Tier 5: Public

POWER AFRICA
NIGERIA POWER SECTOR PROGRAM
PRODUCTIVE USE SOLAR IRRIGATION SYSTEMS IN NIGERIA

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ACRONYMS

Acronym	Definition
AC	Alternating Current
ACSS	Agriculture Credit Support Scheme
ADP	Agricultural Development Projects
AECF	African Enterprise Challenge Fund
AFD	Agence Française de Développement
AfDB	African Development Bank
BOA	Bank of Agriculture
BOI	Bank of Industry
C&I	Commercial & Industrial
CAPEX	Capital Expenditure
CBN	Central Bank of Nigeria
CLASP	Collaborative Labeling and Appliance Standards Program
DBN	Development Bank of Nigeria
DC	Direct Current
DFID	Department for International Development
DISCOs	Distribution Companies
DMB	Deposit Money Bank
DSCR	Debt-Service Coverage Ratio
EnDev	Energizing Development
ESP	Economic Sustainability Plan
FAO	Food and Agriculture Organization
FMBN	Federal Mortgage Bank of Nigeria
FMWR	Federal Ministry of Water Resources
FMARD	Federal Ministry of Agriculture and Rural Development
FRUG	Fadama Resource User Group
GDP	Gross Domestic Product

GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
Ha	Hectare
Hp	Horsepower
Hr	Hour
IEEE	Institute of Electrical and Electronics Engineers
InfraCredit	Infrastructure Credit Enhancement Facility
IRR	Internal Rate of Return
ISV	IEEE Smart Village
JLG	Joint Liability Group
kW	Kilowatt
kWp	Kilowatt peak
Ksh	Kenyan Shiling
L	Liter
MFB	Microfinance Bank
MFI	Microfinance Institution
NBS	National Bureau of Statistics
NEDECCO	Netherlands Engineering and Construction Company
NEP	Nigerian Electrification Project
NEXIM	Nigerian Export-Import Bank
NFDP	National Fadama Development Project
NFG	Nigerian Federal Government
NGN	Nigerian Naira
NGO	Non-governmental Organization
NPV	Net Present Value
PAYG	Pay-as-you-go

PA-NPSP	Power Africa - Nigeria Power Sector Program
PFI	Private Finance Institution
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PV	Photovoltaic
RBDA	River Basin Development Authority
RBF	Result-based Funding
REA	Rural Electrification Agency
REF	Rural Electrification Fund
REPP	Renewable Energy Performance Platform
ROI	Return on Investment
SEIF	Schneider Electric India Foundation
SFI	Syngenta Foundation India
SMEDAN	Small and Medium Enterprise Development Agency of Nigeria
SNL	Shaybis Nigeria Limited
SPI	Smart Power India
SPIS	Solar-powered Irrigation System
SSA	Sub-Saharan Africa
TAM	Total Addressable Market
UBA	United Bank of Africa
UKAID	United Kingdom Agency for International Development
USADF	United States African Development Foundation
USAID	United States Agency for International Development
USD	United States Dollars
VASFA	Vaishali Area Small Farmers Association
WaaS	Water-as-a-Service

EXECUTIVE SUMMARY

Irrigation improves crop yields and is critical to agricultural productivity. Nigerian smallholder farmers in unserved and underserved rural communities struggle to irrigate their crops, relying heavily on rainfall which is both intermittent and unpredictable. Solar powered irrigation solutions offer a unique solution for Nigerian farmers by leveraging clean, sustainable solar power to run irrigation systems and increase overall productivity. To unlock solar irrigation's potential, many smallholder farmers require both training and financial support.

PA-NPSP developed the following review and analysis to better understand the impact of solar powered irrigation solutions on crop yields and profit for smallholder farmers in Nigeria and inform stakeholders – such as solar mini-grid developers – interested in entering or investing in the market. To achieve this, PA-NPSP conducted a business case scenario analysis which reveals that the economic viability of solar irrigation investments is dependent on the irrigation method, crop type, business model, and financing structure applied. Our analysis – based on available financing mechanisms and interest rates – indicates that shared ownership and lease-to-own models (supported by grants or equity) for solar irrigation investments are more attractive than single owner models. In addition, our analysis revealed that mini-grid electricity tariffs in communities with irrigation activities can be 8-18% lower while still earning a high internal rate of return (IRR) for mini-grid investors with the addition of the productive use load from irrigation. Drip irrigation methods are more favorable than flood irrigation with greater tariff reduction potential given the higher energy demand from drip irrigation as compared to flood irrigation. To encourage sustainable deployment of solar irrigation systems in Nigeria, PA-NPSP recommends the following based on the analysis findings and literature review herein.

- **System Quality and After-sales Services**: To ensure project and financial viability, it is important that the Federal Government of Nigeria (FGN) regulate the quality of solar irrigation pumps, equipment and suppliers available to consumers, as well as technician certifications and supplier service warranties.
- **Utilization Factor and Water Management:** End-users and mini-grid developers can increase profits on solar investments and water management through pump optimization. The off-grid stakeholder community should encourage use of optimally sized solar pumps through training and policies.
- **Facilitator-led Awareness Campaigns:** The research conducted by PA-NPSP in this report suggests the need for a facilitator to equip farmers with relevant knowledge for financial decision making when procuring and operating solar-powered irrigation systems.
- **Targeted Financing for Marginalized Farming Communities:** The off-grid stakeholder community and FGN can support end-users and mini-grid developers in capturing the benefits of solar powered irrigation by facilitating access to targeted loan schemes with low concessional interest rates. In addition, offering grants which cover a portion of the capital cost of irrigation systems will encourage adoption of solar irrigation by marginalized farmers.
- **Further Analysis of Location-specific Business Models:** There is an opportunity for the off-grid stakeholder community to further develop location specific, data-driven business models for solar irrigation given different states require different methods of irrigation, based on the type of crop grown and rainfall patterns in the region.

Each of these are explored and supported in the Business Case Scenario Analysis section of the report. The report includes an introduction, an overview of the benefits of solar powered irrigation in Nigeria, a detailed review of solar powered irrigation technologies and deployment models, a discussion of financing options, a scenario analysis with results and sensitivities of different variables, and a conclusion summarizing insights from the literature review and scenario analysis.

REPORT STRUCTURE

The main body of the report summarizes the study and a series of appendices provide greater depth of analysis and additional data.

This report is divided into the following sections:

Introduction: This section provides an overview of PA-NPSP, the report objectives, the methodology used, and sets the stage for the analysis.

Drivers for Solar Irrigation: This section provides a detailed description of the need for solar irrigation and the benefits.

Irrigation Technologies: This section provides a brief overview of the different irrigation types as well as the application efficiency and crop suitability of each of the identified types. It provides a brief history of irrigation in Nigeria highlighting the different irrigation schemes that exist as well as the solar irrigation projects planned/currently being executed beyond Nigeria. The challenges that affect the adoption of irrigation are also discussed.

Deployment Models: This section describes the different models through which solar irrigation can be adopted by smallholder farmers; highlighting the advantages and disadvantages of each model.

Options for Financing and Partnerships: This section identifies the possible partnerships and options for financing the procurement of solar irrigation.

The Business Case Scenario Analysis for Solar Irrigation: This section evaluates the economic viability of solar-powered irrigation technology based on financial analysis of thirteen scenarios, under widespread business models along with the methodology and assumptions used to prepare the financial models.

Recommendations: This section provides recommendations necessary to encourage the sustainable deployment of solar-irrigation systems in Nigeria, based on this study's findings.

INTRODUCTION

Irrigation is critical to agricultural productivity and highly dependent on access to electricity. Smallholder farmers in unserved and underserved rural communities, where electrification is a challenge, struggle to irrigate their crops and heavily depend on rainfall. Several studies have shown irrigation improves crop yield and subsequently farmers' income, yet irrigation is still underutilized in Nigeria.

Solar irrigation provides opportunities for farmers by leveraging clean, inexpensive and sustainable solar energy. However, many smallholder farmers lack the knowledge and financial support required to leverage solar irrigation systems.

This study by the U.S. Agency for International Development (USAID) Power Africa Nigeria Power Sector Program (PA-NPSP) seeks to achieve the following objectives:

- Provide an overview of the market for solar irrigation in Nigeria
- Identify the benefits, challenges, current environment, and opportunity for growth
- Offer recommendations for the deployment of solar irrigation systems

METHODOLOGY

This report includes an analysis of different investment case scenarios using techno-economic analysis which evaluate solar-powered irrigation technology and business and financing models suitable for rural farmers, energy access companies, and entrepreneurs. This includes a financial analysis of various scenarios, under different business models (e.g., shared, PAYG, lease-to-own or equity cum subsidy) and financing structures. The study focuses on crops grown across several states in Nigeria with high potential for improved yield through irrigation.

To support this analysis, PA-NPSP conducted desk research drawing from100 primary literature sources. In addition, PA-NPSP conducted interviews to validate the study assumptions with over 10 stakeholder organizations in Nigeria across the off-grid energy and agriculture sectors, including private sector companies, non-governmental organizations, donor agencies, financial institutions, and government agencies.

