and extension services, the project assessed tools and practices to improve on-farming water management.

Across project countries, ILSSI applied the Integrated Decision Support System (IDSS), a suite of models, including the Soil and Water Assessment Tool (SWAT), Agriculture Environment/Policy eXtender (APEX), and Farm Scale Nutrition and Economic Simulation Model (FARMSIM). Led by TAMU researchers jointly with national universities, IDSS enabled the assessment of the holistic impacts of SSI on agricultural production, environmental sustainability, and household income. IDSS results were validated by data collected through pilot studies in farmers' fields, from representative groups of households in each site, and through surveys. This analysis indicated the potential extent to which SSI could be developed, the locations to be developed based on specific crop combinations, and the likelihood of water scarcity over time as SSI expands for each project country.

Project Impact:

ILSSI researchers conducted around 103 water resource assessments across project countries and the West Africa Region. In addition, 1,295 early and mid-career scientists in the public, private and research sectors were trained on analytical models to strengthen local capacity to undertake water resource assessments.

In addition, IDSS tools enabled researchers to conduct climate change scenario analyses. Results showed rising temperatures and evapotranspiration, changing rainfall patterns, and climate-influenced changes to hydrological systems. Across project countries, the analyses identified medium- to long-term shifts in land suitable for irrigation, particularly for irrigation using surface water. In Tanzania, warmer temperatures and land use changes may interact to reduce water availability, such as in the Ndembera watershed. In the Blue Nile in Ethiopia, rising temperatures are expected to increase evapotranspiration by 7.8%, and dry seasons are expected to get more rainfall and rainy seasons less rainfall; climate change will alter seasonal streamflow in major rivers. In Ghana, around 9% of land is currently suitable for irrigation using surface water and shallow groundwater. However, climate change is expected to create shifts in areas most suitable for irrigation. By 2050, suitable land in South Western River Basin System may increase by 12%, and in the Volta and Coastal River Systems significantly decrease. The implication from studies across countries is that climate change is increasing the need for supplemental rainy and dry season irrigation. However, the most suitable areas for irrigation will change with the climate.

In Mali, ILSSI supported the application of multiple methods to generate evidence on water availability for different uses, including Water Accounting. To sustainably expand SSI, researchers and decision-makers need to know how water is used during wet and dry seasons — and how much could be used for agriculture. For example, ILSSI research partners applied Water Accounting methods and tools in Ségou and Sikasso, Mali. The surface and groundwater resources analysis across seasons showed high potential for expanding irrigated production. That suitability, however, varied seasonally. Research showed that though surface water could support lower-water crops like okra and sweet potato during the wet season, there was almost no available surface water during the dry season. The lack of surface water means that farmers need groundwater and stored surplus water from the wet season for dry season crop production. In Mali and elsewhere, verifying water availability and use is essential for investing in and implementing irrigation interventions to prevent climate maladaptation and worsening water scarcity.

Nearly all studies considered groundwater a critical resource for irrigated production and domestic and WASH uses in SSA. However, it can be harder to establish groundwater irrigation potential within and across seasons, with implications for smallholder agricultural water management. For example, research on aquifers in the Ethiopian Highlands showed that groundwater levels in shallow wells fluctuate across locations on the slopes and across seasons. Farmers need such localized information to make decisions on suitable technologies and planting schedules. In addition, studies in Ghana indicated that decreased seasonal rainfall and longer dry spells often leave insufficient water to meet requirements for crops that used to be produced in the rainy season, such as cocoa. And, while southern Ghana has the highest potential for surface water irrigation, farmers in northern Ghana are increasingly pumping shallow groundwater to irrigate vegetables and other crops. Water quality is often suitable for irrigation in northern Ghana. However, as one study highlighted, shallow groundwater availability varies significantly; some areas have insufficient shallow groundwater to meet crop water requirements throughout the dry season. Based on information generated by research, ILSSI advised farmers in case study areas on planting schedules and recommended crops based on crop water requirement and water availability.

In addition, ILSSI studied potential approaches to improve on-farm practices, such as conservation agriculture, soil-moisture monitoring, deficit irrigation, and solar-powered water lifting. ILSSI project partners compared various tools and approaches to improve field-level agricultural water management. Most farmers in project sites had begun to irrigate in recent years, so basic soil moisture monitoring tools enabled the farmers to learn about crop water needs and to better manage irrigation scheduling. In addition, farmers in project sites implemented conservation agriculture (C.A.) in addition to conventional tillage practices on their farms. Through research by North Carolina A & T and local partners, a case study in Ethiopia observed 26% reduced soil evaporation and 35% higher yield in onion with mulch and drip irrigation. In Ethiopia and Ghana, mulching with drip irrigation reduced water use by 18-45% and increased crop yield. However, farmers indicated numerous challenges to applying C.A. practices, particularly a labor shortage, and mulch (due to competing uses), suggesting that farmers need more options for mechanized C.A. and alternatives to local mulch. Overall, improved access to information about water use and changed irrigated agronomic practices led to increased crop yields, reduced yield variability, increased farm profit, and enhanced nutrition compared to standard farm practices. Generally, ILSSI studies showed that SSI water lifting technologies (i.e., pumps) should be part of a bundle of technologies, practices, and information access to achieve the best outcomes for farm households.

The use of pumps is scaling up by farmers themselves, and only recently through development projects and NGOs. Farmer practices in on-farm water management are critical, but managing water resources to ensure sustainability must occur at multiple scales and levels — from on-farm learning tools and conservation practices to improved watershed and basin-scale irrigation planning and monitoring. Because SSI tends to be developed by farmers outside public programs or extension, farmers lack access to production information, guidance on best tools and practices for on-farm soil and water management, and localized recommendations on crop-water requirements for supplemental and dry season irrigation of multiple crops. In addition, many farmers have little experience or local knowledge specific to irrigation. Furthermore, most public agricultural and irrigation departments lack the capacity to provide information to farmers; information is not available on field-to-basin scale data to guide farmer practice, monitor water use and availability, and plan and regulate water use to prevent scarcity. The information gap is exacerbated by climate change and increased uncertainties. Adding to the complexity, most studies suggest the development of conjunctive use of surface and groundwater resources to avoid water scarcity risks; treating rainfall and groundwater as an interconnected system can better support the sustainable expansion of small-scale irrigation. Research and extensive stakeholder engagement highlight an urgent need for public investments to support smallholder irrigators to adapt to climate change based on current conditions and anticipated changes to the hydrological systems.

D. Supporting groundwater governance to safeguard small-scale irrigation sustainability

As a result of growing urban growth, food demand, affordable drilling and pumping technologies, and climate change, groundwater resources are rapidly depleting in many places around the world. Across most SSA, smallholder farmers and rural households rely on groundwater for agricultural production and domestic uses. Some areas are experiencing a drop in groundwater levels and declining quality. However, national institutional and individual capacity is insufficient to support sustainability in most countries, especially with the lack of policies or governance institutions to guide and monitor groundwater use. Most institutions fail to integrate groundwater in water management strategies and policies. With limited state capacity to regulate or monitor groundwater extraction, community institutions, and collective action are crucial for sustainably managing groundwater resources.

Toward that end, ILSSI supported IFPRI to pilot an experiential learning intervention in Ethiopia and Ghana using a groundwater game to help raise awareness of groundwater over-extraction and improve understanding of the importance of collective action in governance. The groundwater game was played in areas where SSI is expanding but where extraction and competition over groundwater have yet to reach alarming levels. The game is designed for use by NGO field staff, government extension services, or other facilitators of community natural resource management processes.

Many users share groundwater resources without realizing their interconnectedness and the resource dynamics. Understanding the biophysical and systems-level characteristics of natural resources, the social dilemma in common-pool resources management, and the need for cooperation can aid communities in forming institutions to address governance challenges. IFPRI facilitated game participants through multiple rounds, each representing a year, where they experienced in a short period of time how choosing between a Crop A (low water use, low income) and Crop B (high water use, high income) influenced groundwater levels, and how each person's choices affected the overall resource. Players first made decisions without communicating and, in later rounds, were allowed to discuss and plan decisions and develop rules for more sustainable groundwater management.

Research conducted alongside the game implementation showed that the experience has had a clear effect on shifting mental models regarding the characteristics and use of groundwater resources. Before the game, most communities did not perceive groundwater as a shared or depletable resource but rather as private property unaffected by crop choices or intensity of use. Following the game, farmers realized that groundwater is a common pool resource and that their individual choices impact availability for the whole village. Additionally, the participants recognized the value of communication and collective action in resource management and the necessity of groundwater rules for better groundwater management.

Project Impact:

In Ghana, one year after the game intervention, focus group participants from participating communities frequently mentioned that they had started to select crops based on (lower) water requirements, limit planting of water intensive crops, and created water saving schedules to manage water use.

Two years after the games were implemented in Ethiopia, the learning experience continued to resonate with farmers. As one participant reflected: "When the water goes down, we remember the games."

