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Solar Powered Irrigation Systems (SPIS) Potential and Perspectives in sub-Saharan Africa

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Aknowledgements

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List of Abbreviations

AfDB	African Development Bank
AWM	Agricultural Water Management
BADF	Banque Agricole du Burkina Faso
CSA	Climate Smart Agriculture
DGAHDI	General Directorate of Hydro-agricultural Development and Irrigation
ESMAP	Energy Sector Management Assistance Program
FAO	United Nation Food and Agriculture Organization
XOF	West African Franc
GGGI	Global Green Growth Institute
GHG	Greenhouse Gas
GIZ	German Development Cooperation
ICARDA	International Center for Agricultural Research in the Dry Areas
IEA	International Energy Agency
IFC	International Finance Corporation
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
ISFM	Integrated Soil Fertility Management
IWMI	International Water Management Institute
MFIs	Microfinance Institutions
Mha	Million hectares
MWE	Ugandan Ministry of Water and Environment
RWR	Renewable Water Resources
SDGs	Sustainable Development Goals
S-ISP	Solar Irrigation Service Provider
SLWM	Sustainable Land and Water Management
SNNP	Southern Nations, Nationalities and Peoples
Solar PV	Solar Photovoltaic
SPaRC	Solar Power as a Remunerative Crop
SPIS	Solar Powered Irrigation Systems
SSA	Sub-Saharan Africa
TRWR	Total Renewable Water Resources
ULE Drippers	Ultra-Low-Energy Drippers
USAID	United States Agency for International Development
USD	United States Dollar
VAT	Value-added Tax
WA+	Water Accounting Plus
ZAABTA	Zirobwe Agaliawamu Agri-business Training Association

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Burkina Faso

Formation des UAT in Burkina Faso

Executive Summary

Africa experiences more droughts than any other region in the world. It is also the second most affected region in terms of floods. At least 215 million people were impacted by these extreme weather events between the period of 2010-2022. The high dependence on rainfed subsistence agriculture and the degradation of land and forest resources (a result of poor farming practices, illegal or poor fishing practices, and livestock grazing) aggravates the impacts of climate change on people's lives. It amplifies vulnerabilities and limits adaptative capacity to the impacts and risks associated with climate change.

Agriculture is the main source of income and employment for the majority of Africa's population. In sub-Saharan Africa it is estimated that investment in agriculture is up to 11 times more effective in reducing extreme poverty than investment in any other sector. Therefore, the agriculture and water sectors are fundamental drivers for economic growth, poverty reduction, food security and community development.

Reversing the current climate change trajectory requires innovative solutions to preserve the environment and ensure biological diversity. Climate-Smart Agriculture (CSA) and Nature-based Solutions are essential components of the global effort to achieve the goals of the Paris Agreement. They complement decarbonization by helping protect us from climate change impacts and establishing climate-resilient societies - through the development of adaptive capacities.

This report is based on comprehensive two-year projects that were implemented in three sub-Saharan African countries: Burkina Faso, Uganda and Ethiopia. The projects were undertaken in collaboration with the Global Green Growth Institute's (GGGI) national partners in each country.

This report evaluates the recognized and demonstrated impact of CSA practices on yields. It also examines the productivity of key agricultural crop value chains and showcases an approach to locally mainstreaming CSA that enhances value chain development. It discusses the potential role of small-scale solar-powered irrigation technologies in improving agricultural productivity - by improving food security and the livelihoods of smallholder farming communities. It also analyses current and projected irrigation potential with respect to solar energy, land and freshwater availability in Africa. In doing so it demonstrates that fears of a looming crunch between population growth, freshwater and land availability are unwarranted - at least in a mid-term plan aimed at the wide-scale adoption of small-scale irrigation technologies.

Effective regulations for water abstraction and water use need to be tailored to prevent environmental challenges - such as aquifer depletion, water pollution, soil degradation and low field application efficiency. In order to overcome challenges and barriers to large-scale uptake of CSA (including solar-powered irrigation), this report showcases a tailored approach to capacity-building among of key stakeholders, technical guidelines enabling public investment pathways, and financial business models.

Burkina Faso

1. General context

Africa is highly vulnerable to climate change because of social, economic and environmental factors. Climate change will interact with non-climate drivers to amplify the vulnerability of agricultural systems - particularly in the semi-arid areas of Africa (Niang, et al., 2014). Urgent actions are required to combat the impacts of climate change.

The breakthrough objective for the food and agriculture sector is to make climate-resilient, sustainable agriculture the most attractive and widely adopted option for farmers by 2030 (IEA, 2022). The agrifood sector requires transformative changes (or breakthroughs) to reduce emissions and ensure food and nutritional security. Changes should focus on making smallholder producers more climate resilient and be achieved without damaging natural resources. Innovations in practices, technologies, policies, institutions and financing - across various subcomponents of the agricultural value chain - are necessary to achieve the breakthrough objective.

The Global Green Growth Institute (GGGI) - in collaboration with its technical and financial partners - recognizes the necessity of promoting Climate Smart Agriculture (CSA) in Africa. The CSA approach promotes increased agricultural productivity, adaptation to climate change, and mitigation of greenhouse gas emissions.

Many countries in Africa face challenges in meeting the growing demands of food, water and energy - particularly as they experience increasingly severe climate conditions. Meeting these demands forms the basis of sustainable economic and environmental development in a country or a region. Nevertheless, sectors that are discussed in this report (i.e. food, water and energy) form a nexus of high correlation. A change in one sector will certainly have direct - or indirect - impact on another sector. According to the United Nations Food and Agriculture Organization (FAO), the global demand for food is expected to rise to 60% by 2050. Increasing food demand puts a great strain on existing water and energy systems which are needed for agricultural usage - such as irrigation and fertilizers. Agriculture, being one of the world's largest economic sectors, accounts for roughly 70% of global freshwater and 5% of global energy consumption. Supply of sufficient water is key for successful irrigation as it eventually results in improved agricultural yields. Simultaneously, the supply of water - from the source to the irrigation field - requires energy.

Burkina Faso

Surface water bodies are the most common source of water due to ease of transportation. However, underground water is also commonly tapped for irrigation in instances where surface water is unavailable. Globally, surface water makes up roughly 57% of current irrigation water demand while underground sources make up the remaining 43%. Irrespective of the type of water sources, irrigation requires a significant amount of energy. While electric pumps are common and reliable in grid areas, a large part of the demand in off-grid areas is met through fossil fuel-based generators. The disadvantages of this fossil energy supply are known and result in high operating costs and frequent maintenance. They also contribute to environmental damage as ground water soil can be contaminated by fuels, lubricants or CO_2 emissions. The total Greenhouse Gas (GHG) emissions from the agri-food chain contribute to over 20% of global GHG emissions each year. Replacing fossil energy supply with Renewable Energy (RE) sources is an attractive alternative as they feature several economic, managerial and ecological advantages.

Solar Powered Irrigation Systems (SPIS) are the most attractive renewable alternative to address the problems associated with fossil fuel-based irrigation. They have a low operating cost, require minimum maintenance, are easy to use and, most importantly, are environmentally friendly. An off-grid solar pumping system that replaces a typical diesel generator unit will save about 1kg of CO_2 per kilowatt-hour of output (FAO/USAID, 2015). Given the continuous fall in cost of solar photovoltaic (solar PV), SPIS are becoming a more economically viable option for water supply in the agriculture sector. SPIS can potentially provide a significantly positive impact on the environment, food yields, ground water resource management, gender and access to energy. SPIS have proven to be technically viable and competitive options that have attractive returns on investment. They also have a direct impact on woman empowerment because women are the backbone of rural agriculture in Africa. However, appropriate policies and frameworks on infrastructure are essential for successful scaling-up. This is because many farmers in Africa do not irrigate or are unaware of the advantages of solar powered pumps. In instances where this is not the case, non-technical barriers - such as access to finance - hinder the adoption of such systems.

Despite multiple interventions and efforts by different development and research organizations in various countries, it is reported that the deployment of SPIS has encountered institutional roadblocks and challenges to implementation.

In order to overcome such barriers, GGGI implemented a 2-year pilot project in Burkina Faso, Ethiopia and Uganda which was funded by the Government of Denmark. The projects focused on building the capacity of farmers and institutions. They also sought to identify and put in place bankable (and innovative) business models and arrangements between smallholder farmers, SPIS technology providers and local financial institutions. In doing so, it is expected that an enabling environment can be created that will encourage farmers and the private sector to adopt CSA solutions.