THE CASE FOR SOLAR IRRIGATION IN NIGERIA

Nigeria has an agricultural land area of 69 million hectares (ha), of which 33 million ha are cultivated.[1] Only 10 percent of agricultural land in Nigeria is irrigated. In consequence, most farmers depend heavily on rainfall and cultivate their fields only during the rainy seasons.[2] Recent changes in average temperatures, rainfall, and adverse seasonal variation have greatly affected this method of rain-dependent cultivation. The amount of rainfall in Nigeria decreased at an average of 3.5mm per year between 1960 and 2006. Simultaneously, according to the World Bank Climate Change Knowledge Portal, "temperature increases of 0.03°C per decade were observed between 1901-2016, with stronger increases occurring over the last 30 years of 0.19°C per decade."[3]

Agriculture is a critical sector in Nigeria's economy, contributing 22 percent to the nation's GDP as of Q1 2021.[4] Nearly 70% of the population is engaged in agriculture at a subsistence level.[5] Agriculture is focused primarily in four sectors: crop production, fishing, livestock, and forestry. Crop production remains the largest of the four sectors and accounts for about 87.6 percent of agriculture's total output. This is followed by livestock, fishing, and forestry at 8.1 percent, 3.2 percent and 1.1 percent respectively. Some of the major crops include cassava, yam, maize, sorghum, rice, and millet. These crops together cover 65 percent of the total cultivated area.[1] Cassava, yam, cocoyam, and maize are staple crops in the humid parts of the country, whereas maize, sorghum, millet, cowpea, and groundnut are staple crops grown in the semi-arid parts of the country. The top crops in terms of profit in Nigeria are cocoa, oil palm, cotton, groundnuts, ginger, and sesame.[1] When adopting solar powered irrigation solutions, farmers can experience improved crop yields, reduced cost of irrigation, economic benefits from energy access, and environmental benefits from avoided use of diesel generators. Each of these are discussed in greater detail below.

IMPROVED CROP YIELDS

According to the Food and Agriculture Organization (FAO) 2017 data, Nigeria has an irrigation potential of 2.331 million ha, however, only an approximate 331,000 ha of agricultural land are currently equipped for irrigation.[6]

Vegetables, maize, wheat, sugarcane, potatoes, and rice are the most commonly irrigated crops and are grown predominantly in the semi-arid North of the country.[7]

Adopting irrigation in agriculture has been proven to significantly increase crop yield (also known as agricultural output), for crops like rice, maize, tomatoes, and onions.[8] Irrigation, when compared to a rainfed approach, increases the cropping intensity, which refers to the number of times a crop is grown and harvested in a year on a particular field. Irrigation supplies water needed by crops at the appropriate pressure to reduce water loss and increase crop growth, which consequently increases crop yield.

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[1] World Bank Group(2019). "Agricultural land -Nigeria". Source: https://data.worldbank.org/indicator/AG.LND.AGRI.K2?locations=NG

[2] A. Bala. (2012) "Description of cropping systems". Source: https://www.yieldgap.org/nigeria

[3] World Bank Group (2020). "Climate Historical Data". Source: https://climateknowledgeportal.worldbank.org/country/nigeria/climate-data-historical

[4] National Bureau of Statistics (2020). "Nigerian Gross Domestic Product Report Q3 2019". Source: https://www.nigerianstat.gov.ng/pdfuploads/GDP_Report_Q3_2019.pdf

[5] Food and Agriculture Organization of the United Nations, "Nigeria at a glance" Source: http://www.fao.org/nigeria/fao-in-nigeria/nigeria-at-a-glance/en/

[6] World Data Atlas (2021) https://knoema.com/atlas/Nigeria/topics/Land-Use/Area/Total-area-equipped-for-irrigation

[7] Bashir Adelodun and Kyung-Sook Choi (2018, October 4). "A review of the evaluation of irrigation practice in Nigeria: Past, present and future prospects". Source: https://academicjournals.org/journal/AJAR/article-full-text-pdf/3EAF05558713 Vol. 13(40), pp. 2087-2097, Article Number: 3EAF05558713

[8] Farm Link Kenya. Rice Farming in Kenya. Source: https://www.farmlinkkenya.com/rice-farming-in-kenya/

In Nigeria, irrigation has increased crop yield by up to 30 percent when compared to rainfall dependent crop yield (Table 1). The yields from selected crops show there is an inefficiency in the agricultural sector. The country's rice production is lower, even with enhanced irrigation, and when compared to a neighboring African country with similar GDP per capita, Kenya, producing between 7 - 10 metric tons per ha. Although the country ranks higher in terms of maize production, yields are still low when compared to other countries like South Africa and India producing an estimated 4 metric tons per ha of maize. Compared to South Africa, the United States, and India, Nigeria ranks lowest based on FAO statistics of agricultural land area equipped for irrigation.[9]

Table 1: Comparative Analysis of Selected Crop Yields, by Country

Crop	Yield (Nigeria)[6]		*Total Addressable Market (TAM) (Naira/ha)	Yield - (Metric Tons/ha)			
	Rainfed (Metric Tons/ha)	Irrigated (Metric Tons/ha)		South Africa	India	USA	Kenya
Rice	2.51	3.58	463,380	2.8[10]	2.6[11]	8.53	7.5[12]
Maize	2.97	3.87	268,848	2.50[13]	4.0[14]	10.4[15]	1.82[16]
Tomato	6.41	8.42	745,027	67.1[17]	20.25[18]	90.29[19]	125
Pepper	4.25	5.76	271,800	8.1	0.27[20]	4,259[21]	0.98[22]

[9] Food and Agriculture Organization. Aquastat Data. Source: http://www.fao.org/aquastat/statistics/query/results.html

[10] Knoema. Paddy rice yield. Source: https://knoema.com/atlas/South-Africa/topics/Agriculture/Crops-Production-Yield/Paddy-rice-yield

[11] Statista (2019). India's yield of rice. Source: https://www.statista.com/statistics/764299/india-yield-of-rice/

[12] Farm Link Kenya. Rice Farming in Kenya. Source: https://www.farmlinkkenya.com/rice-farming-in-kenya/

[13] FAO, White Maize: A Traditional Food Grain in Developing Countries (Chapter 3) http://www.fao.org/3/W2698E/w2698e03.htm

[14] Indian Institute of Maize Research (IIMR), Maize. Source: https://www.agrigoaexpert.res.in/icar/category/agriculture/fieldcrops/cereals/maize.php

[15] Yield Gap. Description of cropping systems, climate, and soils. Source: https://www.yieldgap.org/united-states

[16] Knoema (2020). Kenya - Maize yield. Source: https://knoema.com/atlas/Kenya/topics/Agriculture/Crops-Production-Yield/Maize-yield

[17] Tilasto. South Africa: Tomatoes, yield (hectogram per ha). Source: https://www.tilasto.com/en/topic/geography-and-agriculture/crop/tomatoes/tomatoes-yield/south-africa

[18] National Horticulture Board (2015). Tomatoes. Source: https://vikaspedia.in/agriculture/crop-production/package-of-practices/vegetables-1/tomato-1

[19] Map of Countries by Tomato Production. Source: https://www.atlasbig.com/en-us/countries-tomato-production

[20] AgriFarming. Black pepper farming information guide. Source: https://www.agrifarming.in/black-pepper-farming

[21] Agricultural Marketing Resource Center. Bell and Chili Peppers. Source: https://www.agmrc.org/commodities-products/vegetables/bell-and-chili-peppers

[22] FAO stat (2019). Pepper yield for Ethiopia. Source: https://www.tilasto.com/en/country/kenya/geography-and-agriculture/pepper-yield

Onions	6.10	6.60	228,295	40[23]	35[24]	56.4[25]	17[26]
Sugarcane	6.50	26.00	-	60[27]	78[28]	86.1[29]	60[30]
Wheat	-	2.80	1,167,824	5.0[31]	3.51[32]	3.1[33]	2.71[34]

**Estimated Total Addressable Market (TAM) based on the difference between irrigated and rainfed yields in Nigeria*

Based on the cumulative TAM (Table 1), farmers could gain an additional NGN 3.2 million (US$7,981) per ha through increased irrigation. This potential gain underscores Nigeria's agricultural sector's potential for increased productivity and economic growth, and the necessity to implement the necessary improvements such as irrigation. Figure 2 depicts the crops with the highest potential for increased yield from irrigation, across states in Nigeria.[35]

23 Enza Zaden, South Africa's Onion yield. Source; https://www.enzazaden.com/za/news-and-events/trends-and-inspiration/onions-south-africa-from-good-to-great

24 The National Horticultural Research and Development Foundation. Agriculture new onion variety for higher yield. Source: https://www.thehindu.com/sci-tech/agriculture/New-onion-variety-for-higher-yield/article15619307.ece

25 Atlas, World onion production by country. Source: https://www.atlasbig.com/en-ie/countries-by-onion-production

26 James (2019, January 4). The Introductory Guide to Onion Farming in Kenya https://smartbusiness.co.ke/the-introductory-guide-to-onion-farming-in-kenya/

27 Toongatt Hulett (2017). Cane Growing Process. Source: http://www.huletts.co.za/ops/south_africa/agriculture.asp

28 Statista (Updated 2019). Annual yield of sugarcane in India. Source: https://www.statista.com/statistics/764345/india-yield-of-sugarcane/

29 Our World in Data (2018). Sugarcane yields. Source: https://ourworldindata.org/grapher/sugar-cane-yields

30 NDEMO, B. (2018, March 28). Sour facts that blight the local sugar industry. Source: https://www.businessdailyafrica.com/bd/opinion-analysis/columnists/sour-facts-that-blight-local-sugar-industry-2195724