Studies on the games reflected these changes in perception and behavior. Six months after the games were implemented in Ethiopia, communities remembered the importance of communication, rules, and collective action for groundwater governance. Some community members suggested introducing turns for groundwater irrigation and practicing soil and water conservation activities. Two years after the games were implemented in Ethiopia, the learning experience still resonated with farmers. As one reflected, "When the water goes down, we remember the games." In Ghana, one year after the game intervention, participants frequently mentioned that they had started to select crops based on (lower) water requirements, limited planting of water-intensive crops, and created water-saving schedules to manage water use.

This intervention showed that games should complement existing participatory activities to empower communities to self-govern their common resources. The games work as catalysts to encourage community discussions, prepare water management rules, and strengthen local governance. Communities discuss and prepare their own strategies, as this will more likely lead to actual behavioral change. Yet, while the games are a promising first step, they need to be coupled with other interventions to provide communities with the information and technical skills to manage their groundwater resources effectively and more formal monitoring of groundwater levels and water quality.

At the same time, ILSSI research indicated that partnering with private companies can contribute to water and natural resource sustainability. Private actors - equipment suppliers, produce buyers, smallholder producers, or other value chain entrepreneurs – have a direct interest in water resource sustainability and climate change mitigation. Actors across sectors and the spectrum of agricultural water management want better access to robust data and information to reduce risks to water. As one intervention alongside others, private industry actors can be supported to play a greater role in stewardship. Interventions are needed with farmers, rural households, and communities to enable local-level management, which can then be linked to other scales and private industry efforts in the future, particularly as strategies for climate adaptation and mitigation are rolled out in each country and national and transboundary institutions are developed and strengthened.

E. Potential to scale solar-powered irrigation through 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. 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. Finally, analysis showed that around 2.3 million hectares of land in Ghana is suitable for solar-powered irrigation. 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. 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. More specifically, assessments indicated solar irrigation is financially feasible in substantial areas in Mali and Ghana using groundwater. 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. 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. Analysis also 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. ILSSI formed several research-private sector partnerships in Ethiopia, Ghana, and Mali to further examine the constraints and potential solar pump distribution business models. 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 contexts.

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.

ILSSI and other development partners such as BMZ, GIZ, and the CGIAR Research Program for Water, Land and Ecosystems, along with private solar pump manufacturers, supported IWMI to generate and tailor the online interactive interface.

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 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. Therefore, ILSSI situated the private sector partnerships within national multi-stakeholder and multi-sectoral dialogues to enhance information sharing, build trust, and stimulate innovation with each country's private sector
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. 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.

While research suggested that women farmers in Ethiopia preferred solar pumps over fossil fuel pumps, irrigation equipment supply companies often ignored the women farmers as a market segment. ILSSI researchers helped companies overcome biased perceptions of women producers through the market segmentation workshops and the multi-stakeholder dialogue process. As outlined below, the project co-developed approaches to overcome women's lower access to inputs, credit, and information for irrigation investments.

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:

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*
8. *Enabling environment analysis tool*

The Tool has been applied in Ghana, Ethiopia and Mali, and integrated in the World Bank's Farmer Led Irrigation Development Guide.

F. 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.

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 100m^2 to 1000m^2 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.

Initial studies on markets for fodder in Tanzania, Ghana, and Ethiopia pointed to Ethiopia as having the highest potential for irrigated fodder development. Deeper market studies in Ethiopia showed growing demand for reliable, good-quality animal feed. 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. 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.

However, Napier grasses showed highest potential for deficit irrigation. 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. 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:

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.

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. 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.

G. 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. 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.

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. 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.

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. 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. Furthermore, even with efforts to support women in obtaining equipment, men might well take over the use or benefits. 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. 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, as indicated above.

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. 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. 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.

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.

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.

5. Accomplishments

A. Achievements on Feed the Future indicators

The outcomes and impacts of research and stakeholder engagement can take years to observe and are difficult to quantify. However, ILSSI reported on relevant FtF indicators across project countries. Table 2 outlines the results; ILSSI exceeded most targets set by the project with USAID. Notably, the number of short-term and long-term trainees reflected high demand by national stakeholders for analytical tools, methods, and field-level information. Moreover, local universities and other research institutions in the project countries are trying to increase skills that address the challenges of climate change and agricultural water management. At the same time, the number of water resource sustainability assessments undertaken by the project helped to address a major knowledge gap, contributing to national evidence on available, potential, and at-risk resources to serve as a resource for planning and future monitoring and evaluation. ILSSI also contributed to policy analysis and provided a knowledge base for evidence-based decision-making on policy, which may only realize impact in the coming years. The project's overall achievements represent the high value placed on water resources and the importance given to SSI by project country governments, development partners, private sector investors, and other stakeholders.

Table 2. Feed the Future indicators (2013-2023)

Indicator No.	Description	Total
EG.3-1	Number of households benefiting directly from USG interventions	6522
EG.3.1-2	Hectares under new or improved/rehabilitated irrigation and drainage services as a result of USG assistance	28,567*
EG.3.1-12	Number of agricultural and nutritional enabling environment policies analyzed, consulted on, drafted or revised, approved and implemented with USG assistance	22

EG.1-14	Value of new USG commitments and private sector investment leveraged by the USG to support food security and nutrition	$4,120,952
EG.3.1.-15	Value of new private sector investment leveraged by the USG to support food security and nutrition	$ 629,700
EG.3.2-1	Number of individuals who have received USG-supported short-term agricultural sector productivity or food security training	7220
EG.3.2-2	Number of individuals who have received USG-supported degree-granting non-nutrition-related food security training	145
EG.3.2-7	Number of technologies, practices, and approaches under various phases of research, development, and uptake as a result of USG assistance	141
EG.3.2-24	Number of individuals in the agriculture system who have applied improved management practices or technologies with USG assistance	6287
EG.3.2-27	Value of agriculture-related financing accessed as a result of USG assistance	$ 652,444
EG.3.2-x41	Number of water resources sustainability assessments undertaken	103

**Data collected 2013-2022*

B. Capacity development

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.

Strengthening skills and capabilities

One component of the HICD activities was developing capacity through short- and long-term training (Table 3). As such, 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.

ILSSI contributed to expanding the cohort of young and mid-career scientists who will provide evidence for policy, planning, and decisions, develop technologies, and support producers to adopt sustainable and effective practices. Graduate students at eight national universities in Ethiopia, Ghana, and Tanzania were supported for field studies, data collection and analysis, and presentation and publication of research. A few students at U.S. universities also received support to conduct research, particularly on policy-relevant topics. Finally, ILSSI supported students to participate in national and global conferences and publish open-access journal articles.

Table 3. Total Number of Long- and Short-Term Trainees

Length	Type of Trainee	Numbers of Trainees
Long-term	Total number of students, graduate students, post-doctoral fellows	145 (M=102, F=43)
Short-term	Total number of short terms trainees	2247
	• Producers/farmers	1198
	• Private sector	55
	• Civil society	691
	• Government	303

Integrated Decision Support System Training (IDSS)

ILSSI sought to address capacity gaps in public and research institutions to guide, monitor, and regulate water use from plot to watershed scale, basin to regional levels, and across multiple uses. Scientists at TAMU provided short-term training courses on IDSS, which were hosted by local institutions based on their needs, priority crops, and local data and case studies. ILSSI researchers followed up training with intensive mentoring. ILSSI trained 1295 men and women (Table 4), representing basin authorities, irrigation agencies, donors and non-government organizations, companies in the water sector, research institutions, and national universities. The higher capacity on a standard set of models and tools contributed to harmonized planning and analytical tools within regions. ILSSI provided training in Ethiopia, Ghana, Ivory Coast, Nepal, Rwanda, and Tanzania. IDSS methods were institutionalized into the Bahir Dar University (BDU) curriculum for sustaining capacity; BDU faculty now provide training for Ethiopian institutions and other African countries. As a result of these efforts, peer-reviewed publications applying IDSS tools in African countries increased multifold, and more scientists and decision-makers have the skills for evidence-based monitoring and planning.

Table 4. Number of IDSS Training Participants by Country

Country	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Total**
Ethiopia	52	72	77	110		82		83		74	550
Ghana			56	70		56	72		71	92	417
Tanzania		67	51	58							176
Cote d' Ivoire									69		69
Rwanda										52	52
USA (trainees from Minority Serving Institutions)										31	31
Total number of Participants	52	139	184	238	0	138	72	83	140	249	**1295**

Strengthening capacities to innovate

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 used an engagement approach to strengthen capacities to generate trust, share knowledge and information, and build lasting collaboration between private companies, public agencies, and research and scientific institutions across sectors.

