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

REPORT ON

SOLAR IRRIGATION

Improving food security, income generation, and gender equity

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FEED THE FUTURE INNOVATION LAB FOR SMALL SCALE IRRIGATION

Demand for solar-powered irrigation is growing across sub-Saharan Africa.

Researchers agree that solar pumps could be a clean and sustainable energy solution for irrigation and have financial, nutritional, and gender equity benefits.

Across sub-Saharan Africa, only 5% of cropland is irrigated. As climate change causes temperatures to rise and rainfall patterns to shift, irrigation technology will be vital for helping smallholder farmers build resilience. Many currently use diesel pumps, but difficulty getting fuel, increasing costs of fuel, and high maintenance for petrol and diesel pumps are inspiring interest in solar pumps. Shifting towards solar could help reduce reliance on fossil fuel for irrigated agriculture in sub-Saharan Africa and decouple energy and food prices.

Solar pumps have been used agriculturally since the late 1970s, but the technology has changed. Solar pumps are also becoming less expensive and more available in frontier markets. However, further expansion will require understanding context-specific factors that influence adoption. The Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI) partners invested in research across the sub-Saharan Africa region for that purpose. ILSSI worked with private-sector solar companies and research and public-sector actors to assess suitability, energy-related trade-offs, supply chains, business models, finance ecosystems, and inclusivity.

Through this work, partners are establishing new ways to actualize the benefits of solar irrigation in equitable, financially viable, and environmentally sustainable ways.

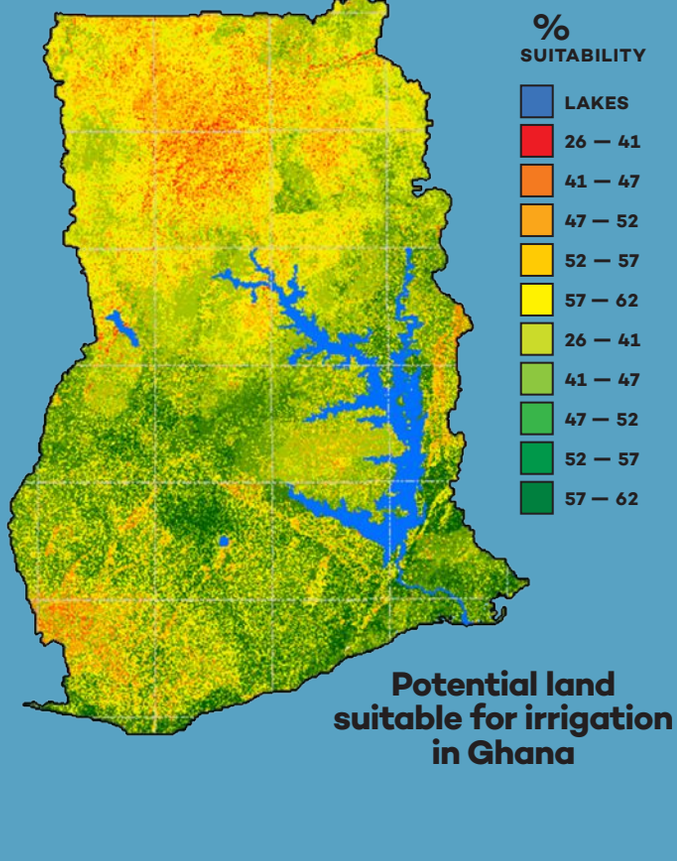
Changing climate requires innovations to address nutritional security

Across Feed the Future countries, smallholder farmers — those cultivating less than 2 hectares of land — account for substantial food production. Much of that agriculture is rainfed rather than irrigated, and climate change is reducing the ability of smallholders to meet growing food demand. In Ghana, for example, smallholder farmers are vulnerable to drought, and the country remains a net importer of food products.

Urbanization and a growing middle class are pushing up the demand for fruits and vegetables, which usually require supplemental and dry-season irrigation.

Farmers often rely on buckets and, less so, fossil fuel-powered pumps for water lifting and field application where land is irrigated. Some pumps use electricity, which can be more efficient and require less upfront capital investment. However, sub-Saharan Africa has the lowest electrification access in the world.

Yet, many countries in sub-Saharan Africa have sufficient irradiation levels in most months of the year to support the minimum requirements of solar pumps. Particularly in parts of West Africa, the Sahel, and Southern Africa, solar is a promising energy alternative to fossil fuels for pumping. Solar pumps could help smallholder farmers increase small-scale irrigation, improving food and nutritional security and income generation.