31 GRAIN SA (2015). Irrigated wheat production – an intensive system requires intensive management. Source: https://www.grainsa.co.za/irrigated-wheat-production-an-intensive-system-requires-intensive-management

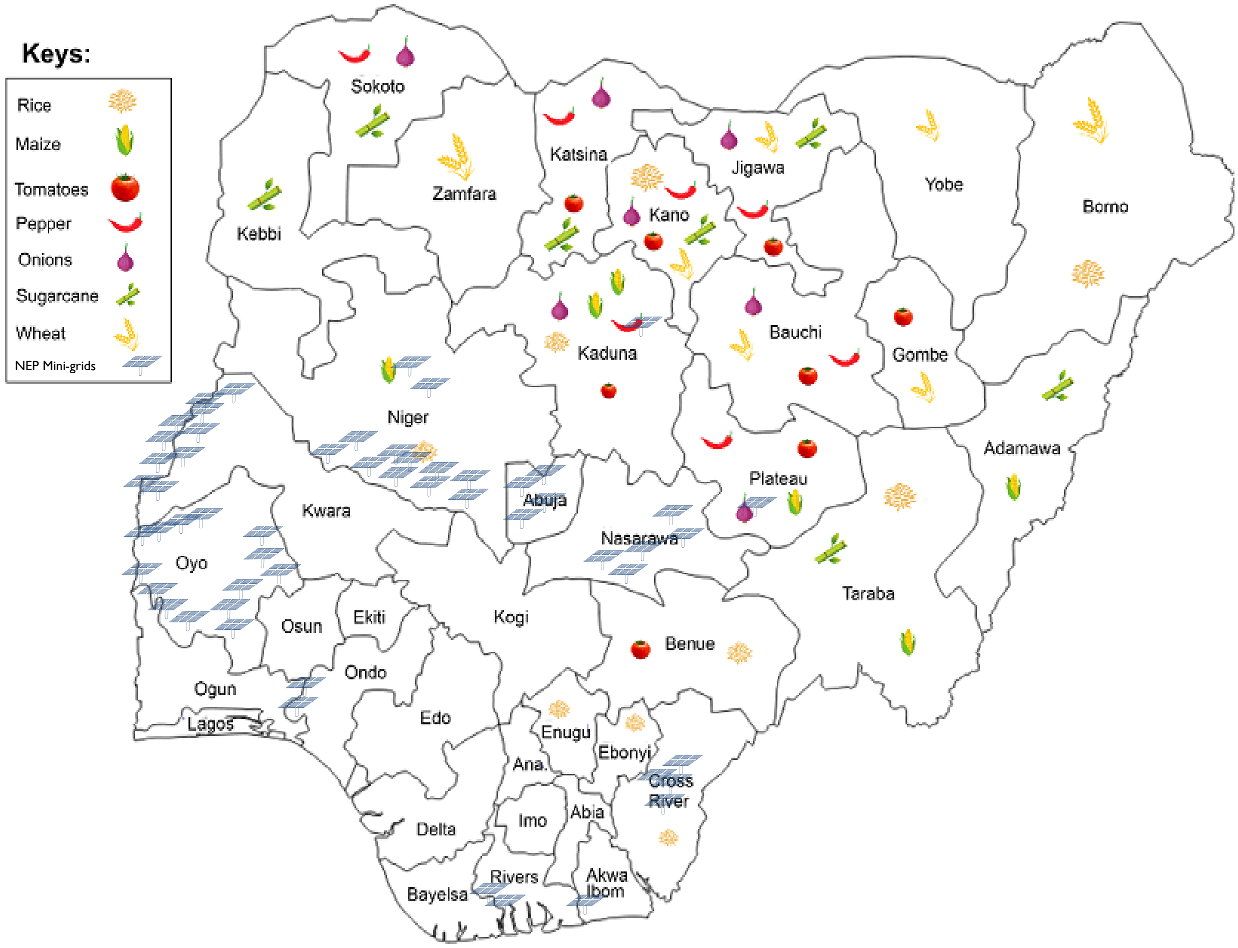
32 Statista Research Department (2020). Annual yield of wheat in India from financial year 2014 to 2018, with an estimate for 2019. Source: https://www.statista.com/statistics/764310/india-yield-of-wheat/

33 Global Yield Gap Atlas (2019). Description of cropping systems, climate, and soils. Source: https://www.yieldgap.org/united-states

34 Knoema. Kenya - Wheat yield. Source: https://knoema.com/atlas/Kenya/topics/Agriculture/Crops-Production-Yield/Wheat-yield

35 Taiwo Oyaniran (2020). "Current State of Nigeria Agriculture and Agribusiness Sector ". Source: https://www.pwc.com/ng/en/assets/pdf/afcfta-agribusiness-current-state-nigeria-agriculture-sector.pdf

Figure 1: Crops with Highest Potential for Improved Yield with Irrigation by State



REDUCED COST OF IRRIGATION

One of the contributors to poor uptake of irrigation is the high capital costs associated with installing irrigation systems and high operating costs of maintaining those systems. Irrigation requires water pumps that transport water from the source to where it is needed. The average cost of solar-powered and diesel-powered water pumps, as shown in Table 2, are prohibitively expensive for most smallholder farmers who live below the poverty line and earn roughly US$1.9 per day.[36]

Farmers can power their water pumps by connecting to the electricity grid, but many rural areas lack access to consistent and reliable grid electricity. In its absence, farmers who use diesel-powered water pumps struggle with the high operating costs associated with diesel consumption. While solar-powered irrigation has a higher initial cost compared to diesel-powered irrigation, the former's investment is usually recuperated due to its significantly lower operating cost.

[36] FAO (2018). Small Family Farms Country Factsheet. Source: http://www.fao.org/3/i9930en/I9930EN.pdf

Table 2: Cost Component of Solar PV and Diesel-Powered Pumps[37]

Items	Diesel Pump (Shallow)	Solar Pump (Submersible)
Power	4 hp diesel engine	4 hp dc motor powered by 5 kWp PV panel
Discharge	150,000 L/day by 760mm discharge pipe	150,000 L/day by 760mm discharge pipe
Diesel Consumption (L/year)	1,400	-
Price of Diesel 2021 (USD/L)	0.59	-
Irrigation Area (Ha)	4	4
Uses of pump (100 days/per person x 6 hour(h) per day x 3 crops per year)	1,800	1,800
Life (years)	10 (with engine overhaul after 5)	20 (panel), 10 (pump)
Cost (US$ including installation)	512	796

In Kenya, Uganda, and Tanzania, DFID's Energy for Efficiency Coalition, Collaborative Labeling and Appliance Standards Program (CLASP) and Acumen interviewed 400 farmers who owned a solar pump for 4 to 5 months.[38] Ninety-one percent of the respondents, all who owned solar pumps, highlighted the significant reduction in expenditure while 81 percent mentioned that the solar pump had improved their lives by increasing their disposable income.

IMPROVED ECONOMICS FOR ENERGY ACCESS PROVIDERS

Nigeria has an estimated installed mini-grid capacity of about 2.8 MW, with 59 mini-grid project sites serving rural consumers, out of which 52 leverage solar energy.[39] The current sites are mostly residential-based mini-grids with only a few developed for specific productive uses. An increasing number of developers are looking for opportunities to supply electricity to commercial and industrial (C&I) customers or other business customers with large, predictable loads (demand for electricity) while also serving residential customers. Anchor loads, or continuous, predictable demands for electricity, have the potential to increase the utilization rate of mini-grids, thus lowering the cost of electricity and increasing profits for the developer.[37] Solar irrigation pumps are one example of potential anchor loads that can be powered by mini-grids whenever surplus power is available.

[37] Hossain, M. A., Hassan, M. S., Mottalib, M. A., & Ahmed, S. (2015). Technical and Economic Feasibility of Solar Pump Irrigations for an Eco-friendly Environment. Procedia Engineering, 105, 670–678

[38] ACE-TAF (2019). "ACE-TAF Uganda Solar Water Pumping Report 2019". Source: https://www.ace-taf.org/wp-content/uploads/2019/10/ACE-TAF-UGANDA-SOLAR-WATER-PUMPING-REPORT-SCREEN-1.pdf

[39] Ruchi Soni and Takehiro Kawahara (2020). "State of the Global Markets Report 2020, Trends of renewable energy hybrid mini grids in Sub Saharan African, Asian and Island nations". Source: https://minigrids.org/wp-content/uploads/2020/06/Mini-grids_Market_Report-20.pdf

ENVIRONMENTAL IMPACT

In 2018, total emissions of CO_2 was 130 million metric tons in Nigeria, accounting for 16% of total Sub-Saharan Africa emissions.[40] Nigeria has the total highest carbon emissions in Sub-Saharan Africa with the exception of South Africa. The adoption of solar-powered water pumps, that replace the current ones powered by diesel, will aid the country towards achieving its pledge of a 20 percent reduction in GHG emissions by 2030. For example, a 3kW diesel water pump emits approximately 3,744 kg of CO_2 per year in comparison to a solar-powered pump with negligible CO_2 emissions associated with its operation. This transition offers a potential reduction of 97-98 percent GHG emissions per unit of energy used for water pumping.[41]

[40] World Bank. Nigeria Data. Source: https://data.worldbank.org/country/nigeria?view=chart

[41] Hans Hartung, and Lucie Pluschke (2018). "The benefits and risks of solar powered irrigation". Source: http://www.fao.org/3/i9047en/I9047EN.pdf

IRRIGATION TECHNOLOGIES

The irrigation systems or technologies refers to the means through which the water is applied to crops. Some crops require the supply of water in high pressure (sprinklers) while others thrive best with a low-pressure supply of water (drip). The choice of the irrigation system depends on three factors: the crop, the amount of water available, and the energy supply. While any irrigation method can be adopted for any crop type, the maximum benefit (in this case high yield) may not be realizable with the inappropriate irrigation method.