ILSSI project partners integrated private companies and public institutions into a range of project activities, from research to capacity development and outreach. For example, IWMI and ILRI partnered with BDU 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 supported engagement between public, research, and private actors to create stronger systemic linkages in irrigated value chains and irrigation equipment supply chains. Through multi-stakeholder dialogue platforms (Table 5), IWMI provided a focused space for networking, exchanging information, and catalyzing innovation in Ghana, Ethiopia, and Mali. Local stakeholders set the agendas based on high-priority learning areas. Producers, entrepreneurs, and companies identified partners and investment opportunities through these platforms. At the same time, NARES and producer organizations increased access to information on water for agriculture and irrigated production inputs, including high-value crops such as fodder and cocoa.

Table 5. Multi-stakeholder dialogues (2019-2023)

Site	Topic	Date	Indvs.*	Orgs.**
Ghana	Kick Start Meeting	Oct 2019	49	38
Ethiopia	Kick Start Meeting	Oct 2019	38	20
Ghana	Understanding the scalability of solar-powered irrigation in Ghana: Market segmentation and mapping pump suitability'	May 2021	36	17
Ethiopia	Value chain approaches to small-scale irrigation development	May 2021	51	24
Mali	Multi-stakeholder dialogues supporting the scaling of inclusive and sustainable agricultural water management in Mali	Jun 2021	35	26
Ghana	Sustainability of cocoa systems: Exploring segmentation, water management, and SSI suitability	Oct 2021	40	25
Ethiopia	Role of off-take markets in unlocking SSI investments	Oct 2021	48	28

Ghana	Market and value chain approaches to farmer-led irrigation development	Apr 2022	51	28
Ethiopia	Scaling sustainable and inclusive farmer-led irrigation	May 2022	41	20
Ghana	Innovations for improving irrigation water use efficiency in farmers' fields	Jul 2022	51	23
Ghana	Bundling innovations for scaling farmer-led irrigation development	Nov 2022	63	35
Ghana	Co-designing sustainable and inclusive irrigation to leverage the climate-resilience cocoa initiatives	Mar 2023	49	15
Ethiopia	Facilitating the development of Public Private Partnership implementation strategy for SSI	Jul 2023	21	12
Ghana	Investing in farmer-led irrigation development in Sub-Saharan Africa: Business, development, and research practices	Apr 2023	142	73
Ethiopia	Scaling SSI for food security and resilience in Ethiopia—Findings from the 10 years of research for development under the Feed the Future ILSSI	May 2023	70	50
Washington D.C.	Saving sustainable cocoa production when water becomes scarce: Developing an Integrated Decision Support System (IDSS) to manage water resources for sustainable cacao production	Jul 2023	21	16

**Individual participants*

***Stakeholder organizations represented*

<u>Supporting partnerships between research and farmer cooperatives</u>

As evidence grew for the high potential in the irrigated fodder value chain, ILRI facilitated engagement and partnerships in 'milk sheds' in Ethiopia. ILRI partnered with three dairy cooperatives to develop business models and address market-based constraints jointly. ILRI supported the cooperatives in dialogue with other value-chain stakeholders and projects. For example, cooperatives gained support from public sector agencies to develop infrastructure and to formalize market supply agreements. In addition, cooperatives participated in trainings on fodder seed production, storage, and processing. Overall, cooperatives increased their membership and gained further investment. Fodder and fodder seed production, as well as dairy supply to the market, all increased.

<u>Evidence-based guidance for equitable, impactful, sustainable outcomes</u>

ILSSI created evidence-based guidelines, tools, and videos for building awareness, knowledge, and skills at multiple scales. For example, IFPRI worked with partners to develop guidance materials on nutrition-sensitive irrigation investment and integration of gender into SSI projects. In addition, IWMI created online suitability maps and instructional videos on market segmentation and market linkages, among others. ILSSI also developed guidance for safe irrigated farming practices that are being used by USAID-supported projects and by solar pump companies in farmer training programs. All materials are open-access and, where possible, are available in multiple languages.

C. Outreach and knowledge sharing

Engagement initiated by ILSSI created a strong foundation for the uptake of research evidence, particularly through partnerships with national education and research institutions, international research institutions, government institutions and agencies, private actors, and civil society organizations. ILSSI applied a continuous engagement approach with stakeholders, including national research, institutional partners, and private partners, though with sufficient attention and resources for communications.

Communications

ILSSI's communication on research and engagement activities sought to engage a broad audience of policymakers, program designers, project implementers, practitioners, and private sector investors. A website, quarterly newsletter, and social media platforms enabled broad sharing of research-based evidence and knowledge products, such as briefs, technical guidance notes, and capacity development materials. Reach for knowledge sharing is summarized in Table 6, and specific blogs and webinars, among others, are listed in Annex 3 Datasets, publications and knowledge products.

Table 6. Communications reach (2019-2023)

Outlet	Account	Statistics
Website	ilssi.tamu.edu	40,000 total page views
Social media	Facebook: ILSSI Twitter: @IlssiTAMU	Tweets gained more than 217,000 impressions. Facebook posts reached over 12,000 readers.
Quarterly Newsletter	https://ilssi.tamu.edu/news/	234 subscribers Examples: World Food Day [October 2022] (open rate 43.1%, click rate 11.9%); Planning for the Future of Research in Ag Water Management [January 2023] (open rate 55.8%, click rate 11.5%); Celebrating World Water Day [March 2023] (open rate 47.0%, click rate 14.6%).
News stories	https://ilssi.tamu.edu/news/	90 stories Examples: Small Scale Irrigation and Nutrition: Lessons from East and West Africa, Governing Water—A South-South Exchange with Insights from Ethiopia and Ghana, and How can we address recurring global food and fuel crises? The role of solar powered irrigation
Briefs (technical, policy and others)	See Annex 3, Briefs https://ilssi.tamu.edu/publications/country-research-summary-briefs/	41 briefs

Events

Targeted media were essential to maintaining interest in the ILSSI program throughout the project cycle. However, face-to-face events tended to have more impact on influencing decision-making, design of interventions, and future research and thinking. Therefore, ILSSI convened and participated in national, regional, and global events. Events to share research-generated evidence and messages included national conferences and workshops with relevant stakeholders, participation in regional events such as Africa Water Week, sessions at global events including World Water Week, and the ILSSI global symposium in 2023. ILSSI research was also presented at scientific conferences in project countries, the U.S., and global events.

Publications, papers, and reports

Throughout the project cycle, ILSSI saw strong collaboration across research partner institutions on publications and outreach materials. The figures for each type of publication are summarized in Table 7 below, while the complete list of publications with links to web access can be found in Annex 3. Datasets, publications and knowledge products.

Table 7. Summary of ILSSI Publications (1 October 2013 – 18 August 2023)

Category of publication and/or knowledge product	Total Number (all partners)
Peer-reviewed publication	108
Discussion/Working paper	81
Brief	42
Technical report	3
Conference paper, poster, and/or presentation	130
Outreach and social media (e.g., webinars, blogs, etc.)	93
Capacity development material or product (2019-2023)	7
Student Thesis Papers	108

6. Looking forward: Knowledge gaps and future research

Over the past ten years, small-scale irrigation went from being primarily farmer-led in the 'informal' sector to official public policy such as in the Kigali Declaration and to formal development programming, notably the Farmer-led Irrigation Development Initiative of the World Bank. Investment in research enabled this shift. Evidence on the extent of SSI development, the potential to sustainably expand SSI, and significant economic and nutritional benefits contributed to re-positioning SSI as a viable alternative to infrastructure-based, communal irrigation schemes. A more extensive range of development partners and private sector actors have increased investment toward SSI. The increased development sector attention aligned with research demonstrating commercial scaling pathways. More specifically, ILSSI and other projects tested commercially available technologies and documented the viability of multiple business models and finance instruments to reach various market segments, including the 'bottom of the pyramid'. The broader availability of information for investment decisions also led to changes at the farm level. A more extensive range of irrigation equipment and tools has become accessible to farmers directly through the market, and farmers are better able to get finance for irrigation and complementary inputs. Yet, minimal progress has been observed in applying evidence to support inclusion and avoid deepening social inequities. Taken together, evidence suggests that development partners are more likely to achieve target outcomes if they focus less on the widespread adoption of individual technologies and instead concentrate support on socio-technical bundles suitable to a particular context. 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, stakeholders largely agreed that smallholder farmers are frequently sidelined, and more effort is needed to place them 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. Priorities repeated at multiple events and across countries are listed here in no hierarchical order. 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 one urgent call: 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 GFSS 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 1. Partners (sub-awards and director collaborators) 2013-2023