Potential land suitable for irrigation in Ghana

Suitability mapping

Suitability mapping is critical for the private sector solar pump suppliers to plan for expansion into frontier markets and for research and public sector actors to support sustainable use. For example, in 2018 ILSSI researchers found that approximately 9% of the land in Ghana was highly suitable for irrigation using surface water (at 80% value for land suitability) with additional likelihood for irrigation using shallow groundwater.

When analyzing potential for solar irrigation, researchers found over 2.2 million hectares suitable across the country with high promise in the Northern and Northeast Regions. However, the decline in total rainfall and increasing intermittent dry spells during the rainy season will continue to reduce land area suitable.

Source: Worqlul et al. 2019

Knowing land resources and uses is vital for expanding solar irrigation

Abundant solar energy is not the only prerequisite to enable smallholder farmers to access and invest in solar pump use. **To establish where solar-powered irrigation would be most viable, ILSSI research partners used multi-criteria analysis and an open-source geographic information system (GIS) to assess suitability.**

Analysis for several Feed the Future countries considered solar irradiation, topography, groundwater and surface water availability across seasons, crop selection, land use types, and market-related factors such as road infrastructure and distance to markets.

In Ethiopia, the research found that solar-powered irrigation would suit 9% of currently irrigated land and 18% of presently rainfed land. Farmers could use irrigation on that land to supplement shorter rainy seasons and grow more during the dry season.

18%

OF ETHIOPIAN **RAINFED** LAND IS SUITED FOR SOLAR-POWERED IRRIGATION

9%

OF ETHIOPIAN **IRRIGATED** LAND IS SUITED FOR SOLAR-POWERED IRRIGATION

Managing solar-powered irrigation to manage environmental risk

Expanding the use of solar pumps could increase productivity and improve nutrition and livelihoods while reducing fossil fuel emissions that come from fossil fuel pumps. However, there are growing concerns over the risks to water availability. Some research suggests that low operational costs of solar pumps could lead to the over-extraction of groundwater.

Solar irrigation should be developed as part of a bundle of technologies and practices to prevent over-extraction. For example, low-cost irrigation scheduling tools and drip irrigation can reduce water used in the field. In addition, supporting water harvesting and storage can extend surface water use and reduce reliance on groundwater for irrigation.

Environmental risks must be considered as demand increases for irrigation technologies, including solar pumps. More evidence-based research on water availability for different uses is needed, such as through Water Accounting. In addition, solar pump technologies should also be considered as part of a bundled solution to support the sustainable adoption of solar irrigation for climate adaptation, mitigation, and co-benefits.

CASE STUDY 1

Solar irrigation suitability in Mali

To sustainably expand solar-powered irrigation, researchers need to know how water is used during wet and dry seasons — and how much could be used for agriculture. ILSSI research partners applied Water Accounting methods and tools in Ségou and Sikasso, Mali. The analysis of both surface and groundwater resources across seasons showed high potential for expanding irrigated production.

80K
270K
HECTARES

OF LAND IN SÉGOU AND SIKASSO, RESPECTIVELY, HAS LOCAL GROUNDWATER RESOURCES THAT COULD SUSTAINABLY SUPPLEMENT IRRIGATION

4.4M
HECTARES

OF LAND IS SUITABLE FOR SOLAR IRRIGATION IN MALI

That suitability, however, varied seasonally. The researchers found that though surface water could support lower-water crops like okra and sweet potato during the wet season, there was almost no available surface water during the dry season. The lack of surface water means that farmers need groundwater and stored surplus water from the wet season for dry season crop production. In Mali and elsewhere, verifying water availability and use is essential for investing in and implementing solar-powered irrigation to prevent climate maladaptation and worsening water scarcity.

CASE STUDY 2

Solar irrigation suitability in Ghana

Suitability for solar-powered irrigation is not static. Climate changes, weather patterns, and temperature changes will affect suitability for solar irrigation. In sub-Saharan Africa, temperature and seasonal rainfall variability will continue to increase, while water availability may decrease in some areas. These changes will make some cropland less productive or even take it out of production. Knowing how and where land suitability will change in the future is critical for ensuring farmers' climate resilience and making long-term agricultural development plans. ILSSI research partners used SWAT and APEX models and GIS-based tools to analyze the impact of climate change on future land and irrigation suitability.