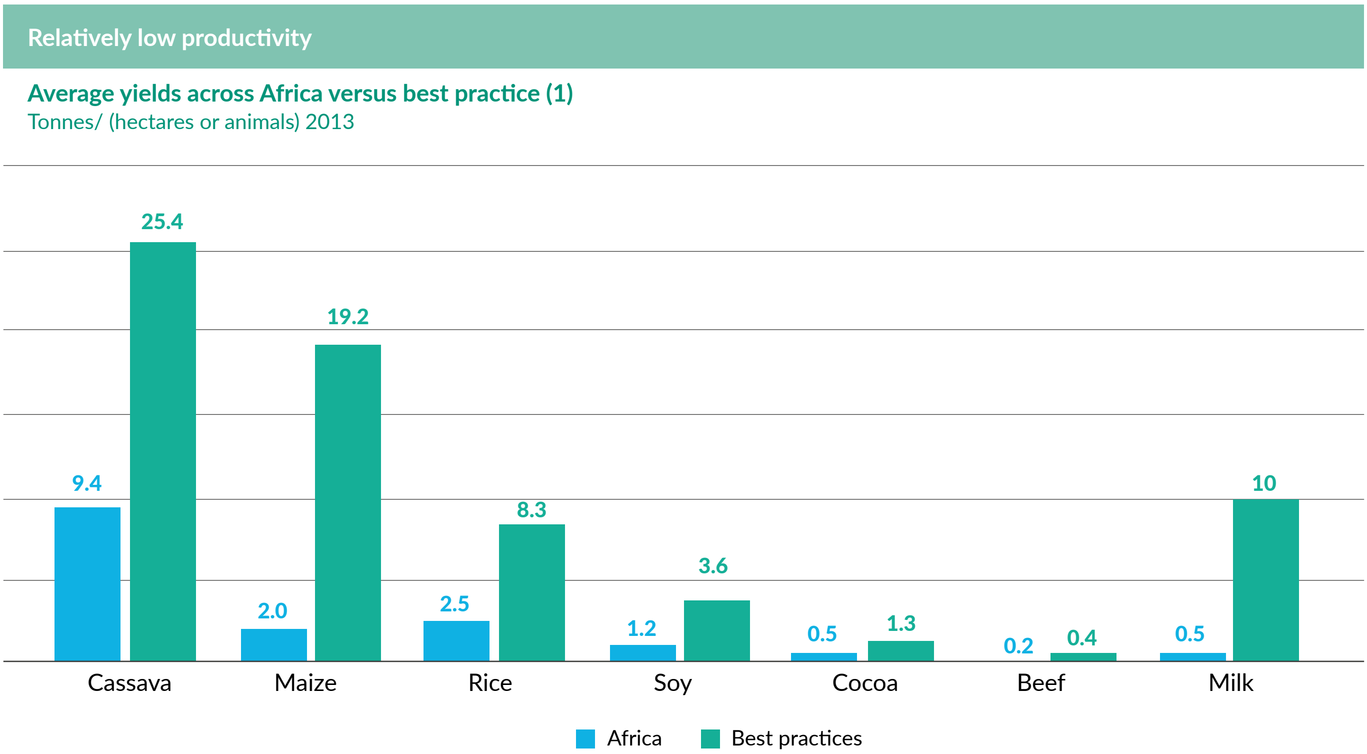
Senegal

2. Why are mainstreaming irrigation practices crucial in African agricultural policies?

There are a number of success stories about climate-smart agriculture practices in major agro-ecological zones in Africa. Studies have found increases in crop yields, incomes and the adoption of CSA practices by farmers. They consist of technological options based on the principles of Sustainable Land and Water Management (SLWM); Integrated Soil Fertility Management (ISFM), risk management approaches such as seasonal weather forecasts, index-based crop insurance and safety nets; and participatory climate smart village approaches (Nyong et al., 2007; Mugwe and Otieno, 2021; Bationo et al., 2012; FAO, 2010; Giller et al., 2009; Liniger et al., 2011; Neate, 2013; Nielsen and Reeberg, 2010; Blessing et al., 2017; Zougmore, 2014).

While recognizing that CSA interventions and practices are context-specific (McCarthy & Brubaker, 2014), the goal of achieving transformative change in the agrifood sector cannot happen without scaling up proven innovative technology solutions. This must occur by incorporating fit-for-purpose business and financial models to attract investors. Investors have identified key technologies - covering both on-farm products and post-harvest services - as being of particular interest. Demonstrating significant CSA impact benefits - in terms of adaptation, mitigation, biodiversity benefits and/or improved productivity (Casey et al., 2021) – appears to be an effective approach to encouraging transformative change. Solar-powered irrigation systems, in particular, seem to be the sustainable agricultural preference when considering socio-economic factors (i.e. the use of labor, low operation cost, etc.) and environmental factors (i.e. low-carbon emissions). In studies undertaken by Dalberg in 2019 focused on agriculture in sub-Saharan Africa, it was found that irrigation practices could boost maize yields by 141–195% while high-value crops could also increase by 300% per year (Dalberg, 2019). Given their current low yields under agricultural water management, there is a high potential for yield increases in most African countries (AfDB, 2016; Figure 1). The International Water Management Institute's (IWMI) comprehensive assessment of Agricultural Water Management (AWM) benefits assessed that 75% of additional food in the next decade could come from the world's low-yield farmers - increasing their production to 80% of the amount achieved by high-yield farmers (IWMI, 2016).

Figure 1. Average yield yields across Africa versus best practices



Notes: (1) Best practices = average of top 10 countries in the world by yield in the commodity.
Source: FAOstat; World Bank; IFPRI; IITA, ICCO, Dalberg analysis).

African agriculture is currently predominantly rainfed and it is particularly susceptible to climate change (Niang and Ruppel, 2014). This means that future crop yields will be significantly reduced - putting the food security of smallholders particularly at risk (Sidibe et al., 2017). An increase in irrigation - where it is hydrologically, technically and financially feasible - can form an important strategy to protect food security and livelihoods. This is the reason why countries in sub-Saharan Africa are currently focusing on expanding irrigated agriculture to enhance food security and livelihoods (African Union, 2020). With less than 6% of agricultural land currently irrigated (Wiggins and Lankford, 2019) and a population growth rate of around 3%, it is estimated that irrigated land in Africa will need to expand by 25% by 2025 to feed the population and reduce poverty (African Union, 2020).

3. What is solar irrigation potential in Africa?

The potential of solar irrigation depends on three resources: sunshine, freshwater and land.

3.1 Solar Energy Potential (PV potential) in Africa

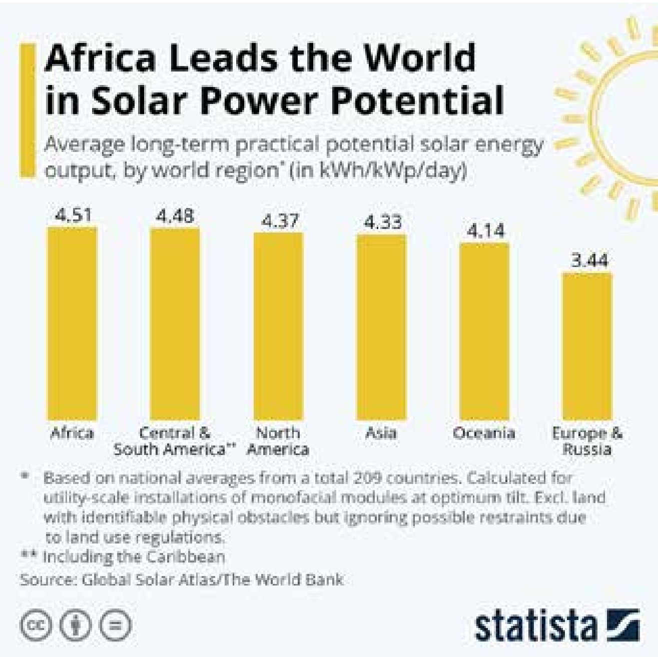
Africa offers the installation of solar energy on a scale of 4.5kWh/kWp/day - the highest in the world (Figure 2). Globally, only the countries in Africa (when calculated together) average above the threshold of 4.5 kWh/kWp per day (Armstrong, 2022). In addition, since 2012 the utility-scale generated by solar energy projects in Africa has reduced to 61% - this is lower than USD 1.30 per watt. However, some of the challenges include the high cost of production and waste management.

Currently, over 5 million African households use off-grid systems such as pay-as-you-go. Therefore, it is estimated that an African off-grid solar market could offer an opportunity to save up to USD 24 billion annually. Moreover, the International Renewable Energy Agency (IRENA) estimates that with the best enabling policy, power generation in Africa using solar energy will grow to 70 Gigawatts by 2030. By reducing costs and increasing eco-friendly features, the growth potential of solar energy can be realized.

Land availability is one of the biggest challenges in the solar sector. This is because solar PV plants require a vast array of land. Therefore, countries with issues regarding land ownership, terrains and local politics may not have adequate space for solar plants. In such contexts, the agrivoltaics system appears to be a promising alternative solution (GGGI ongoing work in Rwanda).

In summary, the level of solar irradiation is particularly location-specific and depends on geographic latitude and the clearness of the sky. The higher the irradiation, the smaller the required area of PV panels and supporting land will be. Solar PV panels constitute a leading share of the total cost for SPIS. Therefore, solar insolation has a significant effect on the costs of SPIS and is a factor influencing economic - rather than technical – feasibility. This is as sufficiently large PV panels can provide electricity even at low levels of irradiation (Kelley et al. 2010).

Figure 2. Average potential of solar energy around the world



3.2 Freshwater and land potential

One of the major questions on the future of irrigation is whether there will be sufficient freshwater to satisfy the growing needs of agricultural and non-agricultural users. Agriculture already accounts for roughly 70% of the freshwater withdrawals in the world and is usually seen as the main factor behind the increasing global scarcity of freshwater. In the framework of its study ***World Agriculture: Towards 2015/2030 (AT2030)***, the United Nation Food and Agriculture Organization (FAO) reviewed the current status and role of irrigation in 93 developing countries and assessed the likely situation of irrigation in 2015 and 2030.

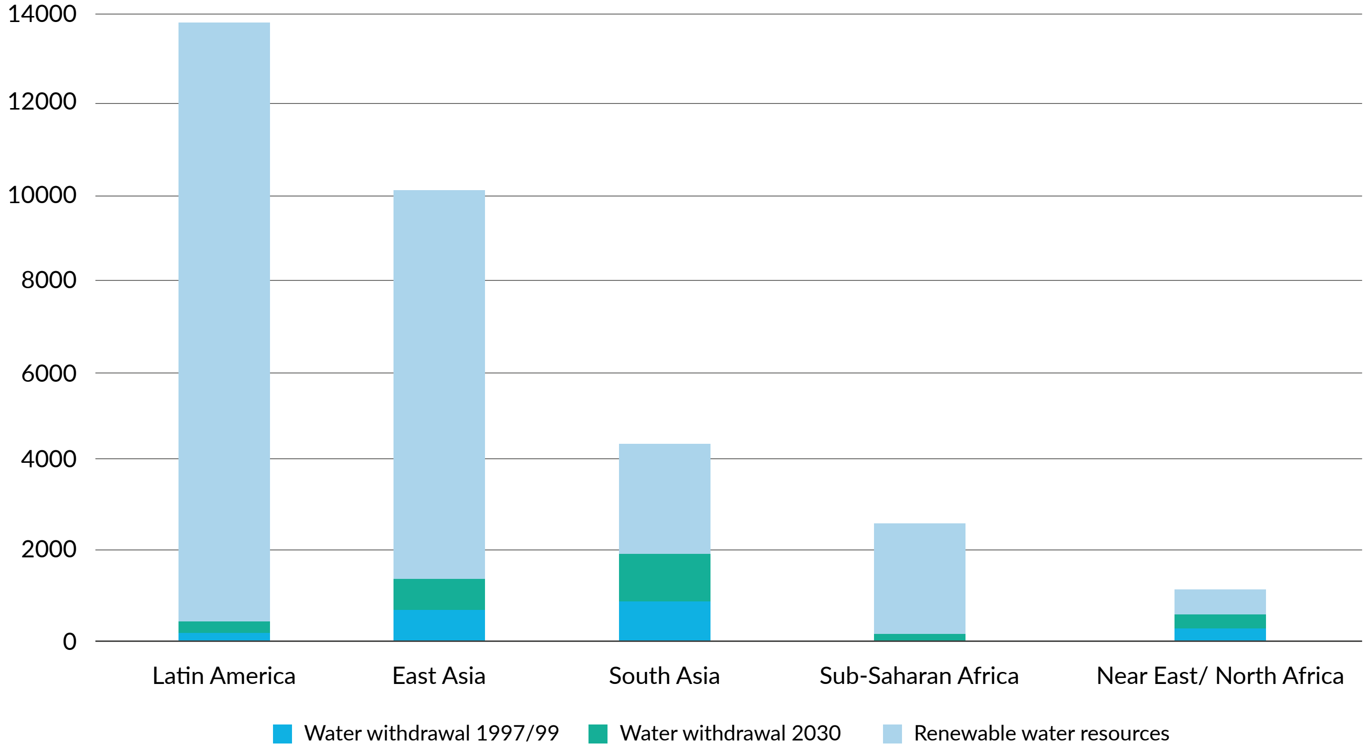
In the ***AT2030*** study, a water balance-approach was used to estimate current and future water use in agriculture for 93 developing countries. This was based on a global map of irrigation and climatic datasets. The estimation of the water balance for an average year was based on three digital geo-referenced data sets for precipitation (Leemans and Cramer, 1991); reference evapotranspiration (Fischer et al., 2013); and soil moisture storage properties (FAO, 1995). In most regions there is expected to be no shortage of land or water for irrigation, but serious problems are predicted to persist in certain countries and regions.