The following are the diverse types of irrigation methods:

- **Surface Irrigation (also known as flood irrigation):** Distribution of water through gravity without a water pump
- **Localized Irrigation:** Low pressure distribution of water to crops through a network of pipes
- **Drip Irrigation:** Distribution of water to areas near the root of the crops (higher maintenance and reduced risk of losing water through evaporation)
- **Sprinkler Irrigation:** High-pressure distribution of water to crops using sprinklers
- **Center Pivot Irrigation:** Use of sprinklers to distribute water to crops in a circular pattern
- **Sub-irrigation:** Distribution of water across the farmland by raising the water table, through a system of pumping stations, canals, gates, and ditches
- **Manual Irrigation:** Manual delivery of the water to the crops where it is needed

Table 3 shows some characteristics of different irrigation systems including their efficiency, crop suitability, and the typical irrigation head required.[42]

Table 3: Irrigation Methods Suitability

Method	Application Efficiency	Typical Head (m)	Crops
Surface (flood) irrigation	40–50%	0.5	All crops except cereals
Sprinkler	70–80%	10 – 20	Row, field, and tree crops e.g., maize, sugarcane, soybean.
Low-pressure drip irrigation	80%	1 – 10	High-value crops including tomato, cabbage, cauliflower, onion, okra, cucumber, peas, spinach, oranges, bananas, watermelon, grapes, strawberries
High-pressure drip irrigation	85–95%	10 – 100	High-value crops including tomato, cabbage, cauliflower, onion, okra, cucumber, peas, spinach, oranges, bananas, watermelon, grapes, strawberries

[42] GIZ (2018). "The Toolbox on Solar Powered Irrigation Systems (SPIS)". Source: https://energypedia.info/images/8/89/SPIS_Toolbox_All_Modules.pdf

Surface irrigation can be adopted for any crop except cereals - due to excess water in plant root zone decreasing the oxygen available to roots - whereas drip irrigation and sprinkler irrigation are best suited for high-value cash crops due to their high capital investment and maintenance cost.

COMPONENTS OF A SOLAR-POWERED IRRIGATION SYSTEM

A solar-powered irrigation system (SPIS) could be a stand-alone system as in Figure 2, in which case it is the combination of various components including solar PV panels, motor pumps, and controllers working together to supply water to an area of land. In a SPIS, the solar power captures energy from the sun and powers the operation of the water pump, which in turn supplies water directly to crops, or a reservoir for storage. SPIS could also be powered through centralized power generating rural mini-grids. The components of SPIS are detailed below, the first four of which are additional equipment for a stand-alone system:

- **Solar Photovoltaic (PV) panel**s are a vital component of solar pumps. PV panels capture the sun's energy and convert it into electricity. Each PV panel (module) is made up of multiple solar cells that trap light particles or photons from the sun and these photons knock electrons loose. The flow of the displaced electrons leads to a generation of electricity (DC energy). Depending on the volume of water being pumped, an array of solar panels may be necessary to power a solar pump effectively. To pump between 25-35m^3/day (7 hours / day) of water to irrigate one ha of land, the solar PV panels would be required to have a capacity of about 1 kW.
- The **mounting structure** holds the solar PV panels in place and tilts solar panels to maximize solar energy captured from the sun. A more expensive but effective solution is the solar tracker, a dynamic structure that changes the angle of the panels to follow the direction of the sun throughout the day. The solar tracker increases the energy captured by 25 – 30 percent.
- The **controller** acts as a link between the solar panels and the water pump to regulate the amount of energy supplied to the water pump for it to operate efficiently. The controller protects the water pump against over and under voltage, reverse polarity, overload, and over-temperature.[38]
- An **inverter** converts the direct current (DC) power generated by the solar panel to alternating current (AC) needed by the water pumps. To convert DC energy to AC energy, inverters change the direction of the DC input and produce an AC output. There are three types of inverters commonly used by SPIS: string inverters, power optimizers, and microinverters.[43]
- The **water pump** extracts water from its source (rivers, lakes, dams, wells, reservoirs, or underground canals) and moves it to the area where it is needed. There are two main types of water pumps depending on the origin of its water: surface and submersible water pumps. The former extracts water from sources up to six meters away and distributes it within a farm area. A submersible pump, in contrast, extracts water from underground water sources typically between 10 – 120 meters deep and pumps the water up to the farm area for the crops.[44]
- The **monitoring system** helps to track the operation of the entire SPIS. It monitors and controls the water pressure, flow, and level to ensure that the system operates within its limits and lasts longer. A typical monitoring system consists of a pressure gauge, flow meter, and water dipper. In some cases, monitoring systems may include data loggers that record and store information around the operation of the system.

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[43] Chris Deline (2016). Photovoltaic Solar Energy – From Fundamentals to Applications. Source: https://doi.org/10.1002/9781118927496.ch47

[44] Thomas F. Scherer (2017). "Irrigation Water Pumps". Source: https://www.ag.ndsu.edu/publications/crops/irrigation-water-pumps#section-13

- A **reservoir** allows for the storage of extracted water. It also helps in increasing or decreasing the water pressure as the need arises. It is especially necessary for situations where water needs to be distributed before sunrise and thus a good way of managing energy demand when excess power (from a mini-grid) is available. A water sensor is used to prevent overflowing (wastage) when the reservoir is full and triggers additional water to fill up the reservoir when it is empty.
- An **irrigation head** is a critical part of the system since it manages the water quantity, quality, and pressure. The head has the following four components: valves (to control the quantity of water distributed), filters (to remove dirt and particles that could potentially block the system), a fertigation system (to help mix the water extracted with fertilizers) and a pressure regulator (to help increase or decrease the pressure).[45]

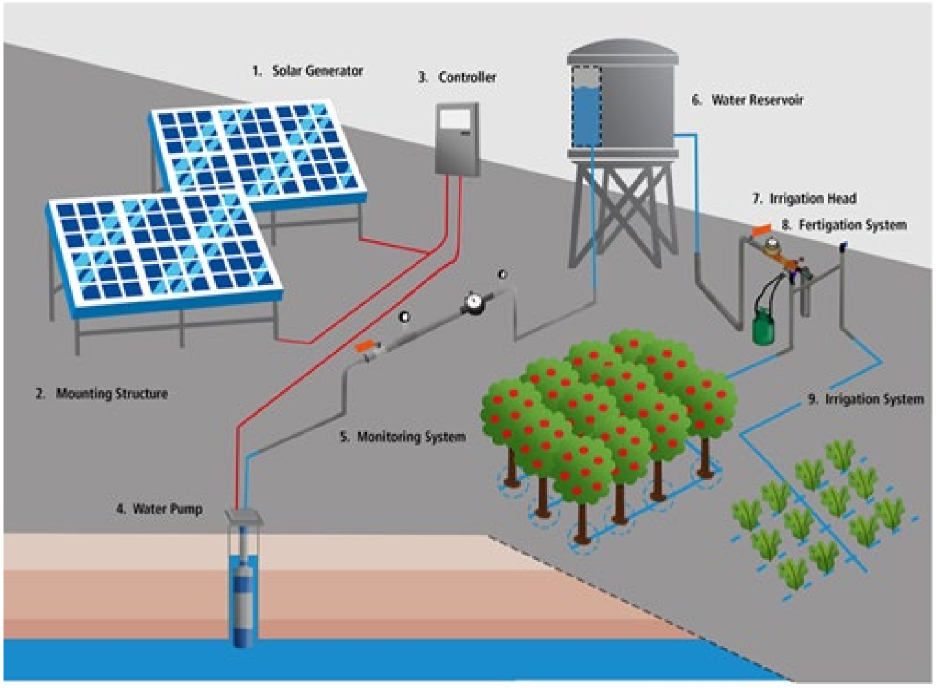
STAND-ALONE SOLAR-POWERED IRRIGATION SYSTEMS

The three most common configurations of stand-alone solar-powered irrigation systems (SPIS) are called the best-practice, the simple, and the hybrid.