In Ghana, roughly 2.3 million hectares of land are currently suitable for irrigation, though most food production is rainfed. ILSSI research partners found that by the 2050s to 2070s, rainfall is expected to increase across much of Ghana, while temperature and evapotranspiration will likely raise and increase water demand. Southern Ghana accounts for much of the country's potential suitable land, but a rainfall deficit and reduced groundwater recharge is expected under climate change scenarios.

Due to climate change, over 9% of Ghana's currently suitable land is expected to become ill-suited for irrigation in the 2050s. By the 2070s, that number is expected to reach 17%. These changes mean that Ghana lawmakers should consider enacting policies to increase heat-tolerant agriculture and sustainable use of water resources, among other mitigation measures.

The study suggested that solar pumps offer smallholder farmers a vital climate adaptation option. Moreover, as irrigated agriculture expands, program planners, investors, and the private sector will need a solid capacity to apply decision-making tools for evidence-based investments.

17%

OF GHANA'S CURRENTLY SUITABLE LAND IS LIKELY TO BECOME UNFAVORABLE FOR IRRIGATION BY THE 2070s

Counting out the costs of solar-powered irrigation

While most studies show that solar-powered pumps are more profitable for farmers than fossil fuel pumps, the initial capital cost to purchase a pump is higher. **As demand for solar pumps increases, it's necessary to understand the costs for water-lifting equipment across energy types to determine context-specific suitability.**

In Ethiopia, up to 28% of small-scale irrigators use motor pumps, particularly fossil fuel pumps. While initially cheaper than solar pumps, diesel pumps come with high life-cycle costs. They regularly need replacement parts and maintenance, such as oil and coolant changes. However, the skilled labor to fulfill those services is difficult to access for farmers in remote, rural areas. Maintenance and repair are also expensive.

The most costly element for diesel pumps is what powers them: in most countries in sub-Saharan Africa, diesel accounts for 70–90% of a diesel pump's life-cycle costs. And, as recent energy crises have demonstrated, farmers face challenges in getting access to fuel.

70-90%

OF A DIESEL PUMP'S LIFE-CYCLE COSTS GOES TOWARDS FUEL
(SOURCE: XIE ET AL. 2021)

Solar pumps, meanwhile, have higher initial capital costs, and research shows that the initial cost can be one of the most significant barriers to expanding solar-powered irrigation. But they also have lower maintenance costs — and sunshine is free. In a study, ILSSI research partners assessed sub-Saharan Africa's 25-year comparative life-cycle costs of diesel and solar pumps. They found that solar was a more economical energy source for groundwater pumping than diesel in many cases. Solar is more cost-effective in countries with high diesel prices and arid climates, such as Mali and Zambia, whereas it is less cost-effective in countries that subsidize fossil fuels.

As solar-powered irrigation expands, energy costs should be considered alongside the market potential, environmental risks, and climate mitigation strategies.

Initially cheaper diesel pumps have high overall life-cycle costs because of fuel and maintenance. A solar pump, though a larger initial investment, is less costly to maintain and has a genuinely free energy source.

Combined with drip irrigation, solar pumps proved more profitable despite the high initial capital cost.

CASE STUDY 3

Solar irrigation suitability in Ethiopia

In a pilot study, ILSSI researchers assessed the financial feasibility of using solar pumps for smallholder irrigation in two regions of Ethiopia. The pumps in the study used solar panels that had a 10-year lifespan and could irrigate up to a quarter of a hectare of vegetables using a 4-meter-deep shallow well.