The study showed that fears of a looming crunch between population growth and land availability are unwarranted. If, at the global level, the production potential exists to cope with increasing demand, developing countries will be more dependent on agricultural imports. It also means that production in poor areas must increase if food security is to improve. Globally, use of land and water resources for agriculture remains largely untapped. The globally positive situation should not hide the fact that in large areas of the developing world agriculture is facing its limits - either by a lack of water or a lack of land.

Irrigation potential is an important indicator to help assess future irrigation development. It is expressed in units of area and indicates how close countries are from the maximum extension of irrigated land (see ***Table 1.*** data for Ethiopia, Burkina Faso, Uganda and Senegal). Irrigation potential was taken into account in irrigation projections. The irrigation projections to 2030 assume that agricultural water demand will not exceed the available water resources.

Globally, roughly 7% of renewable water resources were withdrawn for irrigation in 1997/99. ***AT2030*** projections for developing countries imply a 14% increase in water withdrawals for irrigation by 2030. By then only 8% of their renewable water resources are expected to be used for irrigation. The shares in sub-Saharan Africa and Latin America are predicted to remain very small (Figure 3).

Figure 3. Irrigation and water resources, 1997/99-2030



While available irrigation potential is almost fully developed in the rest of the world, Africa has much of its potential underdeveloped. Data on agriculturally-managed water and irrigation-equipped areas is uncertain. Uncertainties are largely because of the undocumented expansion of farmer-led irrigation. However, available data indicates that the agriculturally water-managed area in Africa is only 36% of the estimated 42.5 Mha irrigable potential (Molden, 2007; Woodhouse, 2017). The available water and land provide an important opportunity to expand AWM and meet the futures' food demands (Figure 4).

Figure 4. Agriculturally Water Managed Area in Africa

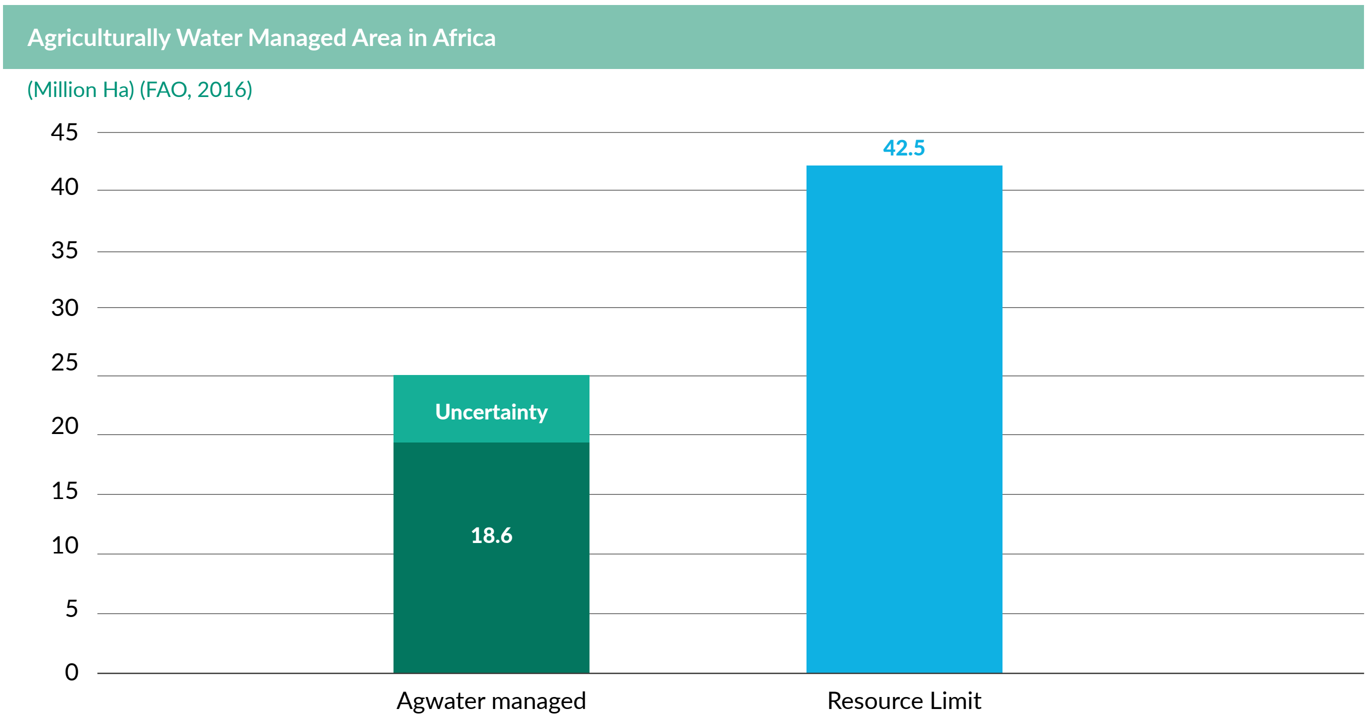


Table 1. Country Fact Sheet (Ethiopia, Burkina Faso, Uganda and Senegal)

		Year	Value	Unit
ETHIOPIA				
Renewable Water Resources (RWR)	**Long-term average annual precipitation**			
	Depth		848	mm/year
	Volume		936.4	km³/year
	Long-term average annual RWR			
	Total Actual (TRWR)		122	km³/year
	TRWR per capita	2014	1 227	m³/year
Water Withdrawal	**Pressure on water resources**			
	Total freshwater withdrawal as % of TRWR Agricultural water	2016	8.648	%
	withdrawal as % of TRWR	2016	7.94	%
	Irrigation Potential		2 700 000	Ha
	Total area equipped for irrigation	2015	858 340	Ha
BURKINA FASO				
Renewable Water Resources (RWR)	**Long-term average annual precipitation**			
	Depth		748	km³/year
	Volume		205.1	m³/year
	Long-term average annual RWR			
	Total Actual (TRWR)		13.5	km³/year
	TRWR per capita		745.6	m³/year
Water Withdrawal	**Pressure on water resources**			
	Total freshwater withdrawal as % of TRWR Agricultural water	2005	6.059	%
	withdrawal as % of TRWR	2005	3.116	%
	Irrigation Potential		165 000	Ha
	Total area equipped for irrigation	2011	54 275	Ha
UGANDA				
Renewable Water Resources (RWR)	**Long-term average annual precipitation**			
	Depth		1 180	km³/year
	Volume		285	m³/year
	Long-term average annual RWR			
	Total Actual (TRWR)		60.1	km³/year
	TRWR per capita		1 540	m³/year
Water Withdrawal	**Pressure on water resources**			
	Total freshwater withdrawal as % of TRWR Agricultural water	2008	1.06	%
	withdrawal as % of TRWR		0.4309	%
	Irrigation potential	2008	90 000	Ha
	Total area equipped for irrigation	2012	11 137	Ha
SENEGAL				
Renewable Water Resources (RWR)	**Long-term average annual precipitation**			
	Depth		686	km³/year
	Volume		134.9	m³/year
	Long-term average annual RWR			
	Total Actual (TRWR)		38.97	km³/year
	TRWR per capita		2 576	m³/year
Water Withdrawal	**Pressure on water resources**			
	Total freshwater withdrawal as % of TRWR Agricultural water	2002	5.699	%
	withdrawal as % of TRWR	2002	5.299	%
	Irrigation potential		409 000	Ha
	Total area equipped for irrigation	2002	119 680	Ha

Field visit site, Burkina Faso

4. Overview of SPIS: what are the key comparative advantages of combined irrigation methods?

In SPIS, electricity is generated by solar PV panels and used to operate pumps for the abstraction, lifting and/or distribution of irrigation water. SPIS can be applied in a wide range of irrigation initiatives - from individual to large-scale irrigation schemes.

The solar generator may also be connected to battery storage and inverter technology in order to store surplus energy for other on-farm uses – such as household electrification or productive appliances. Though there are many promising developments in battery technologies, they are currently still costly, maintenance-intensive and require regular replacement. Currently, a more cost-effective option for storing energy is in the form of water pumped to an elevated tank or reservoir during sun hours. The respective SPIS components can be combined in different configurations - depending on the site-specific biophysical and socioeconomic conditions (Sontake and Kalamkar, 2016; GIZ, 2016).

There are different farmland irrigation methods which, ultimately, define the magnitude of field losses and affect the efficiency of field irrigation. Appropriate and relevant irrigation methods are important to ensuring sustainable planning - especially in terms of water use and water management. The commonly used irrigation methods are surface, sprinkler and drip irrigation. Each method has its own advantages and disadvantages depending on the soil, topography, type of crop, climate, water availability (and quality) and level of investment. These are the guiding factors for selecting an adequate irrigation method. Solar pumps can support drip, sprinkler, pivot or flood irrigation methods when appropriately sized. Depending on the local conditions, a system can also include filtration or fertigation equipment.