The best-practice SPIS configuration is the most common whereby a solar panel on a fixed mounting structure provides electricity for a submersible pump installed in a borehole. As shown in Figure 2, water is pumped to an elevated reservoir a few meters above the ground where it is stored at a constant pressure. When released, it flows into a low-pressure drip irrigation system where the water is filtered before reaching the crops. A tracking system can be incorporated in this type of configuration but requires higher investment and more maintenance. It is also optional to have a monitoring system installed between the pump and the reservoir to measure the water flow and pressure.[43]

[45] Energypedia (2020). Toolbox on Solar Powered Irrigation Systems. Source: https://energypedia.info/wiki/SPIS_Toolbox_-_Solar_-_powered_Irrigation_Systems

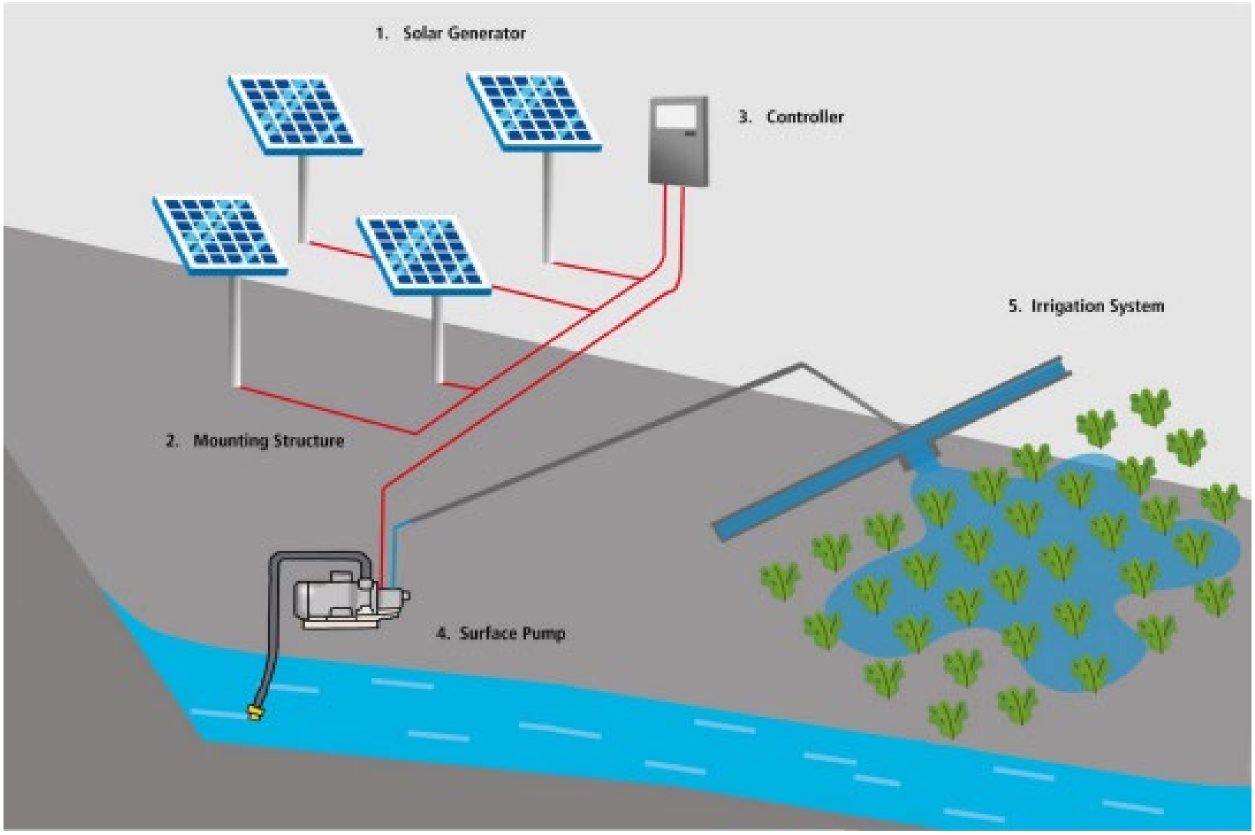
Figure 2: SPIS Best Practice Configuration[46]



In a simple SPIS configuration, a solar panel on a fixed mounting structure provides electricity for a surface pump installed at a reservoir or waterbody. The water is pumped directly to a surface irrigation system and does not pass through an elevated reservoir. The pressure and pump flow to the irrigation system correlate with the actual solar irradiance, which fluctuates over the course of the day, especially with a fixed mounted solar panel. The main benefit of this configuration is the simple installation and comparatively low costs. Nevertheless, it has the disadvantage that the farmer has limited control over the distribution of water in the field during the day since there is no reservoir to regulate flow and pressure.[43]

[46] Hahn, A., Sass, J. & Fröhlich, C. (2015): Manual and tools for promoting SPIS. Multicountry - Stocktaking and Analysis Report. GFA Consulting Group

Figure 3: SPIS Simple Configuration, with Tracking System[44]



A hybrid SPIS configuration involves the use of a solar-powered and a diesel pump. The best practice and the simple SPIS configuration can also be hybrid when they incorporate both energy sources for the pump.

There is a significant opportunity in Nigeria to *power irrigation pumps through rural mini-grids*, in which case the power generation and management components form a part of the central generation system of the mini-grid.

IRRIGATION SCHEMES IN NIGERIA

Despite the immense benefits derived from the adoption of irrigation, Nigeria has struggled to build its irrigation infrastructure and enjoy the accruable merits. The country currently has only irrigated 10 percent of its potential irrigable agricultural land, a low figure given the high investments in the agricultural sector, totaling over US$720 million as of 2015.[47,48] The approaches to implementing irrigation that have been adopted to date fall into one of two distinct but interrelated categories: public schemes (e.g., large-scale irrigation scheme) or farmer-owned schemes (i.e. small-scale irrigation scheme).[49]

Public Irrigation Schemes

A public irrigation scheme (i.e. large-scale irrigation scheme), is typically run by the River Basin Development Authorities of the FGN. These irrigation schemes were launched in the 1970s to foster the

[47] FAO, AGWA, and IFAD (2014, May). National Investment Profile: Water for Agriculture and Energy: Nigeria. Source: http://www.fao.org/fileadmin/user_upload/agwa/docs/NIP-NIGERIA-MAY percent202014-BTI-AM-DM-v6.pdf

[48] FAO Aquastat (2019). https://knoema.com/FAOAQST2019/aquastat

[49] Hua Xie, Liangzhi You, Hiroyuki Takeshima (2017, August). Invest in small-scale irrigated agriculture: A national assessment on potential to expand small-scale irrigation in Nigeria. Source: https://pdf.usaid.gov/pdf_docs/PA00TJGF.pdf

construction of large dams and pumping systems in parts of the country with relatively low water supply, particularly in the North. By 1990, the government had constructed 162 dams with the capacity of 11 billion m^3, capable of potentially irrigating about 725,000 ha of land. However, due to high operating costs and poor maintenance of these dams, they have provided irrigation to only about 32 percent of the developed area (as of 2004).[50]

Farmer-Owned Irrigation Scheme

By the late 1980s, the FGN launched the Agricultural Development Projects (ADP) to address the issues associated with the public irrigation scheme while also meeting the irrigation needs with the available water resources. The farmer-owned irrigation scheme, also known as the small-scale irrigation scheme, sought to provide smallholder farmers with technologies, such as pulley-buckets, motor pumps, and small reservoirs to foster the extraction of water required for irrigation. ADP also funded the construction of boreholes and tube wells, and by 1992, over 80,000 pumps had been distributed to Fadama Resource User Groups (FRUG), each consisting of multiple farm families. Presently, there are over 1000 FRUGs created with the aim of distributing agricultural inputs and farming equipment to farmers.[51] By 1993, the World Bank launched the National Fadama Development Project (NFDP) in phases (Fadama I, Fadama II, and Fadama III) which built on the ADP in a bid to financially empower farmers to construct irrigation systems. After six years, an additional 55,000 pumps had been distributed through this project.[48] The small-scale irrigation scheme represents about 95 percent of the irrigated crop area in Nigeria.

Table 4: Summary of Irrigation Schemes in Nigeria[5]

Scheme	Duration	State	Service Provider	Donors	Irrigated Crops
South Chad Irrigation Project	1970s	Borno	The Nigerian Government	World Bank	Rice
Kampe-Omi	1983	Kogi	Niko Engineering Limited	The Nigerian Government	Maize, rice, vegetables, sorghum
Tada-Shonga	36 months (2021 - 2024)*	Kwara	Federal Ministry of Water Resources (FMWR)	The Nigerian Government	Rice, maize

[50] Jim Kundell (2008, October 8). Water profile of Nigeria. Source: https://editors.eol.org/eoearth/wiki/Water_profile_of_Nigeria

[51] African Development Fund (2003). Republic Of Nigeria Fadama Development Project Appraisal Report. Source: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/NG-2003-156-EN-ADF-BD-WP-NIGERIA-AR-FADAMA-DEVELOPMENT-PROJECT.PDF

Scheme	Duration	State	Service Provider	Donors	Irrigated Crops
Bakolori	12 months (1979 - 1980)	Sokoto	MASDAR, Sokoto River Basin Authority	Federal and State Governments of Nigeria	Wheat, rice, sorghum, tomatoes, and onion
Kano River Irrigation (TRIMING project)	1960s	Kano	FMWR, Netherlands Engineering and Construction Company (NEDECCO)	World Bank	Rice, wheat, maize, and tomatoes
Fadama Irrigation Scheme	1990 - Present	Oyo, Osun, Bauchi, Gombe, Jigawa, Kano, Kebbi, Sokoto, Zamfara**	Federal Ministry of Agriculture and Rural Development (FMARD)	World Bank	All major cash crops and vegetables in Nigeria

**The scheme started in 2010 but was abandoned along the way.*

***The scheme has been implemented in over 18 states including the states listed in the table.*

Community Irrigation Scheme

In Lajolo village located in Kwara State, Shaybis Nigeria Limited (SNL), with technical and financial support from the Institute of Electrical and Electronics Engineers (IEEE)'s Smart Village (ISV), installed an 8.5kW solar microgrid. SNL completed the installation between September and December 2017 and adopted a pay-as-you-go (PAYG) model using a prepaid metering system. In the past, the village relied on two manual pumps for irrigation purposes.[52] After installation, the solar microgrid powered the water pumps needed for the farmers to irrigate their farms and increase yield. The installation of the microgrid brought about vast benefits to farmers and the entire community beyond irrigation. For example, with the provision of solar-powered streetlights, the community became more secure, and residents became more comfortable doing business at night. In addition, residents, who prior to the installation travelled about 3 km to charge their phones and lanterns, did not need to make that journey anymore. Two women in the community started businesses (provided ice block sales and the sale of refrigerated soft drinks) leveraging the electricity.[53] Due to the fertile land in Lajolo, farmers from nearby villages and hamlets seasonally migrate to Lajolo to grow their crops.