Country	Institution/Organization	Type of partner
United States	Prairie View A & M University	Capacity Development Partner
Ethiopia	Bahir Dar University	Research Partner
	Arba Minch University (AMU)	Capacity Development Partner
	Adama Science and Technology University	Capacity Development Partner
	Addis Ababa University	Capacity Development Partner
	Ethiopia Institute of Agriculture Research	Capacity Development Partner
	Ethiopian Agricultural Transformation Agency/Institute (ATA/ATI)	Knowledge Sharing Partner; Capacity Development Partner
	Ministry of Agriculture and Natural Resources (Small-scale Irrigation Directorate)	Capacity Development Partner
	Abbay Basin Authority	Capacity Development Partner
	Amhara Regional Agriculture Research Institute (ARARI)	Research Partner; Knowledge Sharing Partner
	Southern Agricultural Research Institute (SARI)	Research Partner; Knowledge Sharing Partner
	Appropriate Scale Mechanization Consortium	Research Partner
	Send a Cow-Ethiopia	Research Partner
	Genet Lerobit dairy cooperative	Private Sector Research Partner
	Habebo dairy cooperative	Private Sector Research Partner
	Mishgida Eta dairy cooperative	Private Sector Research Partner
	Rensys Engineering PLC (Sunculture distributor)	Private Sector Research Partner
Ghana	University for Development Studies	Research Partner; Capacity Development Partner
	Kwame Nkrumah University of Science and Technology	Research Partner; Capacity Development Partner
	University of Ghana	Research Partner; Capacity Development Partner
	Animal Research Institute (ARI) of the Council for Scientific and Industrial Research	Research Partner; Knowledge Sharing Partner
	Water Resources Institute of the Council for Scientific and Industrial Research	Research Partner
	International Development Enterprises (iDE)	Research Partner
	PEG Africa, Ghana	Private Sector Research Partner
	Pumptech	Private Sector Research Partner
Tanzania	Sokoine University of Agriculture (SUA)	Research Partner
Mali	Institute of Rural Economy (IER)	Research Partner
	EMICOM (Future Pump distributor)	Private Sector Research Partner
	Ecotech (ENNOS distributor)	Private Sector Research Partner

Annex 2. Country Level Results at a Glance

A. Ghana

GHANA

Key findings

- Around ~211,000 ha of land is economically and biophysically suitable for SSI development
- Available water resources can meet irrigation water requirement in most (~68%) of the suitable land for SSI
- SSI adoption could generate net income of ~$285 million USD/year benefiting 690,000 smallholder farmers
- Irrigation in its current form, is important but not sufficient to dramatically improve nutrition; expansion is severely restricted by labor intensive methods
- Irrigation is positively associated with household dietary diversity (economic access to foods) driven by income increases and production changes, such as increased consumption of meat and vegetables comes largely from producers' own farms
- Climate change may significantly affect the land suitability for irrigation
- Irrigation scheduling can improve water productivity, yields with consistent use
- Motorized pumps are profitable with high value vegetables
- High production costs (including labor, fuel) increase risk, decrease profit
- Climate variability, low soil fertility, and poor land and crop management practices are constraints
- Improved fertilizer rates can substantially increase crop yield
- Cropping of fodder improved soil residual nutrient and increased rainfed season crop
- Feed and Fodder value chain is emerging
- Locale-specific targeting of small-scale irrigation technologies is essential to scaling
- Knowledge sharing will be needed to sustainably develop and monitor water use in the cocoa sector.
- Surface water and groundwater irrigation can complement each other but must be developed conjunctively
- Irrigation sector in Ghana is still in its infancy; opportunities for government and private sector investment
- Policy changes in tax and port charges has increased the cost of irrigation equipment to farmers
- Cocoa growing areas lack sufficient rainfall for production. Supplemental and dry season irrigation is needed
- Fertilizer and purchased seed use is higher in irrigated plots by about 12% compared to rainfed alone
- Adopting solar powered irrigation is more cost effective when compared to solar irrigation
- Approaches for Monitoring Farmer led Irrigation need to be introduced at community and watershed scale
- Access to land and water, gender norms that limit women's ability to control farm assets are constraints
- Women participation in irrigated farming activities lead to an increase in their agency and well-being.

Recommendations

- SSI needs to be carefully sited and managed to reduce negative environmental externalities
- Labor-saving irrigation technologies likely lead to improvements in productivity, income and nutrition outcomes

- Improvements in dietary diversity require complementary nutrition-sensitive and specific interventions
- Water management and productivity need to be improved in order to increase incomes
- Appropriate credit for agriculture and irrigation may incentivize investment in the SSI technology market
- Interventions that aim to increase inclusivity of economic development should increase women's access to information, technologies and tools, while also addressing household level decision-making
- Demand for off-farm produced feed exists in an emerging feed and fodder value chains, but farmer/markets awareness is needed on benefits and production
- Planning, monitoring and managing water in agriculture at different scales is needed to support sustainability.
- Skilled, human resource pipeline for private and public sectors will be critical to scaling small scale irrigation
- Poorest smallholders need interventions to be able to invest in irrigation

B. Ethiopia

ETHIOPIA

Key findings

- Potential for substantial land and water resources exist for scale SSI in Ethiopia. ~1 million ha of land is economically and biophysically suitable for SSI development
- High potential for net income of ~2.6 billion USD/year from SSI adoption
- Irrigation can be promoted as a nutrition-sensitive agricultural intervention
- Irrigation has a strong positive effect on the household's economic access to food and on nutritional outcomes of women and children
- Irrigated fodder can contribute to animal and human nutrition
- Groundwater is inadequate in some areas requiring conjunctive surface water use and improved field level water management and tillage practices
- Irrigation scheduling improves yields, produce quality, and reduces costs
- CA increases crop yield, reduces yield variability, and improves soil
- SSI technologies are profitable with high value vegetables
- Labor is a key factor in profitability and technology adoption
- Access to appropriate financing is low; access to credit may increase adoption
- SSI technology supply chain is underdeveloped
- Movement towards more women's involvement in decision-making
- Women tend to have significantly less access to information and training on irrigation
- FEAST is useful as a rapid tool to assess feed resources and prioritize interventions
- Promising forages include oats-vetch mixes and Napier and Desho grasses; multi-purpose forages offer multiple benefits
- Forages as cash crops have potential (fodder markets exist already); the sale of irrigated forages is more profitable for small holders with low producing animals
- locale-specific targeting of small-scale irrigation technologies is essential for the adoption of small scale irrigation
- Women are more credit constrained than men

- Solar and diesel/petrol pumps are not low-cost for smallholder farmers and there are no financial products, either from microfinance institutions or suppliers, to enable loans.
- Irrigated fodder requires less water and chemicals
- Shifting from vegetable production to irrigated fodder increases farm income by approximately 17%
- Solar has higher economic viability over diesel pumps
- improved forage production and quality feed supply are key for smallholder dairy transformation
- On average, dairy producers obtained a net return of ETB 20,000 (ha) from the production of irrigated fodder per household per year
- men view an empowered woman as a renegade going against the grain of the community's culture, norms, and social relations
- High seasonal variation of diets can be offset, at least in part, by irrigation
- Children in irrigating households in Ethiopia had higher Z scores, on average, than WHZ of children in non-irrigating households.
- Groundwater likely is an overall better-quality source for domestic purposes than surface water;
- Multiple uses of irrigation water for WASH are more promising for households using groundwater
- PSNP has rehabilitated degraded lands and increased water availability for multiple uses
- PSNP investment in soil and water conservation through public works helped improve soil fertility and increase availability of food and livestock feed

Recommendations

- Nutritional benefits of irrigation may increase with complementary activities
- Irrigation interventions should be considered as a package: water lifting, application, scheduling tools, fertilizer guidance, CA practices
- Groundwater recharge should be enhanced
- Appropriate institutions at multiple levels should be strengthened to prevent negative externalities of SSI
- Interventions should target women farmers specifically
- Programs/projects should consider trade-offs between technologies
- Policy makers and researchers need to give more attention to substituting high value crops to replace Khat
- Community approaches and capacity strengthening in water governance is needed
- targeted interventions is needed to ensure smallholders are not omitted from planning and monitoring from institutional framework on irrigation
- Increased emphasis needs to be placed on the functionality and maintenance of constructed irrigation and watershed infrastructure,

C. Mali

MALI

Key findings

- High popularity/availability of solar home products can increase awareness/uptake of Solar Powered Irrigation Systems.
- Optimal yield, supplementary irrigation is necessary for vegetable production in Mopti region.
- Fertilizer and purchased seed use is higher in irrigated plots by about 12% compared to rainfed alone

- Irrigated intensification will contribute to water pollution from agro-chemicals without proper management
- It is estimated that for many farmers an investment of more than 250'000 CFA in a solar pump requires saving in advance
- The new 2 HP pump opens up new opportunities on the solar pump market in Mali, as it meets the irrigation needs of representative areas of fields operated by cooperatives grouping together several small farmers
- To bring solar pumps to scale it is important to important to continue supporting awareness campaigns for the new technologies available on the market
- Providing guarantees to help cooperatives and farmers acquire technologies is an effective approach to initiating the adoption of a new technology
- It is difficult to sale solar pumps in areas where the product has not yet proven itself and where producers do not have feedback from other producers
- Long-term watershed rehabilitation practices should be coupled with immediate income generating activities

Recommendations

- Planning, monitoring and managing water in agriculture at different scales is needed to support sustainability
- Community approaches and capacity strengthening in water governance is needed,
- there is a need for liquidity to invest in advance in the purchase and supply of solar pump quantities benefiting from economies of scale
- Skilled, human resource pipeline for private and public sectors will be critical

D. Tanzania

TANZANIA

Key findings

- Approximately ~754,454 ha of land is economically and biophysically suitable for SSI development,
- A net income of ~780 million USD/year from the SSI adoption benefiting 3 million smallholder farmers Yields improved under deficit irrigation for tomato and eggplant

In addition, the project aimed to generate greater trust, knowledge sharing, and collaboration between the private companies, public agencies, and research and scientific institutions across sectors to strengthen capacity for sustained innovation.