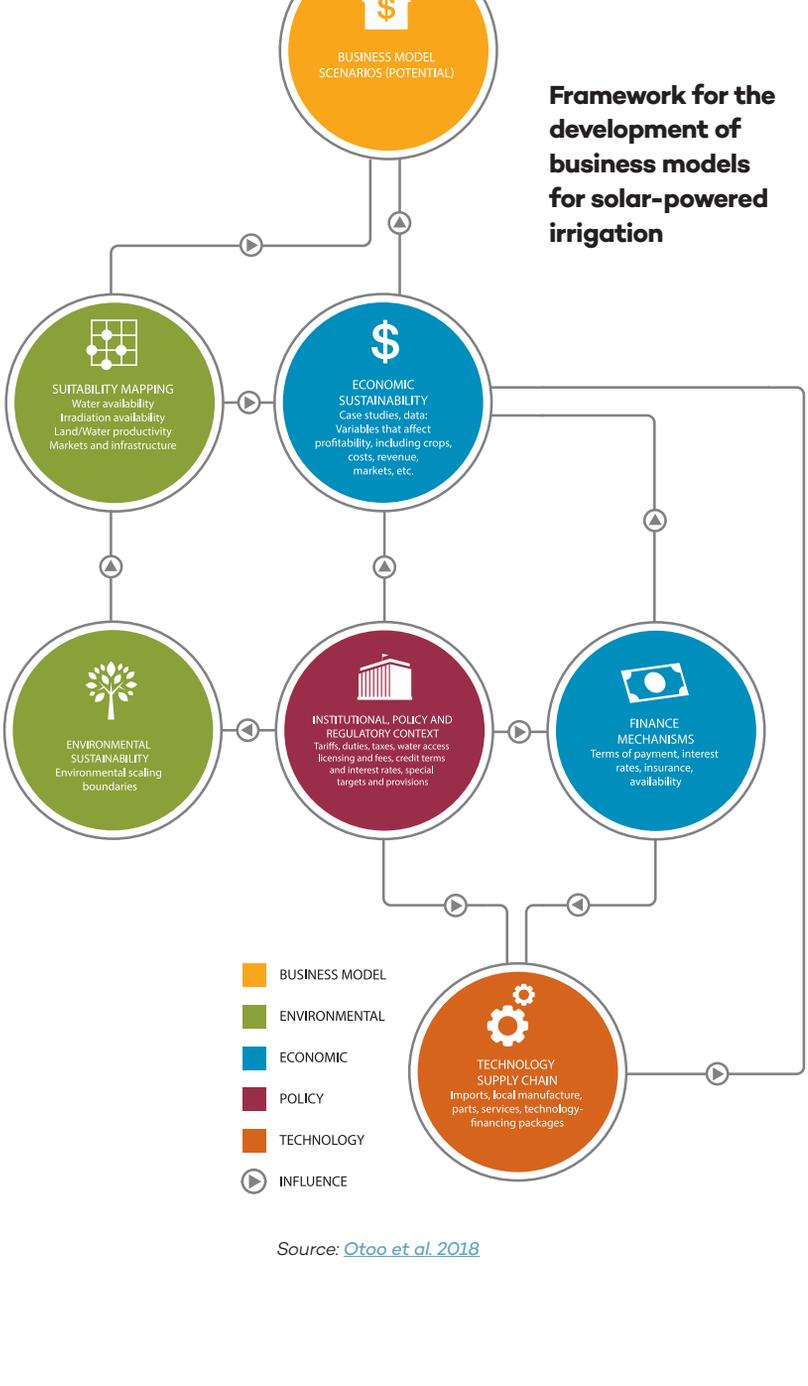
Researchers found that using drip irrigation with solar pumps significantly increased the amount of irrigable land and decreased labor requirements and costs. Combined with drip irrigation, solar pumps proved more profitable despite the high capital cost. Researchers also found there was a minimum amount of cultivated land needed for making solar irrigation financially feasible depending on crop type; high-value vegetables showed the most profit and promise.

The study assumed the farmer would purchase the solar pump on credit, so as the interest rates increased, the minimum amount of land needed to be profitable also increased. This suggests that farmers could generate significant profits if they can access low-rate financing.

In addition, **bundling solar pumps with other technologies and services can increase farm income.** For example, combining solar irrigation with easy-to-use soil moisture measurement tools enables farmers to learn about and improve water management practices. Farmers adopted those tools when they saw the benefits — improved yields and higher produce quality — and higher farm income.

Navigating the institutional, policy, and regulatory contexts

For solar-powered irrigation to reach potential scale in sub-Saharan Africa, financing mechanisms must be accessible across the irrigation system. Farmers, manufacturers, distributors, financing organizations, irrigation service providers, and other support services in the market ecosystem need access to finance. Those financing mechanisms — and solar-powered irrigation itself — are influenced by stakeholders' institutional, policy, and regulatory context. Institutional context affects the private sector's involvement in solar pump distribution and the suitability of business models for each socio-economic context.



Framework for the development of business models for solar-powered irrigation

Source: [Otoo et al. 2018]

Developing sustainable business models for distributing solar pumps requires better knowledge of the institutional and regulatory landscape, environmental suitability, social barriers that affect demand, and the finance ecosystem. ILSSI formed research-private sector partnerships to explore the potential of different solar pump business models in Ghana, Ethiopia, and Mali. ILSSI research partners also provided technical backstopping to strengthen company capacity, for example, the provision of information on land suitability and water availability, market segmentation analysis, and joint testing of different modalities for distribution. ILSSI identified nuances in market-based approaches to scale solar pump access across countries through these partnerships with solar pump distribution companies.