IRRIGATION SCHEMES BEYOND NIGERIA

As shown in Table 2, solar water pumps require high capital investment, which is a challenging obstacle for many smallholder farmers. In response to this barrier, efforts by the government and other donor and private agencies have been geared towards providing subsidized and more affordable solar irrigation services. In 2018, the FAO recommended the use of solar-powered irrigation as a new way to increase agricultural yields, highlighting its potential for catalytic growth in adoption as the cost of solar PV panels

[52] Smart Village. Shaybis Nigeria Limited – Nigeria. Source: https://smartvillage.ieee.org/project/shaybis-nigeria-ltd-nigeria/

[53] Salihu, T. Y., Akorede, M. F., Abdulkarim, A., & Abdullateef, A. I. (2020). Off-grid photovoltaic microgrid development for rural electrification in Nigeria. The Electricity Journal, 33(5), 106765. doi:10.1016/j.tej.2020.106765

decrease.[54] The World Bank further underlined this positive trend in affordability of solar PV cells, for which costs have dropped dramatically from about US$15.50 in 1997 to about US$0.3 in 2015.[55]

The potential for solar irrigation has led to various private and public investments in the development and deployment of solar irrigation systems in sub-Saharan Africa (SSA) and beyond. In December 2019, the African Development Bank (AfDB) provided a grant of US$21.7 million to the Sudanese government to encourage the installation of 1,170 solar pumps in farms in two states; West Kordofan and North Kordofan.[56] In 2013, the Government of Bangladesh signed a USD10 million grant agreement with the World Bank providing solar irrigation pumps to farmers.[57]

In the deployment of solar irrigation systems across continents, different models are adopted to provide support to the farmers (see Appendix A). In the Nile Delta, facilitators trained about 196 farmers on the use and maintenance of solar irrigation systems to de-risk the investments. In Jharkhand, India, farmers contributed 25 percent to the development of a solar irrigation system, the balance of which was funded by Syngenta Foundation India (SFI) and Schneider Electric India Foundation (SEIF) to reduce the financial burden associated with an investment in solar irrigation for the farmers.

Deployment models of solar irrigation projects across continents strongly indicate the need for adequate financing, appropriate training on use and maintenance, and affordable payment options. These measures are paramount for encouraging the uptake of solar-powered irrigation by farmers.

CHALLENGES TO IRRIGATION IN NIGERIA

The potential for irrigation in Nigeria is immense. Although poorly managed and in most cases abandoned (primarily due to high operating costs and poor maintenance culture), the following challenges inhibit the country from broad implementation of irrigation systems:

- **Limited Supply of Electricity**: Depending on the irrigable land area, a water pump requires between 0.37 to 4.85 kW of electricity to operate. Nigeria has an installed generation capacity of about 13,000 MW of electricity out of which an estimated 5,500 MW is distributed on average.[58] Approximately 26% of Nigerian's rural population has access to electricity, limiting the employment of electric-powered irrigation systems via existing energy systems.[59] In light of this, it is unrealistic to depend on on-grid electricity for irrigation especially in rural areas where the majority of farmlands are located.
- **High Cost of Diesel Pumping:** Given the rising cost of diesel (US$0.5 per liter) and the high energy requirements of a water pump, it is too expensive for farmers to afford diesel-powered water pumps. Based on research carried out at the lower Niger Basin Ilorin, one ha of land typically requires 391 liters of diesel per season, costing a total of NGN 94,790 (given the current cost of diesel is NGN

[54] Enviro News Nigeria (2018). FAO approves 'climate-friendly' solar irrigation pumps for agriculture. Source: https://www.environewsnigeria.com/fao-approves-climate-friendly-solar-irrigation-pumps-for-agriculture/

[55] World Bank (2017, January 10). "Solar Water Pumping: Ready for Mainstreaming?". Source: https://www.worldbank.org/en/news/infographic/2017/01/10/solar-water-pumping-ready-for-mainstreaming

[56] African Development Bank (2019, December 23). Sudan: African Development Bank approves US$21.783 million grant for roll out of solar-powered irrigation. Source: https://www.afdb.org/en/news-and-events/press-releases/sudan-african-development-bank-approves-21783-million-grant-roll-out-solar-powered-irrigation-33367

[57] World Bank (September 30, 2013). Project Signing: US$10 Million Grant for Solar Irrigation in Bangladesh. Source: https://www.worldbank.org/en/news/press-release/2013/09/30/project-signing-10-million-grant-for-solar-irrigation-in-bangladesh

[58] ACE-TAF (2020). Stand Alone Solar (SAS) – Market Update: Nigeria. Source: https://www.ace-taf.org/kb/stand-alone-solar-sas-market-update-nigeria/

[59] World Bank (2019). Access to electricity, rural - Nigeria. Source: https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=NG

242.43 per liter).[60] This cost discourages adoption and usage. Furthermore, most farmers are burdened with locating petrol stations to buy fuel, which are typically located far distances from their land.

- **Cost of Water Pumps:** As already discussed, the cost of acquiring water pumps for irrigation is high, and often unaffordable for farmers. The government has made efforts in the past to provide funding opportunities to support the adoption of irrigation in rural communities, but these initiatives have been inadequate in solving this large-scale problem. Between 2004 and 2010, two of Nigeria's irrigation schemes, Kampe-Omi and Tada-Shonga, received less than 50 percent of the funds required for their operations.[61] Added to the insufficient distribution of the required funds, the participating farmers did not have adequate financial resources to manage the project efficiently. These two factors led to the ineffectiveness of the schemes which resulted in the irrigation of only 17.12% of the total potential irrigable land (7,300 ha) for the two schemes.[59]
- **Inconsistent and Unsustainable Policie**s: The Nigerian government has developed and adopted a number of policies to encourage irrigation. Unfortunately, these policies are often inconsistent and ineffective. Water and agriculture are treated as separate entities and governed by two separate ministries: the Federal Ministry of Water Resources (FMWR) and the Federal Ministry of Agriculture and Rural Development (FMARD). These ministries along with state irrigation departments and the River Basin Development Authority (RBDA) work independently and create separate, uncoordinated policies, in addition, the Rural Electrification Agency operates in a silo as well. This has resulted in disjointed efforts and policies which lead to an underutilization of resources and difficulty in achieving the goal of irrigation. Furthermore, the sustainability and adequate implementation of existing energy, water and agricultural policies is not guaranteed.[5]
- **Low Farmers Awareness:** Most rural farmers are unaware of solar water pump technologies and their benefits for irrigation and crops. Among the factors affecting farmers' participation in irrigation schemes, poor knowledge of irrigation techniques among the farmers ranked highest among factors that decreased their participation.[62] The necessary organization and execution of awareness campaigns requires heavy investment which often dissuades private entities such as mini-grid developers.
- **Farm Holding Patterns:** In Nigeria, over 70 percent of crops are grown in rural communities. To access the required financial resources to adopt irrigation, rural farmers rely on loans. Moreover, some farmers do not cultivate land that they own but rather lease it during farming seasons. As a result, rural farmers do not have the creditworthiness (collateral) to be eligible for microfinance bank loans. In situations where farmers do own land, the plots are usually small-scale (<0.5ha), limiting the loan amount accessible to them.

[60] Simeon Olatayo, Matthew Segun, Oke Matthew, and Olumuyiwa Idowu (2018). Energy requirements for irrigation water supply of selected schemes in Nigeria. (Source: https://mjae.journals.ekb.eg/article_95798.html Article 11, Volume 35, Issue 2, Page 571-586

[61] Emmanuel Oriola (2014). Assessing River basin system potentials to enhance sustainable irrigation farming operations and management in Nigeria. https://www.researchgate.net/publication/301749198

[62] Adekunle, F. O. Oladipo, I. Z. Busari (2015). Factors Affecting Farmers Participation in Irrigation Schemes of the Lower Niger River Basin and Rural Development Authority, Kwara State, Nigeria. https://www.researchgate.net/publication/291375818

DEPLOYMENT MODEL OPTIONS FOR SOLAR IRRIGATION

According to the UN, sustainable development is development that meets the economic, social, and environmental needs of the present without compromising the ability of future generations to meet their own needs.[63] In order to fulfill this definition of sustainable development, solar irrigation deployment models must incorporate all of these factors in its deployment.