- Recommended crop water requirements can be reduced for certain vegetables according to location
- Motor pumps are financially feasible for high value vegetable production
- Payback period for motor pumps would be less than one year, *if* credit costs are reasonable and credit is accessible
- Pocket gardens use less water and labor than conventional gardens
- Income from pocket gardens is modest, but women can control the income and supplement household consumption
- The suitable land for SSI in the Tanzanian watersheds was generally small since the majority of the watersheds are covered by non-agricultural land
- Since the suitable land for SSI was small, the available water resources was sufficient to support the dry season cultivation, and SSI did not affect the watershed water balance dynamics,

- Multiple cropping of fodder (oats/vetch) improved soil residual nutrient and increased rainfed season crop yield
- System of Rice Intensification (SRI) production ensured higher crop water productivity compared to the traditional rainfed rice
- Motor Pump-based irrigation provided profit, but with a benefit cost ratio less than one; return on investment was reduced by high investment and operating costs (pump, labor, fuel)
- Reduced profit under alternative SSI technologies (motor pump) do not allow households to purchase supplemental food for nutrition (using FARMSIM analysis)

Recommendations

- Recommended crop water requirements can be reduced for certain vegetables according to location
- Irrigation service provision, such as pump rental, could be an effective approach to reducing costs to farmers but still enable irrigated production of vegetables
- Suitable finance products are needed to improve access of farmers to purchase and/or rent pumps
- Home gardens offer a feasible entry point to increase production of vegetables with relatively lower water input, but need to be designed carefully to ensure increased benefits for women farmers
- Expansion of irrigated production will require attention to integrated pest management to maximize benefit
- Irrigated fodder production requires further research on the potential for animal and human nutrition
- Nutrition messaging needs to be integrated into irrigation investments/activities to gain more nutritional benefits

Annex 3. Datasets, publications and knowledge products

A. Datasets

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12. Dile, Yihun T., 2021, "Upscaling Soil and Water Assessment Tool Data for fodder simulation", https://doi.org/10.18738/T8/5NBGEW, Texas Data Repository, V1
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29. Rice Production Northern Region-Ghana 1991-2008
30. Maize Production Northern Region-Ghana 1991-2008
31. Market Prices Kasenanankana District Monthly 2016
32. Food Production of Northern Ghana Kasenanankana District
33. Biophysical Data on Irrigation Experiments-Ghana
34. Evaluation of Irrigation Scheduling Strategies on Partial Nutrient Balance for Tomato Production During the Dry Season at Robit Bata Watershed
35. Improving Subsurface Recharge through Breaking Restrictive Soil Layers by Mechanical Means
36. Evaluation of Wetting Front Detector to Determine Water Demand, Water and Crop Productivity of Selected Fodder Verities Under Supplemental Irrigation-Climate Data
37. Evaluation of Wetting Front Detector to Determine Water Demand, Water and Crop Productivity of Selected Fodder Verities Under Supplemental Irrigation-Desho Agronomic Data
38. Evaluating Simple Irrigation Technologies to Improve Crop and Water Productivity of Onion in Dangishta Watershed-Climate
39. Evaluating Simple Irrigation Technologies to Improve Crop and Water Productivity of Onion in Dangishta Watershed
40. Evaluation of Wetting Front Detector to Determine Water Demand, Water and Crop Productivity of Selected Fodder Varieties Under Supplemental Irrigation
41. Optimizing Use of Groundwater for Irrigation in the Dry Season: The Case of Robit Watershed, Lake Tana Basin Stream Flow Data
42. Optimizing Use of Groundwater for Irrigation in the Dry Season: Th Cause of Robit Watershed, Lake Tana Basin
43. Assessing the Performance of Manual Water Lifting Technologies and Irrigation Scheduling Based on Measured Soil Moisture and Farmers Practice on Irrigated Tomato, and Comparing Soil Moisture Measurement and Estimation Methods: Case Study of Western Amhara Sub Region

44. Evaluation of Wetting Front Detector to Determine Water Demand, Water and Crop Productivity of Selected Fodder Varieties Under Supplemental Irrigation
45. Optimizing Use of Groundwater for Irrigation in the Dry Season: The Case of Robit Watershed, Lake Tana Basin
46. Development of Crop Coefficients and Evaluating the Productivity and Water Use for Napier Grass Under Small-Scale Irrigation: The Case of Robit Kebele

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Adie, A.; Yitayew, B.; Demeke, Y.; Ferede, L.; Yeheyis, M.; Bezabih, M.; Schmitter, P.; Blummel; Yimam, A. Y. 2018. Lessons from pilot trials with small-scale irrigated forage production in the Amhara Region: potential of integrating the perennial forage Napier grass with Desmodium and Pigeon Pea in cropping systems. 2nd Amhara Agricultural Forum 2017 on 16 Jan 2018, Jacaranda Hotel, Bahir Dar, Ethiopia.

African smallholder irrigation: Double yields with half the water! Stockholm World Water Week. Stockholm, Sweden, 30 August 2017.

Assefa, T, MK Jha, MR Reyes, K Schilling. 2017. Commercial Home Gardens under Conservation Agriculture and Drip Irrigation for Small Holder Farming in sub-Saharan Africa. *Annual International Conference of the American Society of Agricultural and Biological Engineers (ASABE)*. July 16-19, 2017, Spokane, Washington.

Aziz, F. Suitability, sustainability and resilience: case study from Mali on vegetables and vegetable seed. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Aziz, F. "The Integrated Decision Support System (IDSS) in Africa: land suitability analysis for cocoa production in Ghana". September 2022. AGU Chapman Conference on Solving Water Availability Challenges through an Interdisciplinary Framework. Golden, CO.

Aziz, F. "Sustainability of cocoa systems: Exploring segmentation, water management and small-scale irrigation suitability". October 2021. Accra, Ghana.

Balana, B. "Constraints on farmer demand for credit and the supply of credit at the farm household level". August 2022. Stockholm World Water Week.

Balana, B. Effects of PW on watershed rehabilitation and irrigation interventions in BHA-supported PSNP areas of Ethiopia. Virtual Presentation to USAID BHA.

Balana, B. Small-Scale Irrigation – Income and economic growth opportunities. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Balana, B.; Abdulai, A.; Lefore, N. 2017. Micro and Rural Finance for Small Scale Irrigation Technologies and Tools: Evidence from Northern Ghana. International Conference on Irrigation and Agricultural Development (IRAD) at the University for Development Studies (UDS). Tamale, Ghana, 30-31 October 2017.

Balana, B. & Appoh, R. (2019). Assessment of private actor participation in the irrigation technology supply chain: Ghana case study. IWMI, Accra, Ghana.

Balana, B.; Appoh, R.; Adimassu, Z.; Lefore, N. 2017. Economic Analysis of Small Scale Irrigation Technologies in northern Ghana. International Conference on Irrigation and Agricultural Development (IRAD) at the University for Development Studies (UDS). Tamale, Ghana, 30-31 October 2017.

Balana B.; Bizimana J.C.; Richardson, J.W.; Lefore L.; Adimassu Z.; Herbst, B.K. 2018. Profitability and Economic Feasibility Analysis of Small Scale Irrigation Technologies in northern Ghana. Conference paper presented at the 'Southern Agricultural Economics Association (SAEA)' 2018 conference Jacksonville, Florida (USA), February 2-6, 2018.

Balasubramanya, S.; Buisson, M.; Mitra, A.; Stifel, D. "Price, credit or uncertainty? Increasing small-scale irrigation in Ethiopia". August 1 - August 3, 2021. Agricultural & Applied Economics Association Annual Meeting, Austin, TX.

Balana, B., Gebregziabher, G., Mul, M., Owusu, A., Kodua, T., & Closas, A. (2019). Solar PV Technology for Small-Scale Irrigation in Ghana: Suitability and Business Cases. IWMI, Accra, Ghana.

Bezabih, M.; Adie, A.; Gemiyu, D.; Zeleke, B.; Schmitter, P.; Blümmel, M. 2018. Lessons from small-scale irrigated forage production trials: potential of annual oat-vetch mixtures. 2nd Amhara Agricultural Forum 2017 on 16 Jan 2018, Jacaranda Hotel, Bahir Dar, Ethiopia.