The irrigation efficiency of sprinkle irrigation ranges between 60% and 90% - with an average of 75% (Gilley and Watts, 1977; Waller and Yitayew, 2016). To ensure efficient utilization of applied water, it is important that irrigation devices are properly installed and operated under design conditions and that there is a good understanding of soil properties, conditions and the anticipated water flow within the profile. For the latter, the HYDRUS model (Šimůnek et al., 2016) has been widely applied to simulate soil water **dynamics under irrigation**. It uses various methods (e.g. drip and surface/flood) and management scenarios.

The irrigation efficiency of sprinkle irrigation ranges between

60% and 90%

Drip systems provide the opportunity to cultivate vegetable crops even at higher water salinity than normal conditions (Karlberga et al., 2007; Li et al., 2022). In general, sprinkler and drip irrigation methods are both preferred over surface irrigation methods in saline environments due to their controlled nature of water application. This is because they allow frequent irrigation with small quantities of saline water that leads to lower salt buildup in the zone and better crop performance. While the drip system is the most suitable approach, its high initial cost is a major limiting factor that limits its use to only high-value and widely spaced crops. Therefore, the choice of irrigation system does not only depend on system performance, but also on economics. Many studies have shown that drip irrigation significantly increases crop yield and enhances water use efficiency compared with conventional flooding irrigation (Liu et al., 2021). Drip irrigation also reduces yield variability and increases nutrient use efficiency (Zhang et al., 2011). In addition, the application of fertilizer through the drip irrigation system also helps to utilize fertilizers more efficiently if judiciously applied. This can help reduce on-farm expenses and the risk of non-point source water pollution from run-off and nutrient leaching. The integration of an appropriate **water filter** - depending on the quality of water source - is of particular importance to avoid clogging of the drippers. The Massachusetts Institute of Technology's Global Engineering and Research Lab has developed a new dripper named the Ultra-Low-Energy (or ULE) Dripper that requires a fraction of the activation pressure and energy to operate when compared with traditional and commercially available drippers. Promising testing of the use of solar panels to power the ULE Dripper technology is being undertaken by the International Center for Agricultural Research in the Dry Areas (ICARDA) in the Middle East and North Africa region.

Burkina Faso

Burkina Faso

5. SPIS performance and benefit

Recent studies showed the advantages of the use of photovoltaic energy over that of the diesel generator is in terms of the net present cost and the cost of energy. While the initial cost of a typical solar water pump system is higher than that of a diesel pump (when accounting for fuel costs and longer lifetime value), the solar water pump costs less over a pump lifecycle (GET. invest, 2019; Shouman et al., 2016; Dalberg, 2019).

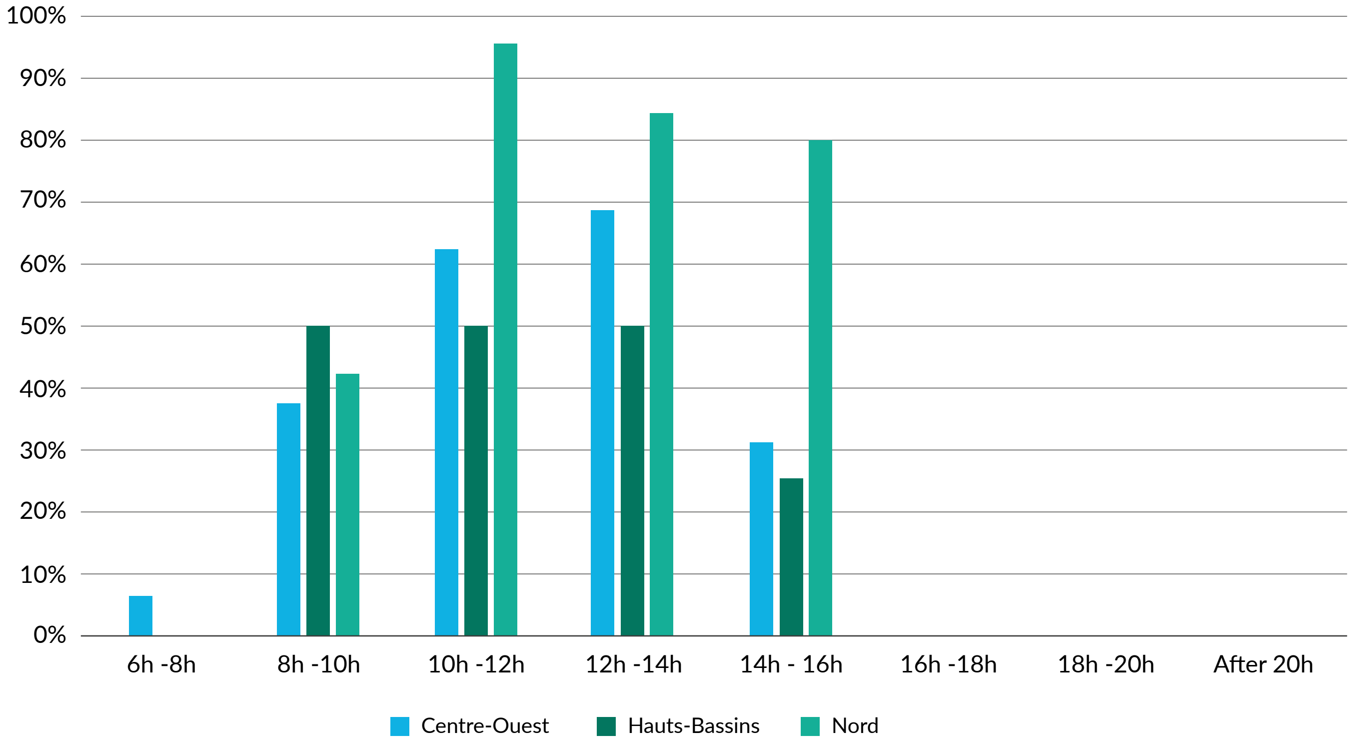
5.1 Burkina Faso case study:

The objective of the GGGI project in Burkina Faso was to provide farmers with SPIS that meet their needs, are affordable, and have a positive impact on their productivity. To achieve this objective in the best way and minimize risks, the project team chose to install four different types of SPIS on five pilot sites. These systems were rigorously evaluated in the field to determine their performance - resulting in the selection of the DCPM 6-24-48-550 (surface pump) and 4DLR6-65-72-550 (submersible pump) solar pumps. This test demonstrates the reliability of SPIS to producers - convincing them to replace their polluting diesel pumps with environmentally friendly SPIS.

The next step of the project involved installing 46 SPIS. This was undertaken once the most efficient and suitable pumps had been identified. Three primary criteria guided the selection of sites and beneficiaries for the installation of SPIS. The first was based on the agro-climatic zones of Burkina Faso; the second on the availability of water resources for irrigation (mainly from dam banks and wells); and the third on the beneficiary producer's reputation, dynamism and ability to inspire change in other individual producers and women's cooperatives. In collaboration with the General Directorate of Hydro-agricultural Development and Irrigation (DGAHDI) and the regional directorates of agriculture, 46 sites (including 38 individual producers and eight women's cooperatives) were identified in the Centre-Ouest, Hauts-Bassins and Nord regions for participation in the pilot phase. Analysis of the areas farmed revealed that in these regions, the average area farmed by producers varied from 0.34 ha (in the Nord region) to 0.53 ha (in the Centre-Ouest region).

Monitoring revealed that the pumps were operated daily from 08:00 to 16:00 - with a peak use between 10:00 and 14:00. Data analysis indicated that 80.43% of beneficiaries used the SPIS during the peak period between 10:00 and 12:00; 76.09% between 12:00 and 14:00; 58.70% between 14:00 and 16:00; and 41.30% between 8:00 and 10:00 (Figure 5). In addition, it was found that 46.34% of beneficiaries owned a petrol motor pump; 21.95% a diesel or petrol motor pump modified to run on gas; 26.83% a gas motor pump; and 4.88% a diesel motor pump. Despite the installation of SPIS on their fields, the farmers continued to use polluting pumps for irrigation needs early in the morning (between 06:00 and 08:00) and in the evening (after 17:00). This was due to the low sunshine at these times. A recommendation from the study was that a storage system and an appropriate irrigation method be integrated into SPIS to enable farmers to abandon the use of polluting pumps.

Figure 5. Pump operating times; Source: field survey (March-May 2023)



An evaluation of beneficiaries' satisfaction was carried out with a focus on producers' water requirements and the performance of SPIS. The assessment of on plots equipped with SPIS revealed an average water consumption of 15.526 m3 (or 3.8 liters/m2) in the Hauts-Bassins and Centre-Ouest regions, but a higher water consumption of 21.9 m3 (or 6.44 liters/m2) in the Nord region. Performance measurements were carried out on the submersible and surface pumps. For the submersible pump, the estimated average time to fill a 20-liter can varied from 11.86 seconds with a good flow rate to 19.00 seconds with a low flow rate. Depending on weather conditions, this was equivalent to a daily flow rate of between 19m3 and 30.35m3. Similarly, for the surface pump, the estimated average filling time for a 20-liter canister ranged from 5.47 seconds with a good flow rate to 9.11 seconds with a low flow rate - resulting in a daily flow rate of between 39.5m3 and 66m3. The results show that these pumps are well suited to farmers' needs and is evidenced by a high level of satisfaction. 58.70% of growers reported that they were "Very satisfied"; 21.74% were "Satisfied"; and 19.57% "Moderately satisfied" with the pumps supplied by the GGGI project. This underlines the pumps' ability to meet farmers' water needs based on their geographical location and crop type.