Across countries, researchers looked at several business models, including a cost-sharing model, a solar-powered irrigation service provider model, and an individual ownership model that included ways to use solar pumps for non-irrigation purposes. Multiple business models were viable, benefiting companies and market segments.

Solar pumps for multiple purposes and growing high-value crops could enhance the return on investment.

Because farmers have different irrigation needs and purchasing capacities, and the institutional and financial context differs, there is no one-size-fits-all business model or financing instrument.

CASE STUDY 4

Increasing access to solar irrigation for women farmers

While women farmers generally have lower access to irrigation technologies across sub-Saharan Africa, the demand and access level vary by institutional, policy, economic, and social context. While asset-based or various PAYGO finance modalities appear promising to increase access to solar pumps for poorer farmers, the actual benefit for women has not met potential. Women have less access to information about financing mechanisms available and how to access those finance instruments.

As one ILSSI study showed, **women may be more risk averse when it comes to debt and have lower demand for purchasing irrigation equipment on credit.** Working with solar pump distribution companies, ILSSI was able to develop more gender-responsive credit assessments, and companies implemented targeted training on financial literacy. As a result, women's access to solar pumps on credit increased, albeit gradually. As credit modalities for solar pump distributors increase, such as through carbon credits, robust information will be needed to ensure that women and poor farmers also benefit. Continued private and research sector partnerships will be required to ensure inclusive access to solar-powered irrigation.

65%

OF WOMEN WHO PURCHASED SOLAR PUMPS FROM PARTNER COMPANIES RECEIVED CREDIT

$65,300

IN CREDIT WAS PROVIDED TO WOMEN IN 2021-2022 TO PURCHASE SOLAR PUMPS BY PARTNER COMPANIES

CASE STUDY 5

Supporting solar irrigation market growth

Connecting customers to solar pumps is often hampered by poorly developed supply chains, high costs, and insufficient understanding of local market needs. Through support from ILSSI and the CGIAR Research Program on Water, Land, and Ecosystems (WLE), researchers conducted studies in conjunction with several solar pump companies to help address market constraints in Ethiopia, Ghana, and Mali.

80%

YEAR-OVER-YEAR INCREASE IN SOLAR PUMP SALES WAS SEEN BY A PARTNER DISTRIBUTOR IN GHANA FOLLOWING TECHNICAL ASSISTANCE

Researchers identified solar pump market segments among farmers based on varied water needs, pump preferences, access to land, and ability to pay. Women, in particular, had less access to land, credit, and information that would help them invest in irrigation, and companies often ignored the high potential of women farmers as a market segment. **ILSSI partners also helped companies establish stronger distribution networks and identify potential customers, which has led to an expansion into new areas to meet demand.** In addition, ILSSI research partners worked with private pump distributors to develop finance solutions, such as a more inclusive pay-as-you-go financing model. Partnerships across private, public, and research sectors help facilitate farmers' access to markets and engage more value chain actors on a broader level.

Key Points

- Solar-powered irrigation is a **promising solution** for transforming small-scale irrigated agriculture across sub-Saharan Africa. Research shows that with the right financial mechanisms and support, solar pumps could help improve food security, income stability, and gender equity in agriculture.

- To accelerate the scaling of solar pumps, suitability analysis should be incorporated into **business models and finance modalities**. Evidence-based credit and finance instruments can enable actors throughout the equipment supply chain to increase distribution and access. But careful attention must be given to ensuring smallholders benefit from the credit, especially women and resource-poor farmers. In addition, a rapid and extensive increase in capacity throughout the irrigation and finance ecosystem is needed to support supply chain growth. Moreover, solar-powered irrigation pumps should be bundled with learning and monitoring tools to enhance water use.

- Solar-powered irrigation has high potential for **climate adaptation**, as well as contributing to reduced Greenhouse Gas emissions and climate mitigation. At the same time, climate change will affect the suitability and profitability of solar pumps over time. Robust information on water quality, quantity, demand, and changing production and socio-economic factors will be critical to ensure smallholder climate resilience and avoid maladaptation.

- Expanding **knowledge and partnerships** across multiple levels — including governments, public agencies, private companies, farmer cooperatives, and research organizations — will be essential for sustainably reaching scale with solar-powered irrigation.

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