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Discussion paper on solar-powered irrigation systems

Smart Energy Solutions for Africa

Solar-powered irrigation systems

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1 Introduction

Efficient solar-powered irrigation technologies are becoming increasingly critical in Africa, a continent heavily reliant on agriculture (Birhanu et al., 2023). Since 2015, food insecurity in sub-Saharan Africa (SSA) has worsened, exacerbated by several global crises and challenges (FAO et al., 2013). Climate change is a major risk factor, contributing to water stress, reduced growing seasons, and more frequent extreme weather events like droughts, floods, and pest infestations (IPCC, 2022), all of which severely impact agricultural productivity. Redirecting government efforts towards the adoption of appropriate production and post-harvest technologies could enable the irrigation of an additional 96 million hectares in SSA, potentially benefiting up to 369 million people (AGRA, 2022).

In SSA, smallholder farmers are responsible for 80% of agricultural production (Falchetta et al., 2023). However, they face constraints in increasing farm productivity as 90% of all croplands are rain-fed, making the farmers dependent on unpredictable rainfall patterns (Falchetta et al., 2023). Given the high solar radiation levels in many African countries, solar-powered irrigation technologies present a promising solution to address these challenges. These systems offer a sustainable and scalable approach to improve water access, enhance food security, and support smallholder farmers, particularly in areas where traditional irrigation methods are not feasible.
This discussion paper shows the potential of solar-powered irrigation technologies, provide an overview of different systems and business models, and give examples for their application in the African context. Additionally, a list of tools and resources is provided to further support stakeholders in understanding and adopting these solutions.

2 The technology

2.1 System components

The main components of solar-powered irrigation systems are the power source (solar panel and load controller), the water pump, the water storage system (if any) and the irrigation equipment (see Figure 1). The solar system provides electricity to the pump, which delivers water from a well, stream, or another source directly into an irrigation system or into a storage tank or reservoir. Solar-powered irrigation systems do not generally require a battery because irrigation typically takes place during daytime (Energypedia, 2020).

Table 1 shows the different technology options available, depending on site-specific conditions and needs and capacities of the farmer.

Component	Alternative Technologies	Determined by
Solarsystem	Fixed vs. tracking	Costs and maintenance intensity
Pump	Surface vs. submersible	Costs and (geo-)hydrology
Reservoir	Reservoir vs. no reservoir	Costs and irrigation system
Irrigation system	Surface vs. drip vs. sprinkler	Costs and pumping system

Table 1: **Alternative technologies for the most important components of a solar-powered irrigation system** (Based on Energypedia, 2020).

Figure 2: **Solar-powered Pump** (Getty Images / Toa55)

2.2 Matching solar pumps to the irrigation system

The type and size of the solar pump is determined by the irrigation system and its water and pressure requirements. The choice of the most suitable irrigation system depends on several aspects, such as the type of crops being grown, the soil characteristics, the availability and source of water, the climatic conditions, the scale of the farming operation, and the financial resources available for investment and maintenance.

Sprinkler irrigation requires high water pressure, demanding a solar-powered irrigation system with high-capacity solar modules and energy storage. In contrast, drip irrigation operates at low pressure, making it more water-efficient by minimising evaporative losses and delivering water directly to the root zone. Drip systems, suitable for high-value crops like fruits and vegetables, can reduce water consumption and use moderately saline water, making them ideal for marginal land. However, they require good quality water or pre-treatment to prevent clogging and need effective irrigation management to achieve optimal performance (Energypedia, 2020). While surface irrigation is more affordable, it is significantly more water intensive, using 20-60 % more water than drip irrigation, making it less suitable for arid regions (MIT GEAR LAB, 2022).

Beyond technical considerations, natural conditions (soil type, slope, climate, water availability, and quality), crop types, and socio-economic factors such as capital investment and labour input for construction and maintenance also play a key role in determining the most appropriate irrigation system (Energypedia, 2020).

2.3 ICT and IoT in solar-powered irrigation systems

ICT (Information and Communication) and IoT (Internet-of-Things) technologies can play an important role in making solar-powered irrigation systems a viable and sustainable solution. For example, the inclusion of remote sensing to solar water pump models can support manufacturers in carrying out troubleshooting more effectively, as well as give advice on optimal use of the pump based on usage data (Maina et al., 2021). Geospatial information tools to identify suitable areas for solar irrigation are also emerging (Maina et al., 2021). Finally, PAYGO models for solar-powered pumps also rely heavily on ICT. For example, an appliance may be remotely disconnected in case of lack of payment (see Business Models section).