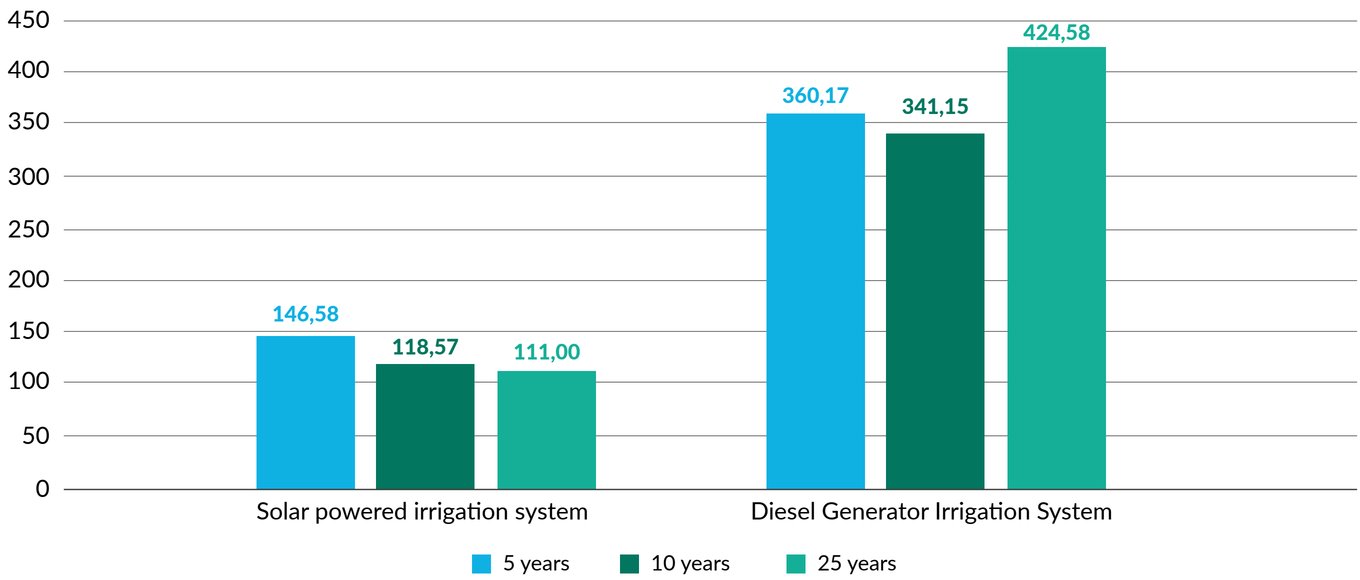
In addition to assessing the performance of SPIS, a comparative estimate was based on the financial gain of farmers who had replaced their diesel, petrol or gas motor pumps with SPIS. The gain over a cropping period was estimated at between at between XOF 55,582 (USD 101.05) and XOF 78,154 (USD 142.1), depending on the type of fossil fuel used and the location (see Table 2 and Figure 6).

Table 2. Estimated financial gain by type of hydrocarbon avoided per producer per crop year

Total pumping time avoided (h)	Gasoline motor pump					
	Ratio R (%)	Avoided pumping ime (h)	Quantity of fuel (liter/day) avoided for a ref consumption of 1.5l/h	Financial gain/day for a reference fuel cost of 850 XOF/liter	Financial gain/90-day campaign with an estimated frequency of 15 times/month (XOF)	Financial profit/ producer/campaign (XOF)
			1.5	850	45	
Centre-Ouest						
13.36	71.43%	9.5	14.3	12,167	547,507	76,649
Hauts-Bassins						
17.44	25.00%	4.4	6.5	5,558	250,119	55,582
Nord						
24.52	34.78%	8.5	12.8	10,873	489,277	78,154
Total						
55.32	**43.74%**	**22.4**	**33.6**	**28,598**	**1,286,948**	**210,386**

In addition to the environmental benefits, the comparison between solar and diesel irrigation systems clearly shows that SPIS is significantly cheaper than diesel.

Figure 6. SPIS and generator-powered system tariff comparison



5.2 Uganda Case Study

A GGGI Uganda (2020) report on "solar powered irrigation landscape analysis" found very promising returns on investment in SPIS. Within the horticulture sector, most adoptions of SPIS reported an impressive production increment of 200% for some farmers - highlighting the significant benefits brought about by an irrigation method without fuel costs.

The assessment outlined SPIS crop irrigation usage. Details of this are summarized below:

35% of SPIS users utilized their system for tomato irrigation;

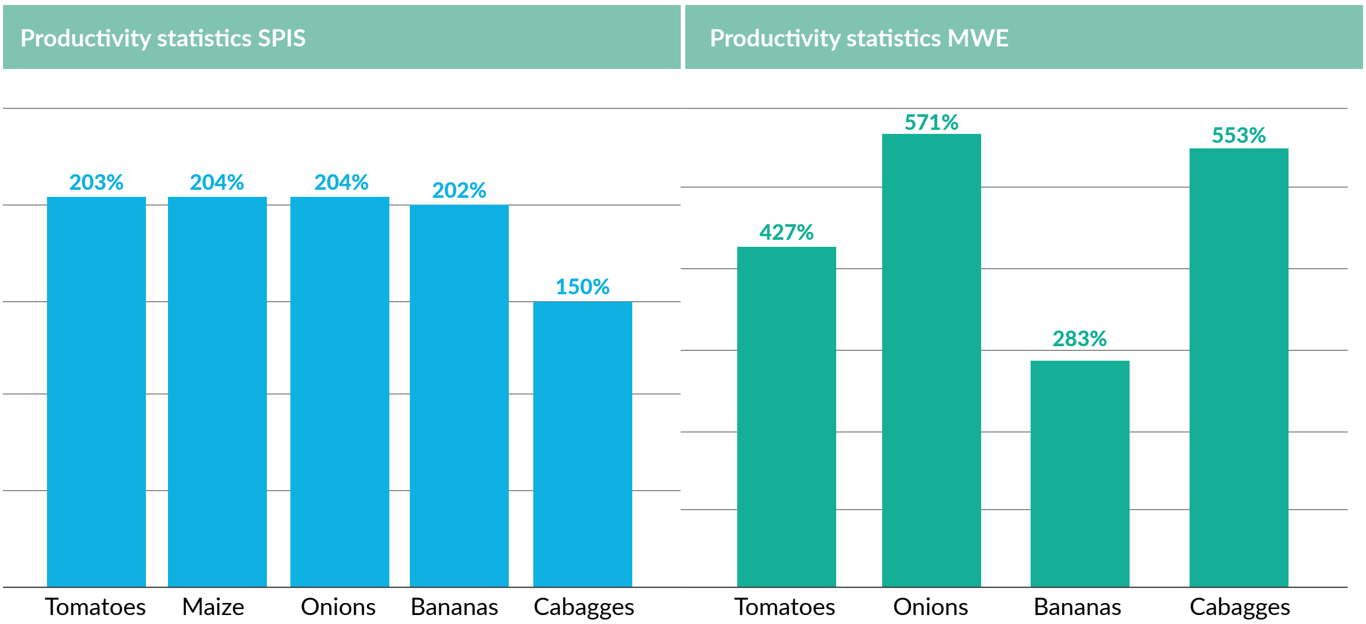
10% of SPIS users utilized their system for banana irrigation;

SPIS users also utilized their system for: **8%** Cabbage **8%** Maize & **6%** Onions

85% of the SPIS users farmed their crops on land over five acres.

The remaining **33%** was used for the irrigation of 21 different crops - among which coffee was mentioned in only 2% of the cases;

Figure 7. Productivity statistics SPIS (blue), Productivity statistics MWE (green)



Tomatoes were by far the most irrigated crop among the 100 SPIS users. SPIS in the study were not commonly used for coffee irrigation – which has previously been stated by government institutions. Furthermore, SPIS users indicated a productivity increment of 193% on average as a result of the investment in SPIS (see blue graph in Figure 7). Compared with the productivity statistics of 13 small scale irrigation sites of up to 5 or 15 acres (KIMANZI, 2020), production increments of up to 400% were achieved for similar crops using agronomy and irrigation. Support was provided by the Ministry of Water and Environment (see green graph in Figure 7).

Field visit site, Burkina Faso

6. What is experience and deployment to date in Africa?

6.1 Overview

Globally, the solar irrigation market has significant potential for growth. One study predicted a global increase of installed units from around 120,000 in 2014 to 1.5 million by 2022 (HYSTRA, 2017). According to analysis undertaken by Dalberg (2020), SPIS could be feasible for ~5.4 million farmers in sub-Saharan Africa (SSA). Roughly 90% of SPIS are currently unserviceable due to affordability. The current serviceable market in SSA only contains 701,000 farmer households. However, if affordability could be addressed, the total serviceable market is projected to rise to 5.4 million farmer households. Therefore, the serviceable market could increase five times by introducing initiatives to boost affordability and consumer financing for SPIS. Although PAYGo appears as a potential solution for this barrier since it brings the upfront cost down, the uptake of SPIS is still low. Current SPIS penetration in SSA is approximately 3% of the total serviceable market - highlighting a nascent industry.

Uganda

6.2 Uganda case study

A market assessment utilized a combination of desk-based research and targeted interviews with farmers. The farmers interviewed were either utilizing fuel-powered irrigation systems or had converted to SPIS. The research sought to understand their experiences in terms of limitations and challenges faced by both irrigation technologies. It also aimed to understand the farmers' motivation for changing to SPIS from fuel powered irrigation systems (GGGI Uganda, 2020).

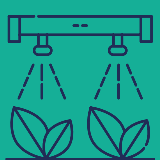
The market assessment identified that SPIS have been promoted in Uganda as an attractive irrigation option due to its low running cost, low maintenance requirements and ease of use. Despite their potential, SPIS have yet not made a breakthrough in the Ugandan market. Since 2020, several small-scale SPIS solutions that specifically target small-scale farmers have entered the Ugandan market. Larger solutions have been around for longer, but also face limited uptake in the country. It was noted that SPIS solutions are not easily accessible for farmers due to limited awareness of both SPIS and irrigation in general; limited distribution to remote rural areas; and limited access to finance. Access to finance has been a particular problem because SPIS are generally more expensive than their fuel-based counterparts. By the end of 2020, the study estimated that between 5,000 to 10,000 SPIS had been sold in the Ugandan market by an array of solar solutions technology providers.

The assessment further estimated that the market size of SPIS in Uganda was expected to increase from 5,000-10,000 users in 2020 to 50,000 users by 2025. Significant efforts and resources on market development are required to achieve such growth in the SPIS market.

Burkina Faso

7. What relevant regulations are necessary to avoid over-pumping groundwater?

Groundwater provides 49% of the water withdrawn for domestic use by the global population and around 43% of all water withdrawn for irrigation (Rodella et al., 2023).



43%
of all water withdrawn for irrigation

While solar-powered irrigation is carbon neutral, it may increase groundwater usage because there are no costs associated with pumping. In areas with supportive hydrogeology, this can improve water security and livelihoods. However, regions heavily reliant on groundwater may face risks if solar irrigation exacerbates existing water deficit (Soumya et al., 2024).