The term "deployment models" refers to the responsibilities and relationships between stakeholders to enable the purchase, deployment, and efficient powering of irrigation systems using solar energy. The following deployment model options focus on medium-scale (100 – 1000 ha), small-scale (10 – 100 ha) and micro-scale (1 – 10 ha) solar irrigation deployment which can potentially be powered by up to 1 MW solar mini-grids and standalone systems (< 10 kW). The estimated maximum requirement for solar power necessary to irrigate a one-ha farmland (25-35m^3/day pump discharge, 7 hours /day) is less than 1 kW . For rice, a crop with the highest irrigation requirements, this translates to roughly a 4-kW power requirement to meet the daily irrigation needs of 130 m^3/ha of rice. For most of the other crops grown in Nigeria, irrigation needs can be met with under 3 kW power requirement.[64]

ECONOMIC SUSTAINABILITY OF SPIS DEPLOYMENT

The economic sustainability of powering solar irrigation systems across different states in Nigeria is determined by 1) input costs for solar irrigation, 2) the expected additional revenues from increased yields due to the use of solar pumps, and 3) the cost of alternative irrigation solutions, such as diesel pumps. These factors are influenced by peak daily water requirements, depth or distance from a water source, solar irradiance, system quality and after-sales services, access to inputs and crop markets, utilization factor, and the cost of alternative solutions. Further detail on the drivers of economic sustainability associated with SPIS deployment are as follows:

- **Peak Daily Water Requirements:** Solar pump capital cost depends on the peak daily water needs of a crop. For example, the peak daily water requirements of crops like onions are 20 percent less than that of sugarcane and paddy. A lower peak daily water requirement entails a smaller capacity index with a lower capital cost.
- **Depth and Distance from Water Sources:** The distance between the water source and farmland determines the pumping head, and therefore the capacity of the solar pump components. Thus, regions with lower water tables require solar pumps with higher capacity and capital cost. Financial constraints often prevent farmers from acquiring the necessary large solar pumps.[65]
- **Solar Irradiance:** The water discharge from solar irrigation pumps vary according to the changes in the solar irradiance depending on the time of the day, month, and location. It is necessary during solar panel sizing to take into consideration the solar irradiance during the months with peak irrigation. This is crucial as solar panels contribute around 30–45 percent to the total solar pump cost and optimal sizing of the solar panels is essential to keep system costs down.[61]

[63] Our Common Future. Report of the World Commission on Environment and Development. Source: http://www.un-documents.net/our-common-future.pdf

[64] Food and Agriculture Organization of the United Nations, "Scheme Irrigation Water Need and Supply." Source: http://www.fao.org/3/u5835e/u5835e04.htm

[65] Agrawal, S., & Jain, A. (2018). Sustainable deployment of solar irrigation pumps: Key determinants and strategies. Wiley Interdisciplinary Reviews: Energy and Environment

- **System Quality and After-Sales Services:** The economics of solar irrigation systems is also impacted by system quality and maintenance. Poor after-sales service has been cited as a major challenge faced by smallholder farmers, particularly in sub-Saharan Africa.[66]
- **Access to Inputs and Crops Market:** Farmers frequently lack access to high-quality inputs, market information about crop prices, and crop markets - key barriers to profitable irrigated farming. These persistent gaps point to the need for a balance between solar irrigation programs and other market linking and extension programs.[63]
- **Scale of Farming:** The capability of farmers to afford the high cost of capital for SPIS is a critical factor for its adoption. The scale of farming determines the necessary capacity of the solar pumps, the revenue from cultivation, and the farmer's ability to procure and access credit facilities.[67]
- **Utilization Factor:** The utilization factor refers to the fraction of time for which the systems are in use, a key determinant of the economic viability of SPISs. For instance, some farmers in Northern West Bengal (India) need irrigation for an average of 8 hours/day for 30 days in a year. Ownership of SPIS by such farmers would imply the system lying idle for the majority of the year, making it economically unviable.[63]

SOCIAL SUSTAINABILITY OF SPIS DEPLOYMENT

Public opinion and acceptance are important for the successful adoption of new technologies such as SPIS and is influenced by its perceived risks and benefits, technology trust, estimated costs, and distributive fairness (gender and social inequality).[68] These influential variables, in turn, are determined by technology awareness, system quality and after-sales services, and system theft:

- **Technology Awareness:** The absence of information and knowledge about new technologies can serve as a barrier to discovering alternative solutions. A survey of 1,600 rural farmers in India revealed that only 27 percent of farmers were aware of SPIS technology of which only 2 percent of the farmers had information about supportive government schemes. Awareness campaigns, technology demonstration, and training exercises are necessary to enable farmers and other stakeholders to make informed decisions about SPIS. For this purpose, a facilitator is necessary to champion awareness campaigns leveraging local knowledge networks, such as farmers' cooperatives, to spread information and increase acceptance of SPIS among farmers.[69]
- **System Quality and After-sales Services:** Apart from being crucial factors for economic viability, system quality and timely after-sales service are also significant determinants of the social acceptability of SPIS. Since SPIS are new technologies to smallholder farmers with little market influence, the distribution of cheap but poor-quality products is a major challenge to the market since it impacts consumers' opinion of the technology. Likewise, lack of timely access to after-sales service can also reduce farmers' confidence and interest in solar irrigation systems.[64]
- **System Theft:** Solar panels consist of almost half of the total system costs and are more vulnerable to theft and physical damage. Several cases of solar panel thefts have been recorded in

[66] Belete Limani Kerse (2017, November 17). A Review Paper on: The Multi-Functional Implication of Integrated Watershed Management: The New Approach to Degraded Land Rehabilitation in Ethiopia. Source: https://core.ac.uk/download/pdf/234662401.pdf ISSN 2224-3208 (Paper) ISSN 2225-093X (Online) Vol.7

[67] Leah C., Eric Gilbertson, Anwar Sheikh, Steven D., and Steven Dubowsky (2010). On the feasibility of solar-powered irrigation. Source: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.207.7008&rep=rep1&type=pdf

[68] N. M. A. Huijts, E. J. E. Molina and L. Steg (2012). Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. Source: https://www.sciencedirect.com/science/article/abs/pii/S136403211100428X?via percent3Dihub

[69] Food and Agricultural Organization of the United Nations. Small Family Farms Country Factsheet. Source: http://www.fao.org/3/i9930en/I9930EN.pdf

developing countries such as India, Zimbabwe, South Africa, and Mali. Safety measures such as fencing, security fasteners, anti-theft bolts, alarms, and system monitoring tools can be adopted to secure solar panels against risks of theft, but further increase the capital costs.[70]

GENDER-RELATED CONSTRAINTS TO SPIS DEPLOYMENT

Over 80% of the farmers in Nigeria are smallholder farmers producing over 90% of the country's farm output.[71] According to the Federal Ministry of Agriculture & Rural Development (FMARD), women account for 75% of the farming population (i.e. smallholder farmers), primarily engaging in farming activities such as irrigation, weeding, harvesting, on-farm processing, and selling of farm produce.[72] However, women farmers are often disadvantaged and have fewer educational, advancement, and income-generating opportunities along with more limited access to credit and land than their male counterparts, despite producing over 80% of food consumed in the country.[73, 74]

Furthermore, in rural and semi-urban communities, women and children are burdened with the primary responsibility of fetching water for their households' domestic use as well as for other agricultural purposes. Access to water through installation of solar pumps for irrigation can also resolve this need. Challenges facing women in the agriculture sector are detailed below.

- **Traditional and customary laws:** In rural communities, particularly in the North, women are restricted from owning and in most cases cultivating farmlands. Under customary laws, women rarely inherit lands and primarily obtain use rights through their husbands.[75] The culture in certain communities in Northern states prevents women from directly engaging in farming activities, which means these women need to hire labor to irrigate their farmlands. This additional labor cost significantly increases the irrigation operating cost for women in these communities.
- **Access to finance**: Inadequate access to financing opportunities is a critical issue faced by women in agriculture. To finance existing operational costs and to expand, additional funding is required. However, in Nigeria, only 10% of the credit offered has been received by women smallholder farmers.[68] According to the National Bureau of Statistics (NBS), in 2018, a total of over 20,000 men accessed loans as opposed to about 8,500 women.[76] One reason for the low access of women to financing opportunities in the agriculture sector is limited knowledge about opportunities and an inability to offer land as collateral in cases where land ownership is in the name of men family members.
- **Access to Land**: In several rural communities, women are prohibited from owning land according to the community laws. This reduces women's access to land necessary for farming. According to a "Gender in Nigeria" report published by the British Council in 2012, women own

[70] Sun Culture. New solar-powered water pumps poised to transform agricultural output. Source: http://sunculture.com/press/new-solar-powered-water-pump-poised-to-transform-agricultural-output

[71] Taiwo Oyaniran (2020). "Current State of Nigeria Agriculture and Agribusiness Sector ". Source: https://www.pwc.com/ng/en/assets/pdf/afcfta-agribusiness-current-state-nigeria-agriculture-sector.pdf

[72] Sahel (2016). Sahel Newsletter Volume 7. Source: http://sahelcp.com/wp-content/uploads/2016/12/Sahel-Newsletter-Volume-7.pdf

[73] FAO (2003), Gender, Key to Sustainability and Food Security. Plan of Action. Gender and Development.

[74] Adenugba, A.O & Raji-Mustapha, N. O (2013). The Role of Women in Promoting Agricultural Productivity And Developing Skills For Improved Quality of Life In Rural Areas. http://www.iosrjen.org/Papers/vol3_issue8%20(part-5)/H03855158.pdf e-ISSN: 2250-3021, p-ISSN: 2278-8719 Vol. 3, Issue 8

[75] FAO AQUASTAT (2016). Country profile – Nigeria. Source: http://www.fao.org/3/i9807en/I9807EN.pdf

[76] National Bureau of Statistics (NBS). Source: https://www.nigerianstat.gov.ng/

only 4% of the land in the North-East and just over 10% in the South-East and South-South regions.[77] Despite women's key role in farming, only about 14% of them have holding rights to farmlands.[78] Women's limited access to land further limits their access to sufficient loans; loan usually requires collateral, most commonly, land.