Figure 3: **Application of a solar-powered irrigation system** (SunCulture in IFC (2019))

3 Business and financing models

As the price of PV panels has fallen significantly over the past two decades, the cost of solar water pumps has dropped by 80 % (Efficiency for Access, 2019a). As a result, more small-sized solar water pump systems have entered the market, making smaller systems more accessible to smallholder farmers. Still, when purchasing a new irrigation system or replacing a diesel pump, the solar product lines have not yet reached commercial scale (IFC, 2019) and the up-front cost remains a significant barrier for many farmers. There are different business models that aim to overcome the affordability challenge which will be discussed in this section.

3.1 Pay-as-you-go (PAYGO) and micro-finance

PAYGO models have become a commonly applied business model to provide affordable energy access from renewable sources, including solar, to off-grid communities. Instead of paying high upfront costs for a system, customers pay for what they can affordably use as they need, often using mobile payment technologies and mobile phone credits (IRENA, 2020a). There is another option for PAYGO which is often referred to as lease-to-own business model whereby once the system is fully paid, ownership is transferred to the customer and the system is permanently unlocked. If payments are not made on time, the system can be cut off. For example, in Mali, ECOTECH, a company that sells solar irrigation systems, has worked with AICCRE to offer PAYGO solutions that transfer ownership after full payment for their systems. They have reached 6,255 farmers in the Sikasso and Niono communities (Dossou-Yovo, 2023).

Another opportunity for off-grid solar companies to offer more affordable consumer financing is to partner with micro-finance institutions (MFIs). This enables the provision of a wider range of credit options for purchasing solar systems and PUE equipment such as solar irrigation systems, particularly to last-mile customers in rural areas.

In addition to offering financing options, MFIs often support off-grid solar companies with distribution, marketing, and sales to reach more customers as well as the provision of training (USAID, 2021).

3.2 Community and shared ownership models

Community ownership and cooperative models provide one option for lowering upfront investments of solar systems and PUE equipment (IRENA, 2020b). The cost-sharing model is an alternative to individual ownership of solar irrigation systems. It involves a group of farmers who jointly own and manage a solar irrigation system, sharing both the costs and benefits. This facilitates access to finance through pooled collateral and potentially lower interest rates as well as increasing system usage (Otoo et al., 2018). However, this model relies on social cohesion within the group and only works with choosing an appropriate management and governance model. The transaction costs of negotiating the joint investment and sharing the usage of the system need to be carefully examined and traded off against the benefits of lower initial investment cost for the individual members. In Ghana, experiences with the cost-sharing model have been mixed. While the Datoyili cooperative failed due to a lack of cooperation and theft of equipment, other cooperatives are still successfully running (Gebrezgabher et al., 2021).

3.3 Service provider model

In the solar irrigation service provider model, a third-party company owns, operates and maintains the solar PV system. With the help of low-cost finance, partial grants and other fiscal incentives, entrepreneurs own and operate solar PV systems to provide irrigation water services to farmers for a fee. The fees from water sales are used to repay the loan (Gebrezgabher et al., 2021). This business model could be attractive to smallholders as it avoids the high upfront costs and the need to manage, operate and maintain the system. Furthermore, instead of promoting individual ownership of solar pumps that may be underutilised, the establishment of young entrepreneurial farmers as solar irrigation service providers could contribute to the creation of a competitive water market by offering farmers an irrigation service at an affordable price (Shah et al. 2018). However, a potential downside of this model is the limited control over the timing and volume of water delivery, which could affect farmers' agricultural practices and crop choice. To mitigate this, service providers should offer flexible service options tailored to farmers' needs (Gebrezgabher et al., 2021).

4 Socio-economic and sustainability impacts

Solar-powered irrigation is one of the best studied solutions in terms of impacts on livelihoods of smallholder farmers. Providing access to modern irrigation can have a significant impact on agricultural yields. In fact, some case studies show that yields can increase as much as two- to three-fold (Efficiency for Access, 2019a). The impact of irrigation is higher when accompanied by additional support such as access to markets to distribute and sell the agricultural produce (IFC, 2019).

When replacing diesel-powered irrigation systems, solar irrigation systems lead to fuel cost savings. In Kenya, where a comparison was made

Figure 4: **Rows of crops under solar irrigation system** (Bonergy, InfraCo, 2022, photo by Audy Valera)

between solar and diesel pumps, the cost of solar pumps can break even with diesel alternatives within the first year, despite higher upfront costs (up to 60% higher), due to lower maintenance and fuel costs. The break-even point depends on the type of crop. For lower-value crops, such as wheat and corn, the breakeven point is typically reached later than for higher-value crops. In cases where farmers already own a diesel pump, the payback period extends to around four years, indicating a limited value proposition (IFC, 2019).