In the Middle East and South Asia, up to 92% of transboundary aquifers show signs of groundwater depletion. The effects of this depletion are already painfully felt in South Asia where groundwater once provided an agricultural revenue advantage of

10-20%. This advantage is now disappearing in areas affected by depletion (Rodella et al., 2023). In fact, more than 500,000 small stand-alone pumps have already been installed in South Asia. Governments have also provided sizable capital cost subsidies on pumps and sometimes facilitated financing (Soumya et al., 2024). For instance, India intends to install 2 million small stand-alone pumps and solarize 1.5 million existing electric pumps by 2026 (Lighting Global/ESMAP, IFC, 2022).

92%
of transboundary aquifers show signs of groundwater depletion

In sub-Saharan Africa, the evidence from the ***AT2030*** report by the FAO demonstrates that the highest solar energy scale of 4.5kWh/kWp/day provides enough confidence for solar irrigation programs to be adopted. The untapped groundwater irrigation potential could be key to improving food security and poverty reduction. While little land is irrigated, local shallow aquifers represent over 60% of the groundwater resource and 255 million people in poverty live above them (Rodella et al., 2023).

60%
of the groundwater resource and 255 million people in poverty live above them

Patterns of water use for agriculture in Africa are changing. In previous years, there has been a focus on large irrigation schemes but many have failed. There have been many research studies conducted into why this has happened (Vibeke et al., 2020). A factor that is often unrecognized in official irrigation policy is the rapid rise in farmer-led irrigation. Farmer-led irrigation is not centered on organized schemes, but is driven by individual farmers investing in technologies with which to access water for irrigation.

The low operating cost can lead to environmental challenges - such as aquifer depletion, water pollution, soil degradation and low field application efficiency (Shah and Kishore 2012, Schnetzer and Pluschke, 2017). Therefore, attention must be given to water resource management policies which are based on the lessons learned from South Asia. Closas and Rap (2017) found that feasibility studies for SPIS commonly focused on technical and economic aspects. However, they lacked an assessment of the availability of, and impact on, water resources. In addition, solar pump supply companies tend to build market strategies on demographics and farm-level business cases (Dalberg, 2020). As a result, there are not enough specific planning and decision-support tools available for water resource management. An unforeseen drop of groundwater levels, however, may also have negative impacts on the profitability of SPIS and their overall economic sustainability.

African agriculture systems and governments do not currently have policies to deal with the new reality of irrigation. Policies focused on integrated water resource management (AU, 2020) - which are key to SDG Target 6.5 - do not account for the current complexities of irrigation patterns. They work based on bringing together water users and stakeholder groups - who may have shared interests; are able to discuss their interests; and have the ability to share water in collective institutions. Farmer-led irrigation is a much more differentiated and individualized process. The types of laws and regulations that sub-Saharan Africa currently has regarding water resource management are no longer fit-for-purpose.

Strategic decision-making in AWM can be improved by driving a data collection agenda and establishing accessible information management systems - particularly to identify and quantify water resources and areas farmed as a result of farmer-lead irrigation development. This will allow surveys to (i) assess groundwater potential to reduce risks and assure sustainable groundwater management; and (ii) assess the impact of cropping and chemicals on soil fertility and water quality. This digital decision-making framework can be associated with sufficient investment in public extension – obtained through partnership with the private sector. This will allow farmers to increase land and water productivity through the adoption of methodologies, tools and other high-yield, low-energy and water-efficiency management technologies. For example, Water Accounting Plus (WA+) would strengthen existing tools for understanding both the demand and supply of water resources in a specific region (Karimi et al., 2013). By incorporating WA+, combined surface and groundwater models, and assessment of flows and replenishment rates, we gain a better understanding of the availability, variability and vulnerability of water resources (Seifu et al., 2020). Translating this information into plans and interventions to scale solar investments could enhance sustainability.

8. What are the key market challenges and barriers to large scale uptake of SPIS?

8.1 Overview

SPIS has proven to be a technically viable and competitive option with an attractive return on investment. However, high initial investment costs (for equipment and installation) and a lack of suitable funding schemes are significant challenges to adopting SPIS. In addition, there is a lack of awareness about the existence of the products, how to use them, and their related benefits. In some rural regions, there are no SPIS distributors and farmers cannot purchase the product. Further challenges lie in the lack of skilled personnel for the design, installation and maintenance of SPIS. There is also a lack of codes and standards to ensure quality, after-sales support and customer misuse. Farmers must also have access to water – typically through a dam, water pan, river, borehole or well. Digging wells or boreholes can prove to be very expensive if they are not already available.

To overcome such challenges and barriers, it is essential to build the capacity of famers and institutions. Bankable and innovative business models and arrangements between smallholder farmers, SPIS technology providers and local financial institutions will need to be identified and put in place. In doing so, an enabling environment can be created for farmers and the private sector to adopt climate-smart agriculture solutions.

8.2 Capacity-building: Uganda case study

A 2021-2022 GGGI project in Uganda aimed to develop human capital through technology demonstrations and capacity-building. It was undertaken by providing training workshops for four key target groups: farmers; SPIS technicians; financial institutions; and government representatives (from both central and local government entities). The sessions for each of the groups were tailored to their specific needs and were based on the gaps that were identified in a market assessment (GGGI Uganda, 2020).

Farmer trainings and demonstration

As part of the project, the farmers' training was the first activity to be carried out. The training was centered on increasing farmers' access to information and improving their awareness on SPIS. Practical demonstrations of SPIS technology were critical to ensure farmers were interested and understood the technology.

The key areas of learning for the farmers were: different irrigation methods; use and application of solar power irrigation; sustainable farming practices; record-keeping; and economic evaluation of crop cycles. Other topics were requested to be covered and offered in separate training sessions. These included: water source development and access; integration of crop and animal production; crop nutrition (use of fertilizers); agricultural machinery; and marketing of products. These other topics could form the focus of future project interventions.

Training of SPIS technicians and district irrigation engineers

A week-long training session of solar technicians from several private companies across the country took place in Kampala in 2022. The aim was to improve technicians' technical capabilities so they would be able to adequately and professionally repair SPIS. The specific objectives of the training were to provide practical guidance to technicians and engineers with limited practical experience in the design, installation and operation of SPIS. A manual was created for technicians and engineers which is the first that has been developed in the country. The manual fills a huge gap in the technical understanding and capability of different actors as it explains how to effectively design, install and operate solar powered irrigation systems.

Training of financial experts from financial institutions

To be able to ensure that financial institutions have a clear understanding of the financial needs of farmers regarding SPIS - as well as to facilitate movement towards flexible and innovative financial instruments targeted towards CSA and irrigation - financial institutions were invited to nominate their staff to participate in a business model training. The training was designed following a needs assessment which was conducted among the financial institutions. It identified several key areas of interest: (i) awareness of solar powered irrigation systems in the market; (ii) risk perception associated with lending finance for SPIS and other agricultural products (including factors that influence the risk associated with lending finance for solar powered irrigation systems); (iii) envisaged operational difficulty experienced by financial institutions in assessing credit risk and administering financing for smallholder farmers; and (iv) relevant investment appraisal tools used for financing SPIS. Financial institutions' lack of flexibility was identified as a significant obstacle to smallholder farmers obtaining credit. Many of the financial institutions required collateral from farmers before they would finance them. However, only a few farmers were in the financial position to provide adequate or acceptable collateral.

8.3 What policy/financing options can mitigate these barriers?

Policies and financial solutions tend to favor large-scale production while reducing smallholder agriculture and reframing agriculture towards export-led production. That is not yet the nature of most production in Africa. Therefore, policies need to speak to the complex and increasingly differentiated realities of African rural livelihoods. They should be informed by the findings and evidence obtained by key international development organizations' various pilot initiatives.

Furthermore, there is considerable risk associated with borehole drilling in the subcontinent. Smallholders tend to take a "hit-and-miss" approach to installing wells - with households often making unsuccessful attempts at drilling before "hitting" water (Carter et al., 2016). Recent research from Ethiopia shows that reducing losses from unsuccessful attempts at borehole drilling has the largest effect on adopting irrigation packages. Government investment in hydrogeology and reliable well-drilling services does not currently exist. This should be made available alongside relevant financial products that do not require collateral. Such public investment is necessary to create an enabling environment for smallholders and the private sector. The private sector will then be able to play an increasing role in irrigation – not only by supplying and selling technologies, but also by providing support in the form of repair and maintenance services, agronomical advice, and marketing of produce (Izzi et al., 2021).

Individual small-scale irrigation is likely to be more conducive than shared irrigation – particularly when considering the increased seasonality of field crop production. However, SPIS equipment remains unaffordable for smallholders. Most policy efforts tend to focus on subsidizing smallholders but there are other, more serious, barriers adopting SPIS. The supply of, and demand for, credit to purchase irrigation technologies is constrained in sub-Saharan Africa (Balana et al., 2021; Merrey and Lefore, 2018). Loans for pumps are often unavailable and existing micro-credit loan limits are lower than pump prices (Nakawuka et al., 2017; Yamegueu et al., 2019).

Ethiopia Case Study: enabling public investment pathway.

Piloting and feasibility study

GGGI Ethiopia has piloted solar-powered irrigation systems at small-scale and large-scale levels. The community, government organizations and development partners have all expressed appreciation for the schemes. In addition, sites for the feasibility study were identified in collaboration with the Agriculture Office and regional, zonal and woreda (district) Irrigation and Pastoralist Offices. The selected sites start from the low head to the high head and were based on the interests of the regional Bureau of Irrigation and pastoralists. The selected sites are located in Oromia state, the Southern Nations, Nationalities and Peoples (SNNP) region and Somali regional states. The location of 50 of these sites is based on the priorities and demands of the government. Shallow and deep well water and Surface water are the water sources at the selected sites.

After the sites were identified, data was collected at 47 of the sites in collaboration with the regional irrigation and pastoralist bureau. The data collected included information about:

- Borehole and surface water;
- The coordination of the BH;
- The solar PV module and collection chamber;
- The distance between the BH and collection chamber;
- BH and solar PV;
- The estimated daily water demand; and
- Available water sources.

Based on the data collected, a feasibility study of solar-powered irrigation systems for climate-smart agriculture was conducted. The feasibility study document contains the (i) technical design of each component (for each site); (ii) the bill of quantity with the estimated price; (iii) the technical specification of each component; (iv) the procurement methodology; and (v) other relevant guidelines that support the sustainability of the SPIS. To implement the elements set out in the feasibility study in the target area, roughly USD 8.81 million is required. On this basis, the Ministry of Agriculture has committed to include SPIS deployment projects under ongoing development programs. This is intended to increase agricultural productivity by expanding irrigation facilities. The objective is to achieve the strategic targets set out in the country's ***Ten Years Development Perspective*** by the year 2030.