Bizimana, J., Richardson, J.W., Bryant, H., Herbst, B.K., Clarke, N.P., Dile, Y.T., Lefore, N., Gerik, T.J., Srinivasan, R., & Worqlul, A.W. "Economic and Nutrition Impacts of Irrigated fodder in Lemo woreda-Ethiopia". 2020 Carter Conference at University of Florida*,* April 15-17, *2020 (accepted; event cancelled)*

Bizimana, J.-C.; Worqlul, A. W.; Henry, B. "Yield-Index insurance and farmers' resilience: An analysis using an integrated approach". Accepted, Conference, August 2021, Austin, Texas.

Bryan, E. (2019). Linkages between small-scale irrigation and women's empowerment: Evidence from the Upper East Region, Ghana. Presentation at ILSSI Stakeholder Consultation, Accra, Ghana.

Bryan, E. "Small-scale Irrigation and Women's Empowerment: Lessons from Northern Ghana". GENDER Platform Conference Cultivating Equality. October 2022. Virtual.

Derseh, M. ILSSI Irrigated fodder research for development: lessons from cooperative based interventions. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Derseh, M. Innovation Lab for Small Scale Irrigation (ILSSI): Irrigated fodder research and development achievements. US Embassy, Addis Ababa, February 2023.

Derseh, M. Livestock production and resilience in African smallholder systems. Conference on Water, Climate, and Food Security for Students and Early Career Scientists. Prairie View University, March 2023.

Derseh, M. Potentials and benefits from irrigated fodder: highlights from the ILSSI research. ILSSI knowledge sharing workshop, 25 May 2023, ILRI, Addis Ababa, Ethiopia.

Derseh, M.; Adie, A. "Research for Development in irrigated fodder: Experiences from the Innovation lab for Small Scale Irrigation project". International Livestock Research Institute.

Dile, Y., Ayana, E.K., Worqlul, A.W., Xie, H., Bizimana, J., You, L. Lefore, N., Gerik, T., & Clarke N. "Estimating blue and green water resources availability in Ethiopia". American Geophysical Union (AGU) Meeting, December, 2019 in San Francisco, California.

Dile, Yihun T.; Worqlul, A. W.; Xie, H.; Ayana, E. K.; Bizimana, J.C.; Srinivasan, R.; You, L.; Lefore, N.; Gerik, T.; Richardson, J.W.; Clarke, N. (2018, December). Potential of Small-scale Irrigation to Improve Livelihoods in Ethiopia. American Geophysical Union (AGU) Conference.

Dile, Y. T.; Worqlul, A. W.; Xie, H.; Bizimana, J.-C.; Srinivasan, R.; You, L. Lefore, N.; Clarke, N. "Impacts of scaling small-scale irrigation on nutrient loading to freshwater ecosystems in Ethiopia". Invited Talk. March 2021. ILSSI Virtual Research Meeting.

ElDidi, H. "Experiential learning: Groundwater games and collective action in Ethiopia". January 2022. Sustainability and Development Conference.

ElDidi, H. "Groundwater governance: Findings from experiential games in Ethiopia". August 2022. Stockholm World Water Week.

ElDidi, H. The groundwater governance toolbox: Elements to increase sustainability of groundwater use in Africa. 2023 UN Water Conference Side Event. Groundwater: Potential and Pitfalls for Africa. Policy Seminar. Virtual. March 2023.

ElDidi, H.; Zhang, W. Getting Ahead of the Game: Experiential Learning on Groundwater Governance and Collective Action. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

ElDidi, H.; Zhang, W.; Gelaw, F.; Teka, N.; Mekonnen, D.; Yimam, S.; De Petris, C.; Ringler, C.; Meinzen-Dick, R. September 16, 2021. Experimental learning: Groundwater games and collective action in Eth… (slideshare.net) Tropentag 2021.

Gebregziabher, G.; Haileslassie, A.; Lefore, A. 2018. The viability of solar irrigation in Ethiopia. 2nd Amhara Agricultural Forum 2017 on 16 Jan 2018, Jacaranda Hotel, Bahir Dar, Ethiopia.

Gebrehaweria, G.; Hagos, F.; Lefore, N.; Haileslassie, A.; Barron, J. Impacts of household irrigation technologies on poverty reduction: Experience from Innovation laboratory for Small-Scale Irrigation (ILSSI). 2nd Amhara Agricultural Forum 2017 on 16 Jan 2018, Jacaranda Hotel, Bahir Dar, Ethiopia.

Gedfew, M.. Sustainable smallholder intensification through improved water management requires adjusted fertilizer recommendation, European Geosciences Union Conference. Austria. 23-28 April 2017.

Gedfew, M.P.; Schmitter, P.; Nakawuka, P.; Tilahun, S.; Steenhuis, T.; Langan, S. 2016. Partial Nutrient Balance at Farm plot level under Different Irrigation Water Management for Tomato production.

Poster presented on the Small Scale and Mirco Irrigation for Ethiopian Smallholders project. Amhara Agricultural Forum hosted by the Small Scale and Mirco Irrigation for Ethiopian Smallholders, a Canadian-Dutch funded project. Bahir Dar, 8-9 December 2016.

Gedfew, M.; Schmitter, P.; Nakawuka, P.; Tilahun, S. A.; Steenhuis, T.; Langan, S 2017. Sustainable smallholder intensification through improved water management requires adjusted fertilizer recommendation. 19th EGU General Assembly, EGU2017, proceedings from the conference held 23-28 April, 2017 in Vienna, Austria.

Getaneh, S. "Drivers to Adoption of Irrigated Fodder Technologies and its Impact on Smallholder Farmers' Income: Evidence from Innovation Lab for Small Scale Irrigation Project Sites, Ethiopia". October 2022. Bahir Dar University.

Getaneh, S.; Tesfaye, E.; Abera, D.; Bezabih, M. "Drivers to adoption of irrigated fodder technologies and its impact on smallholder farmers' income: the case of Amhara and SNNPR regions of Ethiopia." September 2022, Ethiopian Society of Animal Production (ESAP), Hawassa University, Ethiopia.

Getaneh, S.; Tesfaye, E.; Abera, D.; Bezabih, M. "Economic Impacts of Irrigated Fodder Adoption in Ethiopia: Evidence from Smallholder Dairy Producers". September 2022. Ethiopian Society of Animal Production (ESAP), Hawassa University, Ethiopia.

Giordano, M. Enabling resilient, equitable smallholder farming systems through improved agricultural land and water management (IWMI). Advancing Canada's Feminist International Assistance Policy through Agriculture and Food Systems, Ottawa, Canada. 6 -7 September 2017.

Giordano, M. A. 2015. International Water Management Institute. Unlocking the Potential for Smallholder Agriculture in Sub-Saharan Africa and South Asia. Dupont Event Summit.

Hagos, F.; Gebregziabher, G.; Lefore, N.; Haileslassie, A. 2018. Credit access and adoption of Small Scale irrigation technologies: case of ILSSI sites in Ethiopia. 2nd Amhara Agricultural Forum 2017 on 16 Jan 2018, Jacaranda Hotel, Bahir Dar, Ethiopia.

IFPRI, "Last Mile Energy Access for Productive Energy Use in Agriculture in Sub-Saharan Africa – What and Where is the Potential?" American Geophysical Union Meeting, December, 2019 in San Francisco, California.

IFPRI. (2018, December). Solar Irrigation Potential Poster. American Geophysical Union (AGU) Conference.

IWMI. "Dynamics of small scale irrigation development: Subsidizing and capitalizing pathway of scaling" presented at the 2nd International conference on 'Irrigation and Agricultural Development, at University for Development Studies (UDS), 25th to 27th February 2020 in Tamale, Ghana.

Jha, M.K.; Assefa, T.; Reyes, M.R. 2018. Modeling of Commercial Home Gardens under Conservation Agriculture and Drip Irrigation for Small Holder Farming in sub-Saharan Africa. *Annual International Conference of the American Society of Agricultural and Biological Engineers (ASABE)*. July 29 - August 1, 2018. Detroit, Michigan.

Kadyampakeni, D.; Appoh, R.; Barron, J.; Boakye-Acheampong, E. 2017. Analysis of Water Quality of Selected Irrigation Water Sources in Northern Ghana. International Conference on Irrigation and Agricultural Development (IRAD) at the University for Development Studies (UDS). Tamale, Ghana, 30-31 October 2017.

Lefore, N. (2019). "Applied research and models: Scaling agricultural water management in Sub-Saharan Africa". American Geophysical Union (AGU) Meeting, December, 2019 in San Francisco, California.

Lefore, N. "Asset based irrigation finance, constraints and opportunities". Energy Sector Management Assistance Program (ESMAP) | Solar Irrigation and Water Pumping, World Bank. Invited Virtual Talk. March 2022.

Lefore, N. Capacity for sustainable agricultural water use. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Lefore, N. "Solar Powered Irrigation: Achieving Inclusive Access for Women". Cultivating Change: Increasing Women's Access to Off-grid Productive Use of Energy for Agriculture, Power Africa, United States Agency for International Development (USAID). Invited Virtual Talk. March 2022.