Impacts of solar irrigation on livelihoods go beyond increases in yield or income. When coupled with drip irrigation, solar-powered irrigation systems are proven to significantly increase nutritional intake, particularly during the dry season (Burney et al., 2010). An increase of the quality and availability of food and a decrease in food imports has also been observed (RES4Africa, 2019).

To achieve the socio-economic and sustainability impacts in the long term, and to avoid groundwater depletion, it is essential to embed solar irrigation solutions in the Water-Energy-Food nexus.[1] This requires a solid understanding of farming practices, water demands of different crops, and the water availability patterns (Energypedia, 2020).

There needs to be local capacity building to select the most appropriate solar irrigation solution, as well as awareness raising and incentives for efficient irrigation. Potential solutions to mitigate the risk of over extraction include making water-table data available to solar water pump companies and smallholder farmers, smart metering on pumps to track water usage and allowing pre-set pump operation times, encouraging pump sharing, and strict water accounting to regulate groundwater use (Efficiency for Access, 2019a).

5 Scaling-up

Delivering access to energy, while ensuring the security of water and food resources, is at the heart of development goals in Africa. This is of particular importance in rural regions, which rely predominantly on agriculture. There are currently 500 million rural dwellers in SSA, and these are set to become more than 900 million by 2050 (Falchetta et al., 2022). More than two-thirds of them currently have no access to electricity (crucial for crop irrigation, processing, and storage) and the majority of cropland is rainfed only, resulting in reduced and unstable yields (Falchetta et al., 2022; Mumssen, 2022).

Given the high solar radiation levels in many African regions, solar irrigation technologies are a promising solution to address these challenges. To scale up the deployment of solar irrigation systems, a variety of levers are needed:

- **Innovative financing models** need to be further promoted to expand the access to affordable financing options for smallholder farmers, such as PAYGO, leasing programs, and targeted agricultural credit facilities (IFC, 2019; Efficiency for Access, 2019b).

- **Provision of training** on technical knowledge and farming practices, irrigation management, fertilisation, pest control, crop rotation, and extensification–intensification trade-offs (Falchetta et al., 2023).[2]

- **Increase awareness** to foster the acceptability of solar irrigation through field demonstrations and campaigns organised by government and technology suppliers (Falchetta et al., 2023; Gebrezgabher et al., 2021).

- **Strengthen water resource governance** by developing and enforcing policies and regulations to ensure the sustainable management of water resources for irrigation (Falchetta et al., 2023).

- **Foster partnerships** among governments, private companies, and development organisations to leverage resources, expertise and investments (Falchetta et al., 2023; IFC, 2019).

[1] Extensification–intensification trade-offs refer to the choice between increasing agricultural production by either expanding the cultivated land (extensification) or by improving yields on existing agricultural land (intensification).

[1] The water-energy-food (WEF) Nexus concept offers an integrated framework with which to reduce trade-offs and increase synergies in securing goals of energy, water and food security (Terrapon-Pfaff et al., 2018; Srigiri and Dombrowsky, 2021).

[2] Extensification–intensification trade-offs refer to the choice between increasing agricultural production by either expanding the cultivated land (extensification) or by improving yields on existing agricultural land (intensification).

6 Application within the SESA replication actions

Havenhill, Nigeria

The idea: An integrated approach for smart solar irrigation systems on an irrigation-as-a-service basis.

The technology:
- Smart solar irrigation systems, comprising four key components: PV generator, submersible systems, motor cable/electrical system, and overhead storage/water distribution system.
- The PV generator encompasses solar panels and a sun switch.
- The submersible system includes a DC pump, PS2 controller, well probe, and flow sieve, ensuring precise water delivery.
- The motor cable/electrical system is equipped with essential kits like a cable split kit, surge protector, pressure sensors, and grounding rod.

The business model:
- Irrigation-as-a-service model: No upfront costs for customers to install the irrigation infrastructure on their land. Instead, a fee of 20% of the farmer's crop per growing cycle is charged for the ongoing use of the facility. This fee represents Havenhill's income and is used for the maintenance and sustainability of the solar irrigation system.