Technical guidelines

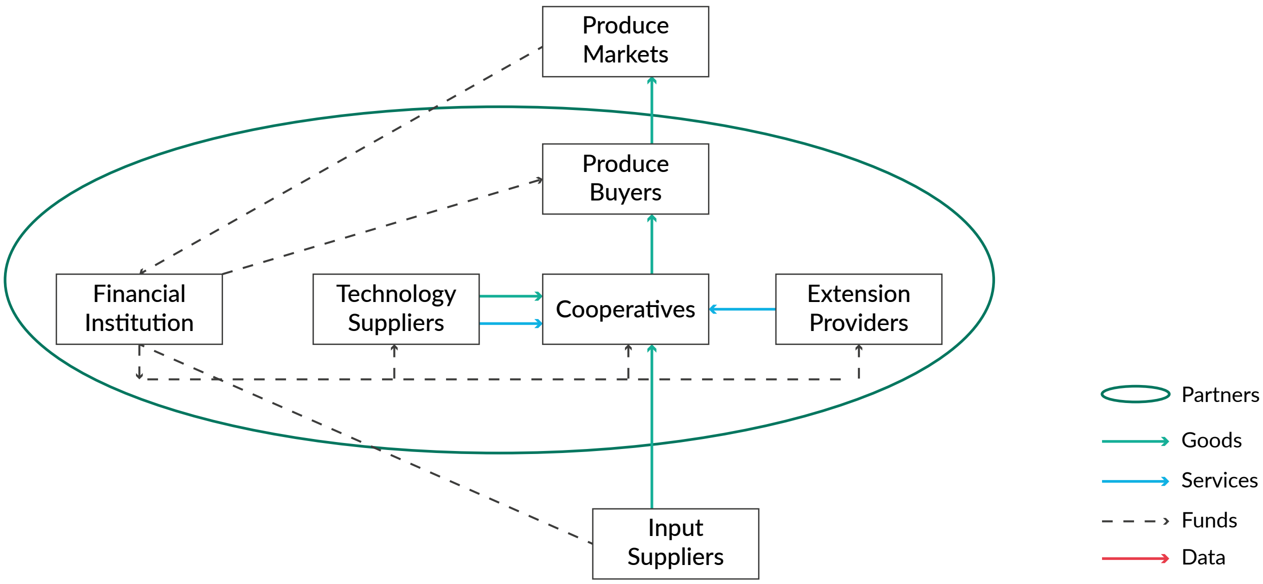
Procurement guidelines have been prepared for Ethiopia to obtain electromechanical equipment required for agriculture. This has been formulated by the Ethiopian government (at the national level) and the World Bank (at the international level) and comprises of different procurement methods. However, procurement guidelines focusing on solar technology for water supply systems (for drinking and irrigation) is yet to be developed for the country. Technical guidelines for the procurement of solar-powered irrigation systems are crucial to obtaining quality materials and ensuring the technology's sustainability. To enhance the technology in the country, GGGI Ethiopia has developed technical guidelines for the procurement of solar-powered irrigation systems. The guidelines identify the components that should be incorporated in the systems; the quality of each material (such as construction materials); the efficiency of each component; the certification required for each material; and the overall performance of different components.

The technical guidelines that have been developed for SPIS procurement have been evaluated and validated by different key stakeholders. Key stakeholders include the Ministry of Agriculture; the Ministry of Water and Energy; the Ministry of Irrigation and Lowland; and different regional bureaus. The technical guidelines received recognition from the Ministry of Agriculture. Different stakeholders are currently using the guidelines to procure solar water supply systems for different applications.

Uganda Business Model Case study

Following a market assessment, it was clear that lending to - and investing in - SPIS and CSA has provided significant challenges. These challenges include transaction costs and production and market risks. However, the opportunity to build and implement a business model that is centered on small-scale farmers' access to CSA provides a basis for increasing revenues; assuring buyers of consistent quality and reliable quantities of produce; and reducing the transaction risk of investors. Recognizing these factors, a business model was formulated and implemented focusing on the creation of partnerships between farmers (via cooperatives/farmers organizations), technology suppliers, produce buyers, extension providers and financial institutions. The business model took into consideration the interests of the different stakeholders and how they could be aligned. This can be found outlined in Figure 8.

Figure 8. Partnership-based business model



In the partnership-based business model, every stakeholder benefits from their relationships. For example, farmers gain access to CSA practices and technologies; CSA technology providers gain access to new markets; produce buyers/markets gain access to regular and reliable supplies; and financial institutions' transaction risks are reduced (due to the nature and effects of other partners' collaboration). This results in increased revenues for all stakeholders.

In the partnership-based business model the roles of each stakeholder are as follows:

- Production of agricultural produce (farmers);
- Supply of CSA technologies (e.g. drought and heat-tolerant seeds, solar-powered irrigation systems, etc.) and support of sustainable land management practices (extension providers);
- Access to produce markets (produce buyers); and
- Provision of credit - as well as receipt and transfer of funds from produce markets to suppliers (financial institutions).

Due to the focus on smallholder farmers, it is crucial that the project targets large farmer-based organizations to take advantages of the benefits that come with demand aggregation. Through aggregated demand that is availed by the farmer groups, it has been found that smallholder farmers can obtain SPIS at costs that are up to 40% lower than when they purchase the SPIS individually. Aggregation of demand for SPIS was therefore a key focus of the project design.

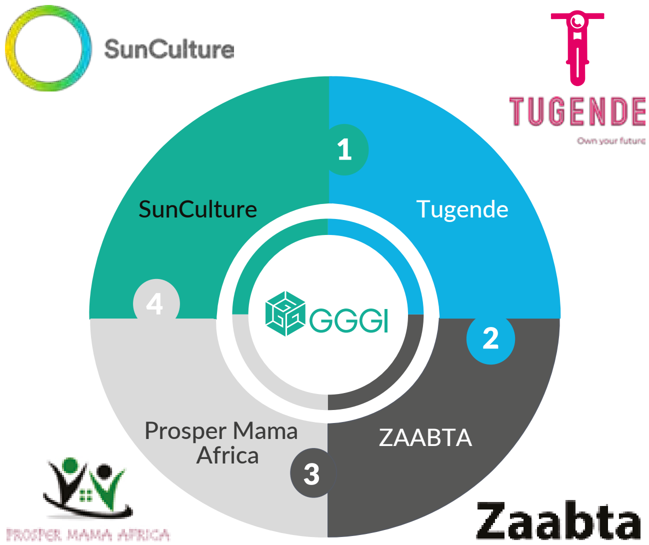
GGGI followed the business model and engaged in partnerships for the project. This involved signing MoUs with SunCulture (a leading SPIS technology leader in East Africa); aBi Finance (a wholesale financial lending institution in Uganda); ZAABTA (a farmer-based organization); and Prosper Mama Africa (a social enterprise). Together, ZAABTA and Prosper Mama Africa have access to almost 30,000 farmers across Uganda. This approach enabled investment to amount to over USD 40 million. This was comprised of USD 10 million from SunCulture and USD 32 million from aBi Finance.

ZAABTA and Prosper Mama Africa have access to almost
30,000
farmers across Uganda

Increasing investment flows to CSA practices (including solar irrigation) was one of the main objectives of the project. The investment mobilization target was USD 10 million. As part of the investment mobilization process, roughly 5,000 smallholder farmers (identified through engagement with ZAABTA and Prosper Mama Africa) expressed interest in purchasing SPIS. Each of the farmers indicated that they were at different levels of financial readiness. Some had in place finance for the full cost of SPIS (roughly USD 1,000), while others had only partial funds for the systems. GGGI undertook discussions with SunCulture to encourage them to make SPIS available to the farmers under different financing arrangements – which were to be dependent on the different situations of the farmers. Through aggregation, SunCulture was able to offer financing in partnership with an asset leasing company in Uganda (Figure 9). Furthermore, due to the aggregation and scale of procurement, the price of the pumps availed through SunCulture were up to 40% cheaper than if purchased individually by each farmer. In total, SunCulture's investment commitment of USD 10 million intends to provide SPIS to 10,000 smallholder farmers over a period of two years.

USD 10 million
intends to provide SPIS to 10,000 smallholder farmers over a period of 2 years

Figure 9. Investment set up arrangements



In addition, GGGI partnered with aBi Finance to address the lack of financing available in the Ugandan financial system for green and climate-friendly agribusiness technologies. GGGI supported aBi Finance in the development of a green taxonomy for agribusiness investments - including SPIS. The exercise involved defining multiple agribusiness investments in terms of both adaptation and mitigation - which could potentially be financed through credit lines established by aBi Finance. Following the successful conclusion of the green taxonomy, aBi Finance launched a Green Finance Fund totaling USD 32 million for CSA and SPIS. In total, a sum of USD 42 million was mobilized through the project.

Burkina Faso Business Models Case study

86%

of the population in Burkina Faso are farmers

However, there are no financial products adapted to the sector - particularly in rural areas.

While the government of Burkina Faso is strongly committed to promoting agriculture and solar energy, banks and microfinance institutions (MFIs) are slow to adapt to the government's dynamic approach. Banks, MFIs and private-sector organizations are working on rural development, yet interest in renewable energy technologies lags behind. This is because of perceived higher risks; a lack of knowledge of solar energy technologies for irrigation; a lack of mastery of the agricultural value chain; and ignorance of the production cycle. Burkina Faso has 15 registered commercial banks and four banking-type financial institutions. The financial services sector is dominated by banks - all of which are risk-averse and have strict collateral requirements that are rarely met by small and medium-sized enterprises. High interest rates on the local commercial market also make access to financing difficult for farmers.

Senegal

The duration of financing for agriculture depends on the agricultural product and varies from one to five years maximum. There are currently no structured financing programs for farmers or associated business partners and limited access to finance has restricted the promotion or distribution of solar irrigation systems in the country. Until the Banque Agricole du Burkina Faso (BADF) officially launched its activities on March 29, 2019, there weren't any banks or financial institutions specializing in financing agricultural activities.