Lefore, N., Taddele, Y. D., Worqlul, A. W., Srinivasan, R., Gerik, T. (2020). Economic and Nutrition Impacts of Irrigated fodder in Lemo woreda-Ethiopia. Presentation at Agricultural & Applied Economics Association (AAEA), Kansas City, MO.

Leh, M. Accounting for water use in FLID. "Investing in farmer-led irrigation development in sub-Saharan Africa: Business, research and development practices" Accra, Ghana. April 2023.

Leh, M.; Schmitter, P.; Minh, T. T. "Solar Suitability Mapping Framework". February 2021. Virtual IWMI Research Meeting.

Mekonnen, D. Enabling Investment in Irrigation in Sub-Saharan Africa Presentation: Small-scale irrigation: how to ensure equity and nutrition benefits—insights from ILSSI and beyond. Stockholm World Water Week. August 28, 2017.

Mekonnen, D. Expert validation workshop on irrigation development in Africa. March 2022. African Union Commission, Senegal.

Mekonnen, D. "Farmer Led Irrigation and Links to Nutrition and Gender". October 2020. CGIAR WLE Webinar.

Mekonnen, D. Beyond the Drinking Glass: Expanding our Understanding of Water-Nutrition Linkages (IFPRI/ILSSI session). Presentation: Irrigation-nutrition linkages: Insights from the ILSSI project and beyond,. Stockholm World Water Week. August 31, 2017:

Mekonnen, D. (2018). Irrigation-Nutrition Linkages. Presentation at National Information Platform for Nutrition – Ethiopian Public Health Institute, Addis Ababa, Addis Ababa.

Mekonnen, D. (2019). Irrigation-Nutrition Linkages. Presentation at USAID Mission Ethiopia, Addis Ababa.

Mekonnen, D. "Irrigation-Nutrition Linkages in Sub-Saharan Africa: Lessons from small scale irrigations in Ethiopia, Ghana, and Tanzania". October 2020. Invited Talk, Seminar in Water Economics online (SWELL).

Mekonnen, D. "Multi-Disciplinary and Multi-Sectoral Definitions and Descriptions of Water Availability: An Economist's Perspective". September 2022. AGU Chapman Conference. Golden, CO.

Mekonnen, D. "Small-scale irrigation and nutrition: Lessons from East and West Africa". September 2022. Feed the Future Innovation Labs Annual Meeting. National Press Club, Washington DC.

Meinzen-Dick, R. Women's Empowerment in (Irrigated) Agriculture. "Upscaling Solutions: Expanding access to irrigation for smallholders in sub-Saharan Africa", Water for Food Global Conference 2017, University of Nebraska. Lincoln, Nebraska. April 2017.

Meinzen-Dick, R. Tools for Groundwater Governance. NEXUS Gains Talks. November 2022.

Melaku, D. Market linkage pathway to catalyze smallholder farmers' investment in irrigation. International Livestock Research Institute, May 2023.

Minh, T. T. Agricultural research for development and FLID for all. "Investing in farmer-led irrigation development in sub-Saharan Africa: Business, research and development practices" Accra, Ghana. April 2023.

Minh, T. T. Bundling and catalyzing solar-based technologies and services: Experiences from Ghana, Ethiopia, and Mali. "Investing in farmer-led irrigation development in sub-Saharan Africa: Business, research and development practices" Accra, Ghana. April 2023.

Minh, T. T. "Evidence-based partnership strategies to accelerate innovation scaling in irrigated agricultural value chains". August 2022. Africa Climate Week, Libreville, Gabon.

Minh, T. T. "Finance needs of irrigation equipment suppliers expanding into new markets and taking on risks to reach smallholders market segments: Insights from Ghana and Mali". Stockholm World Water Week.

Minh, T.T. Partnering with private sector to reaching more smallholder farmers: Potential and constraint. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Minh, T. T. "Scaling innovation: adaptability and agility for climate smart agriculture". CGIAR Research Program on Water, Land and Ecosystems (WLE) Webinar.

Minh, T. T. "Systemic, adaptive approach for scaling groundwater irrigation in West Africa". March 2022. IWMI-ECOWAS Webinar.

Minh, T. T.; Schmitter, P.; Leh, M.; International Water Management Institute, Bahir Dar University, Rensys. Solutions supporting partnership to scaling small scale irrigation in Sub-Sahara Africa. Workshop, Bamako, Mali.

Muche, H.; Abdela, M.; Schmitter, P.; Nakawuka, P.; Tilahun, S. A.; Steenhuis, T.; Langan, S. 2017. Application of Deep tillage and Berken Maresha for hardpan sites to improve infiltration and crop productivity. ICAST conference 2017, Bahir Dar University.

Muche, H.; Abdela, M.; Schmitter, P.; Nakawuka, P.; Tilahun, S.A.; Steenhuis, T.; Barron, J.; Adie, A.; Blummel, M. 2018a. Biological and mechanical techniques to increase infiltration in rainfed agriculture of the Ethiopian highlands. 2nd Amhara Agricultural Forum 2017 on 16 Jan 2018, Jacaranda Hotel, Bahir Dar, Ethiopia.

Muche, H.; Abdela, M.; Schmitter, P.; Nakawuka, P.; Tilahun, S.A.; Steenhuis, T.; Barron, J.; Adie, A.; Blummel, M. 2018b. Promoting biological and mechanical techniques for enhancing rainwater infiltration and crop productivity in the Ethiopian highlands. 18th International Symposium on Sustainable Water Resources Development on 8-9 Jun 2018, Araba Minch University, Arba Minch, Ethiopia.

Muluken, E.; Minh, T. T.; Melaku, D. Multistakeholder Dialogues: A Pathway to Unlocking Innovation Scaling and Sustainable Agricultural Transformation. International Research Livestock Institute, May 2023.

Musumba, M.; Bizimana, J.-C. "Agricultural Diversification and Implications of Policy Shifts Among Smallholder Farmers". August 1 - 3, 2021. Agricultural & Applied Economics Association Annual Meeting, Austin, TX.

Nigussie, L.; Lefore, N.; Schmitter, P.; Assefa, T.; Tilahun, S.A. 2018. Gender and water lifting technologies for multiple purposes and Irrigation. 2nd Amhara Agricultural Forum 2017 on 16 Jan 2018, Jacaranda Hotel, Bahir Dar, Ethiopia.

Obuobie, E. "In-field Experience with Groundwater Governance in Northeast Ghana". August 2022. Stockholm World Water Week.

Ofosu, A. Multi-stakeholder dialogues: An interactive learning platform for FLID. "Investing in farmer-led irrigation development in sub-Saharan Africa: Business, research and development practices" Accra, Ghana. April 2023.

Ofosu, A. Promoting Solar Irrigation with shallow groundwater sources among Smallholder Farmers in West Africa. Energizing Agriculture and Enabling Just Energy Transitions in South Asia conference, Indian Institute of Technology Gandhinagar, Gujarat. February 2023.

Omondi, I. Gender Relations and Women's Empowerment in Small-scale Irrigated Forage Production in the Amhara and SNNP Regions of Ethiopia. Virtual FFD Meeting, International Livestock Research Institute. May 2023.

Passarelli, S. 2015. International Food Policy Research Institute. Tapping Irrigation's Potential for Women's Empowerment.Dupont Event Summit.

Richardson, J., Henry, B., Derseh, M. B., Worqlul, A. W., Taddele, Y. D.... (August 2020). Economic and nutrition impacts of irrigated fodder and crossbred cows on households in Lemo woreda-Ethiopia. Presentation at Agricultural & Applied Economics Association (AAEA), Kansas City, MO

Ringler, C. (2019). Achieving nutrition outcomes through improved agricultural water management: What are the options?. Presentation at Pennsylvania State University.

Ringler, C. (2020). Approaches to Strengthening Climate Resilience, Gender and Nutrition through Integration: Insights from the GCAN and ILSSI projects. Presentation at IWMI hosted seminar, Accra, Ghana.

Ringler, C. (June 2020). Harmonizing Actions on Water and Nutrition within the United Nations. Presentation at American Society of Nutrition, Virtual.

Ringler, C. "Integrating Nutrition in Irrigation Investments". October 2021. Water for Food Global Forum, Daugherty Water for Food Global Institute, University of Nebraska.

Ringler, C. "Irrigation and Scale: The Good, the Bad and the Ugly". May 2022. USAID-IFPRI Virtual Event.

Ringler, C. "Solar-powered irrigation: Constraints & opportunities under climate change?". May 2022. USAID-IFPRI Virtual Event.

Ringler, C. "Solar: Benefits and Limitations". August 2022. Stockholm World Water Week.

Ringler, C. "Solar or Diesel: A Comparison of Costs for Groundwater-Fed Irrigation in Sub-Saharan Africa Under Two Energy Solutions". November 2021. Africa Water and Sanitation Week. African Ministers' Council on Water (AMCOW).