The impact:
- This initiative offers an integrated approach by lowering the cost barrier for irrigation infrastructure for smallholder farmers. In addition, Havenhill plans on providing high quality seeds, fertilisers and other inputs on credit, providing training and capacity building programs, and securing supply contracts with large-scale processors and off-takers for the produce to guarantee higher prices.
- No reliance on rain-fed agriculture, enabling year-round cultivation and increased crop output and diversification, resulting in higher incomes for farmers and enhanced food security within the communities.
- Reduced dependency on fossil fuels, mitigating environmental impact while fostering agricultural resilience.

For further information visit:
https://havenhillsynergy.com/
https://havenhillsynergy.com/havenhill-launches-farm-fuse-foster-agricultural-development-last-mile-communities/

Dritoven, Namibia

The idea: Solar irrigation technologies targeting small-scale farmers in drought-prone areas.

The technology:
- Complete solar irrigation systems composed of solar-powered water pumps, drip and sprinkler irrigation systems, pontoon floats system, solar panels and stands, and pipes and water storage tanks.
- Solar-Powered Booster Pumps and Controllers.
- Solar-Powered Hydroponic and Aquaponic Farming Systems.

The business model:
- Community-based lease-to-own solar irrigation business model via a financing agreement where farmers lease a solar irrigation system for two to five years. During the lease period, regular payments are made and once all payments have been made, the farmer owns the system.

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The impact:
- Increased crop yields and improved farm productivity due to consistent water availability supplied by the solar-powered pumping system.
- Reduced dependence on diesel or gasoline powered pumps for irrigation, resulting in less GHG emissions and air pollution as well as cost savings for the farmers.

For further information visit:
https://dritovenengineering.com/

SimuSolar, Tanzania

The idea: Provision of full-service irrigation with solar water pumps, including customised design and financing plans, professional installation, and after-sales service.

The technology:
- A typical system includes the pump, control box, solar panels, panel stands, wire, pipe and connectors, and in some cases drip tape or sprinklers. Every customer receives a bespoke solution, varying in number of panels, length of pipe, depth of installation if a well is used, and options like carts, drip and water tanks.
- Surface pumps for 1 to 30 acres with solar panel arrays from 200 to 4,000 watts that can pump water up to 30 meters uphill and have a production from 1,000 - 40,000 liters/day.
- Submersible pumps with solar panel arrays from 350 – 6,000 watts, pumping water from wells or boreholes up to 150 meters deep and have a production from 1,000 liters/day up to 25,000 liters/day.

The business model:
- Customised lease-to-own business model with a “Pay as you go” system integrated to the pump.
- Provision of full after-sale service and maintenance free-of-charge for 2 years after installation.

The impact:
- Provision of access to pumping technology to improve farm productivity and reduce climate risk for farmers who depend on rain for irrigation.
- Decrease cost of productions and thus increasing profitability of smallholders.
- Increasing quality and quantity of harvests, resulting in increased incomes.

For further information visit:
https://simusolar.com/

7 Relevant tools and capacity building materials

Toolbox on Solar Powered Irrigation Systems (SPIS)

Offers essential information and tools for the implementation of SPIS, including calculation sheets, checklists and guidelines, e-learnings and tutorial videos for practitioners who advise SPIS end-users, financiers, or policymakers. The toolbox also contains guidance on water management and governance, markets, financing, design and maintenance of irrigation systems. It can also be downloaded as an app.

https://energypedia.info/wiki/Toolbox_on_SPIS

World Bank: Solar Pumping Handbook

Handbook on solar pumping including an introduction to pumps and their components, guidance for choosing the right system and locating it, or information on typical water consumption of crops and livestock.

https://documents.worldbank.org/en/publication/documentsreports/documentdetail/880931517231654485/solar-pumping-the-basics

Solar Pumping Toolkit

Offers guidance on solar pumping, including site assessment, technical design and tender, installation and operation, maintenance, monitoring and evaluation.

https://energypedia.info/wiki/Solar_Pumping_Toolkit_-_The_Global_Solar_%26_Water_Initiative

Interactive map "Potential for Solar Photovoltaic Based Irrigation"

Online interactive tool to assess land in SSA that is suitable for solar irrigation. A map with search criteria identifies suitable regions, based on the quality of solar radiation. The parameters to modify include regions, water source (ground or surface water) and pump capacity (from 0-250 m).

https://energypedia.info/wiki/Toolbox_on_SPIS

Global LEAP Solar Water Pump Test Method – Version 2

This document defines methods to evaluate the quality, performance, and general durability of small-scale (less than 2 kilo-watts of power input required) off-grid solar water pumps (SWP) used mainly for agricultural purposes.

https://efficiencyforaccess.org/publications/global-leap-solar-water-pump-test-method-version-2/

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