GGGI carried out a study on the development of solar irrigation in Burkina Faso through its "Promotion of solar irrigation systems and solar mini grids" project. The study proposed economic models based on the context in Burkina Faso and producers' realities. The business models proposed are as follows:

Business model 1: SPIS leasing from suppliers

This model assumes that companies supply the solar irrigation system to contracted farmers and provide the technical support required to build farmers' capacity - so that systems can be operated and maintained. The suppliers may decide that the beneficiary farmers pay for the SPIS as part of a contract that has a flexible financing mechanism (i.e. harvest payments, regular lump-sum payments, etc.).

This model is incompatible with a long-term perennial installation for a producer or group of producers. The reasons for this are:

- Leasing systems are easy to dismantle in the event of non-payment or breach of contract by the customer. The company is able to dismantle the system and reinstall it at a new customer's premises. In some cases, the pump and panels can be freely moved to water points - making the system vulnerable to theft and failure;
- Pumps offered for leasing are generally surface pumps. The maximum suction depth for these pumps is seven meters. At this depth, the only potential beneficiaries are producers with access to surface water (streams, dam reservoirs, marigots) and groundwater (sumps, shallow wells). In addition, these pumps are also limited in terms of flow rate and can generally only irrigate small areas (up to 0.3ha); and
- The systems are sensitive to the customer's conditions of use and after-sales service is not always easy to set-up – often depending on the customer's location.

However, given the attractiveness of the costs of this type of system, it seems worthwhile to analyze the relevance of such a business model.

Business model 2: group financing

This model is designed to facilitate farmers' access to SPIS. Under this model, farmers have access to several sources of financing. In addition to an initial contribution, farmers can receive subsidies from the state, agricultural aid funds, or support funds for women's income-generating activities (Table 3, Table 4). This can limit loan amount taken out with a bank or microfinance institution.

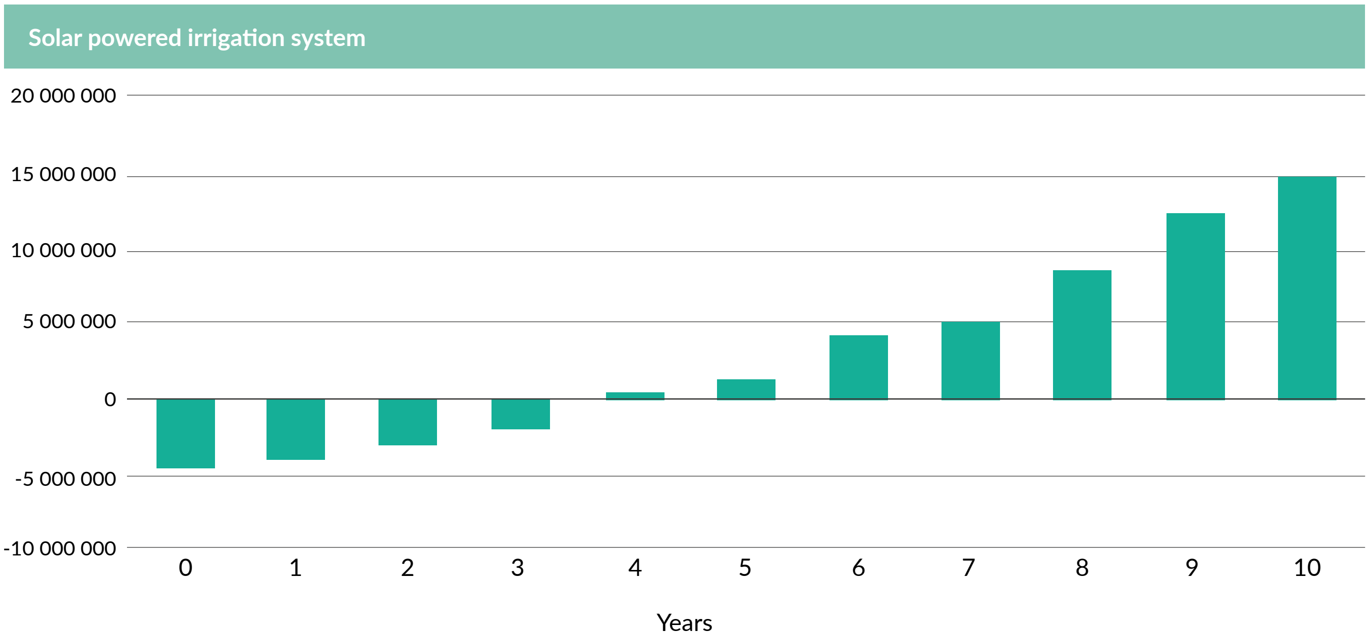
Table 3. Business model assumption

Assumptions	
Target	Small producers - alone or in groups.
Area	0,5ha
Cultivated speculations	Onion, Tomato and Cabbage.
Scenario 3	Onion 70%; Tomato 15%; Cabbage 15%.
Onion Campaign	1
Tomato campaign	Max 2
Cabbage Campaign	Max 2
Production losses	10%
Financing structure	IMF
Grant	40%
Producer contribution	10%
Credit	50%
Repayment term	3 ans
Repayment frequency	Every 3 or 6 months
Interest rates	12%
Proportion of profit to be invested	70%

Table 4. Economic and financial analysis

Basic assumptions	
Total water requirements per day	31.1 m³ per day
Total revenue per year	XOF 2,639,750
Total investment per year	XOF 1,847,825
Inflation	3%
Discount rate	8%
Annual increase in profit margin	10%
Annual increase in fuel prices	4%
SPIS analysis	
Internal Rate of Return (IRR sur 25 years)	34%
Net Present Value (NPV sur 25 years)	XOF 242,105,072
Cumulative cash flow after 25 years	XOF 148,966,669
System life-cycle costs (25 years)	XOF 32,761,486
Time payback period	3 years
Annual loan repayment	XOF 1,135,455.490

Figure 10. Cashflow over 10 years with Contribution 10% - Credit 50% - Subsidy 40%.



The findings in this chapter clearly indicate that the grouped financing economic model offers the best chances of success for farmers in Burkina Faso. The need for subsidies to develop the agricultural sector is nothing new in Burkina Faso. It was already the case several years ago for the financing of agricultural inputs and equipment. The need is even greater for rural producers when it comes to investing in a turnkey solar pump irrigation solution. Two types of subsidies can be envisaged. The first is indirect subsidies on solar equipment - in which countries do not apply value-added tax (VAT) to solar products. The second is specific subsidy mechanisms for SPIS - which are available at the national level in several countries. Subsidies that are managed by the state provide the best cases. This is because they range from 100% to 60% of the total cost of the equipment. They represent 70% of the total production cost for a smallholder producer (Figure 10).

Senegal

9. Conclusion and recommendations

Food production in Africa is still almost entirely rainfed with irrigation playing a minor role. Despite abundant renewable water resources, only 4% of the region's total cultivated area is irrigated. In comparison, it is 37% in Asia and 14% in Latin America. Therefore, Africa is far from realizing its irrigation potential – which is estimated at 42.5 million ha. Helping farmers to access irrigation water by developing small-scale irrigation methods can enable them to boost agricultural production; achieve food and nutrition security; and improve the livelihood of rural communities.

As farming uncertainties resulting from climate change have intensified, there is strong interest amongst policymakers at all levels to advance irrigation development and practices. This is as doing so can act as a catalyst for economic and rural development. However, despite multiple interventions and efforts by different development and research organizations, it is still evident that the deployment of climate-smart agriculture practices (including solar-powered irrigation) has many institutional roadblocks and implementation challenges.

This report captures key lessons from the above-mentioned projects. It has been found that scaling-up CSA practices and solar irrigation in Africa requires a complex network of institutions. Various innovative options are also required to address challenges that vary from place to place. The key lessons learned are as follows:

- Capacity-building must to be tailored to needs and based on a an assessment of knowledge and gaps in knowledge. It should not only be provided to farmers - but also SPIS technicians, financial institutions and government representatives (from central and local government entities). In doing so, all stakeholders will have a better understanding of the different constraints, opportunities and associated impacts of SPIS.
- The SPIS procurement guidelines developed in Ethiopia have been instrumental in enabling public investment pathways in regard to solar PV equipment – particularly to ensure quality and standards. It was particularly important that the guidelines were validated by the country's Ministry of Agriculture; Ministry of Water and Energy; Ministry of Irrigation and Lowland; and by regional bureaus.
- The partnership-based business model in Uganda demonstrates the mutual benefits available for stakeholders - farmers can gain access to CSA practices and technologies; CSA technology providers gain access to new markets; produce buyers/markets gain access to consistent and reliable supplies; and financial institutions' transaction risks are reduced (due to the nature and effects of other partners' collaboration).
- Suppliers leasing SPIS appears to be an attractive and relevant model. However, there are some limitations. The model assumes that companies supply the solar irrigation system to contracted farmers and provide the technical support required to build farmers' capacity – so that systems can be operated and maintained. The suppliers may decide the beneficiary farmers pay for the SPIS as part of a contract that has a flexible financing mechanism (i.e. harvest payments, regular lump-sum payments. etc.).
- The group financing model based on subsidies allows farmers to have access to several sources of financing. In addition to an initial contribution, farmers can receive subsidies from the state, agricultural aid funds, or support funds for women's income-generating activities. Until there is a transformation in the financial inclusion of smallholders and small agribusinesses, some level of subsidy will likely be required to enable them to access CSA technologies. However, even if subsidies can (in the short term) address failures in credit and input markets and facilitate the adoption of improved inputs, they remain an obstacle to the development of private input markets.

GGGI Way forward

- Net metering can be explored to limit the overuse of water in instances where grid-connected solar panels use electric pumps. This may be exemplified by the case of rice farming in the Senegal River Valley.
- Linking solar irrigation to GGGI carbon credit programs will require an integrated assessment and/or accounting frameworks for estimating emissions reductions (Soumya et al. 2024). This will need to be combined with a monitoring system that identifies water–energy–land use changes.
- Promotional models for SPIS - which have already been experimented with in South Asia (Tushaar et al. 2018) - could be piloted by GGGI to address various farming systems in Africa. This could comprise of a developer-centered, farmer-dedicated solar plant; a developer-centered distributed generation model; farmers acting as land-leasers to solar companies; a solar irrigation service provider (S-ISP) model; and solar power as a remunerative crop (SPaRC).
- GGGI should support the pilot implementation of Agrivoltaics in Rwanda and continue feasibility studies being undertaken in Ethiopia and Senegal.

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