Ringler, C. Solar Irrigation – Selected Findings from ILSSI. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Ringler, C. "Strengthening groundwater governance through social learning". November 2021. Africa Water and Sanitation Week. African Ministers' Council on Water (AMCOW).

Schmitter, P. Gebrehaweria, G. Tilahun, S. A. Lefore, N. Barron, J. Assessing the Effects of Smallholder Intensification through Improved Water Management Beyond "Business as Usual": a Multi-Facet Lens on Sustainability. Tropentag Conference 2017. Bonn, Germany, September 2017.

Schmitter P. (2018) Prospects of Solar Irrigation to accelerate Farmer-led irrigation in Sub-Saharan Africa. Presentation at the session: Accelerating Farmer-led Irrigation in Sub-Saharan Africa, at the Building Climate Resilience for Doubling Farmer's Income, IWMI-TATA Partners Meet 2018, Anand, India, 4th – 5th of December 2018.

Schmitter, P. Scaling irrigation for sustainability and resilience of people and systems amid climate change. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Schmitter P. (2018) Solar Irrigation Experiences from Sub-Saharan Africa. Presentation at the session: Accelerating Farmer-led Irrigation in Sub-Saharan Africa, at the Building Climate Resilience for Doubling Farmer's Income. IWMI-TATA Partners Meet 2018, Anand, India, 4th – 5th of December 2018.

Schmitter, P. "Catalyzing solar irrigation for a sustainable future". Stockholm World Water Week.

Schmitter, P.; Haileslassie, A.; Desalegn, Y.; Chali, A.; Tilahun, S. A.; Langan, S.; Barron, J. 2016. Improving on-farm water management by introducing wetting front detectors to small scale irrigators in Ethiopia. Presentation on the Small Scale and Micro Irrigation for Ethiopian Smallholders project. Amhara Agricultural Forum hosted by the Small Scale and Micro Irrigation for Ethiopian Smallholders, a Canadian-Dutch funded project. Bahir Dar, 8-9 December 2016.

Schmitter P.; Haileslassie A.; Desalegn Y.; Chali A.; Tilahun S.; Langan S.; Barron J. 2016. Improving on-farm water management by introducing wetting front detectors to small scale irrigators in Ethiopia. Solidarity in a competing world — fair use of resources September 18 - 21, 2016, organized by the University of Natural Resources and Life Sciences (BOKU Vienna), Austria

Tesfaye, M., Daba, T., Bizimana, J., Balana, B., & Gebregziabher, G. (2019). Farmers Willingness to Pay for Smallholder Water Lifting Technologies: Evidence from Ethiopia. Presentation at Agricultural & Applied Economics Association (AAEA), Atlanta, Georgia – USA.

Tesema M.; Schmitter P.; Nakawuka P.; Tilahun S.; Steenhuis T.; Langan S. 2016. Evaluating irrigation technologies to improve crop and water productivity of onion in Dangishta watershed during the dry monsoon phase. International conference on the advancement of Science and Technology (17-18 July 2016), Bahir Dar University, Ethiopia

Tessema, F. ILSSI's project research processes and progress in Bahir Dar zuria district. Partners' Feedback Workshop, Bahir Dar. November 2022.

Tetteh, R. 2017. Smallholder Irrigation Under Limited Water Supply in selected Communities of Northern Ghana. International Conference on Irrigation and Agricultural Development (IRAD) at the University for Development Studies (UDS). Tamale, Ghana, 30-31 October 2017.

Tilahun, S. Ensuring the capacity to sustain water for agriculture and resilience. ILSSI Symposium. Expanding investment in sustainable, small scale irrigation for agricultural-led growth, resilience and well-being: Lessons from 10 years of research. Washington, DC. March 2023.

Tilahun, S. Ensuring the capacity strengthening to sustain water for agriculture and resilience. "Investing in farmer-led irrigation development in sub-Saharan Africa: Business, research and development practices" Accra, Ghana. April 2023.

Tilahun, S.; P. Schmitter, P.; Nakawuka, A.; Yimer, D.; Lijalem, T.; Enku, T.; Steenhuis, T.; Langan, S.; Barron, J. 2016. Shallow Groundwater Recharge and its Potential for Smallholder Dry Period Irrigation in Lake Tana Basin Presentation on the Small Scale and Micro Irrigation for Ethiopian Smallholders project. Amhara Agricultural Forum hosted by the Small Scale and Micro Irrigation for Ethiopian Smallholders, a Canadian-Dutch funded project. Bahir Dar, 8-9 December 2016.

Van Biljon, C.; Ringler, C.; Bryan, E.; Mekennon, D. (2021) Does Small-Scale Irrigation improve WASH outcomes? Insights from rural Ethiopia. Washington, DC: International Food Policy Research Institute (IFPRI). IWRA 2021 Online Conference One Water, One Health.

Velpuri, N. M.; Rebelo, L.-M.; "Water Accounting: a water resources assessment for the Upper Niger basin, Mali". February 2021. Virtual Meeting. USAID Mission, Mali.

Worku, M. and Adie, A. "Potentials of hybrid Brachiaria grasses as a source of good quality fodder in the Ethiopian highlands". September 2020. The Joint International Grassland and International Rangeland Congress, Kenya.

Worqlul, A.W. (2020). "Nutrition potential of fodder and constraints of fodder production with small-scale irrigation systems in Ethiopia". 2020 Carter Conference at University of Florida, April 15-17, 2020 *(accepted; event cancelled).*

Worqlul, A. W.; Asres, Sisay; Dile, Yihun T.; Bizimana, Jean-Claude; Assefa, Tewodros; Tilahun, Seifu A.; Gerik, Thomas; Lefore, Nicole; Srinivasan, R.; Richardson, James W.; Clarke, Neville. (2018). Sustainable Intensification Assessment of Conventional and Conservation Agriculture in Ethiopia. Conference at Bahir Dar University, Ethiopia.

Worqlul, A. W.; Dile, Y. T.; Bizimana, J.-C.; Derseh, M. B. "Irrigated fodder in Ethiopia: Suitability and potential". December 2020. ILSSI Webinar.

Worqlul, A. W.; Dile, Y. T.; Jeong, J.; Adimassu, Z.; Lefore, N.; Gerik, T.; Srinivasan, R.; Clark, N. (2018, December). Effect of climate change on land suitability for surface irrigation and shallow groundwater potential in Ghana. American Geophysical Union (AGU) Conference.

Xie, H. (2018). Opportunity to invest in dry-season small-scale irrigation to enhance food security in Sub-Saharan Africa: Case studies in Ethiopia, Ghana and Tanzania. American Geophysical Union (AGU) Conference, Washington, DC.

Xie, H.; You, L. Opportunity to invest in dry-season small-scale irrigation to enhance food security in Sub-Saharan Africa: Case studies in Ethiopia, Ghana and Tanzania. AGU annual conference. Washington, DC. December 10, 2018.

Yegbemey, R. N.; Schreinemachers, P.; Tignegre, J. B.; Diarra, B. G. "Development of the vegetable seed sector in Mali and opportunities for irrigated seed production". Invited Talk. March 2021. ILSSI Virtual Research Meeting.

Yilak, D. L.; Tilahun, S.A.; Schmitter, P.; Nakawuka, P.; Enku, T.; Tibebu Kassawmar, N.; Steenhuis, T.S. 2015. Determining the groundwater potential for agricultural use in Ethiopian Highlands. 10th Alexander von Humboldt Conference 2015, Water-Food-Energy River and Society in the Tropics, EGU Topical Conference Series, Addis Ababa, Ethiopia, 18–20 November 2015

Yimam, A. Y.; Nakawuka, P.; Schmitter, P.; Tilahun, S. A.; Bekele. 2018, A.M. Rainfall-Runoff Process and Groundwater Recharge in the Upper Blue Nile Basin: The Case of Dangishta Watershed. 6th International Conference on the advancements of Science and Technology (ICAST) on 5-6 Oct 2018, Bahir Dar Institute of Technology, Bahir Dar, Ethiopia

You, Liangzhi; Xie, Hua; Dile, Yihun; Worqlul, Abeyou Wale; Bizimana, Jean-Claude; Srinivasan, Raghavan. (2018, December). Opportunity to invest in dry-season small-scale irrigation to enhance food security in Sub-Saharan Africa: Case studies in Ethiopia, Ghana and Tanzania. American Geophysical Union Conference.

Zhang, W.; ElDidi, H.; Gelaw, F.; Teka, N.; Mekonnen, D.; Yimam, S.; De Petris, C.; Ringler, C.; Meinzen-Dick, R. Symposium "Games for Triggering Collective Change in Natural Resource Management. August 17-31, 2021. Getting Ahead of the Game: Raising Awareness of Groundwater Depletion in Ethiopia.

Outreach/Engagement

Adamseged, M. E.; Melaku, D. (2023) A glimpse of hope in the role of private sector engagement for scaling irrigation innovation bundles in Ethiopia. Feed the Future Innovation Lab for Small Scale Irrigation Blog. March 2023.

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