ENVIRONMENTAL SUSTAINABILITY OF SPIS DEPLOYMENT

SPIS' environmental sustainability considers its influence on the surrounding environment by way of consumption of water resources and pollution load. Two key determinants of environmental sustainability are the system's end-of-life and water resource management.

Adequate maintenance measures for each component of SPIS at its end of useful life are essential to the environmental sustainability of SPIS deployment. For components such as solar panels, controllers, and inverters that are categorized as e-waste, end-of-life management is especially important since improper disposal could negatively affect the environment. As SPIS deployment increases, their proper disposal at the end of useful life will become more crucial.[63]

A key sustainability concern of SPIS is its impact on freshwater resources. It is critical to ensure that solar pumps are used for irrigation in an environmentally sustainable manner to prevent excessive water withdrawal and depletion, especially in dry land regions in the Northwestern states. Optimal sizing of solar pumps can ensure effective water use since they are only able to operate at optimal levels when the sun is shining.[79] Use of the appropriate size of solar pumps can be encouraged through policies. Additionally, adoption of SPIS under sharing- or as-a-service-based business models may promote more efficient water use, as compared to individually owned systems. However, these models require a higher financial, organizational, and training support from government or developmental agencies.

SPIS DEPLOYMENT OF SOLAR MINI-GRIDS AND STANDALONE SYSTEMS

Leveraging existing mini-grids to power irrigation pumps across Nigeria will require strategic location pairing to take into consideration the distance between the mini-grid site and the farmland to be irrigated.[80] No available literature exists documenting the approximate number of water pumps, powered by mini-grids or standalone solar systems in Nigeria.

A survey of 78 Nigerian farmers, conducted to determine the proximity of farmlands from community centers (where the mini-grids are located) revealed that about 90 percent of farms are roughly 1 mile away from the community center.[81] In cases where mini-grids pairing for irrigation purposes is not economically viable due to the additional cost of extending power distribution lines, standalone systems can be employed.

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[77] British Council (2012). British Council Gender Report - Nigeria. Source: https://www.britishcouncil.org/sites/default/files/british-council-gender-nigeria2012.pdf

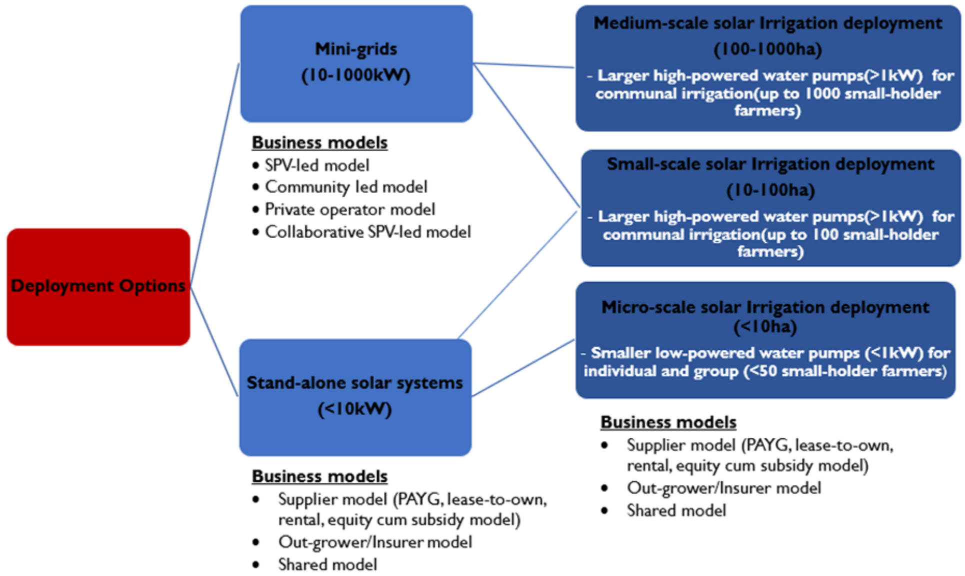
[78] CIRDDOC. Strengthening Existing and Emerging Women Mobilization Platforms and Smallholder Women Farmers' Association in Nigeria. Source: https://cirddoc.org/women-lead-agriculture-in-nigeria/

[79] Kishore, A., Shah, T., & Tewari, N. P. (2014). Solar irrigation pumps- Farmers' experience and state policy in Rajasthan. Economic & Political Weekly, XLIX(10), 55–62

[80] State of the Global Markets Report 2020, Trends of renewable energy hybrid mini grids in Sub Saharan African, Asian and Island nations. https://minigrids.org/wp-content/uploads/2020/06/Mini-grids_Market_Report-20.pdf

[81] Scarlett Santana, Andrew Allee, Zihe Meng, Wayne Omonuwa, James Sherwood, Balaji MK, Kira Rosi-Schumacher. Agricultural Productive Use Stimulation in Nigeria: Value Chain & Mini-Grid Feasibility Study. Rocky Mountain Institute, Deloitte Consulting LLP. 2020

Figure 4: SPIS Deployment Options for Mini-grid and Standalone Systems



BUSINESS MODELS FOR MINI-GRID POWERED IRRIGATION

Mini-grid powered irrigation deployment can be implemented using different business models, each with its respective strengths and weaknesses. The following sections include a brief description of each model. The best suited SPIS for each model below is the "best practice" configuration presented in Figure 2.

Interconnected Mini-grid Model. For this model, the regional distribution company (DISCO) partners with a mini-grid developer through the interconnected mini-grid acceleration scheme (IMAS) to develop and deliver solar mini-grid powered irrigation. This model could be used for under-grid communities where there are existing distribution lines but little or no power supply from the grid. This model allows the distribution company to leverage existing distribution infrastructure available in the community.

Table 5: Advantages and Disadvantages of the Interconnected Mini-grid Model

Advantages	Disadvantages
• It can increase the capital available for investment by attracting new investors, which may support quick scaling to additional communities.[82] • In the under-grid community, there is an existing relationship with the community members and DISCOs which breeds trust thereby leading to better cooperation.	• Opportunities are limited to where the DISCO is willing and able to collaborate with mini-grid developers.

Community-based Model. Under this model, community members (farmers) organize as a cooperative governed by government regulations and are the primary owners and managers of the mini-grid generation and distribution of electricity for the solar irrigation system. Due to the high upfront cost and technicality of the mini-grid set-up and management, community members require financial and technical support from a non-governmental organization (NGO) or a company.[83] In most cases, the revenue generated helps to cover the cost of operations and future reinvestment needs, with any excess returned to members.[80]

Table 6: Advantages and Disadvantages of Community-based Model

Advantages	Disadvantages
• Consumer tariffs are more affordable because lower returns are required due to community-based financial support for project deployment. • Increases revenue generated by/for the community. • Collective investment and ownership of the system motivate the community to work together in a cognizant manner. • Community ownership and buy-in, strong incentive structure for sustainability	• Intensive involvement and interaction of a technical third party partner with the community. • Risk associated with a lack of technical expertise required to operate and maintain the mini-grid by community members. • Difficulty in sourcing for alternate funding opportunities.

[82] Sachiko Graber, Oladiran Adesua, Chibuikem Agbaegbu, Ifeoma Malo, and James Sherwood. Electrifying the Underserved: Collaborative Business Models for Developing Mini-grids Under the Grid. Rocky Mountain Institute, October 2019. http://www.rmi.org/insight/undergrid-business-models/

[83] Tayyab Safdar (2017). Business models for mini-grids. Source: https://e4sv.org/wp-content/uploads/2017/05/TR9.pdf

Private Operator Model. In this model, a private operator plans, builds, manages, and operates the mini-grid to increase agricultural productivity including irrigation. The private operator can carry out these functions with the financial support of commercial loans or private equity as well as government and donor support through grants, subsidies, or loan guarantees, as well as the tariffs from the smallholder farmers based on electricity consumption.

Table 7: Advantages and Disadvantages of Private Operator Model

Advantages	Disadvantages
• Faster to implement. • Mini-grid developers have necessary expertise in deploying mini-grids, which increases the chances of success. • Improves a mini-grid developer's relationship with the community.	• Mini-grid developers bear the brunt of the deployment risks (financially and operationally). • Community has limited ownership of the mini-grid; as such, they have limited input to the project. • Mini-grid developers are solely responsible for raising the capital required for the project. • Mini-grid developers require financial case and economic returns to pursue projects.

Collaborative SPV-led Model. Under this model, different entities own, install, manage, and operate the mini-grid. For example, one entity (e.g., the government) owns the system, while the other entity (private developer) installs, operates, and manages the system. These parties typically enter into a contractual agreement or joint venture that defines the terms of their collaboration. Some contractual arrangements include public-private partnerships (PPP), concession agreements, and power purchase agreements (PPA). The PPP is a long-term agreement between the government and private entities whereby the government leverages private resources (financial and technical expertise) to carry out projects. This sort of relationship can be developed in the deployment of mini-grids to foster irrigation in communities.

Table 8: Advantages and Disadvantages of Collaborative-SPV Model

Advantages	Disadvantages
• The risk is shared among the project stakeholders.[78] • The strength of each stakeholder is harnessed leading to reduced risk e.g. mini-grid developers, DISCOs, government.	• A complicated ownership structure may slow down the decision-making process. [78] • Burdened by government bureaucracy and timelines, and beholden to political priorities (geographies, etc.). • Limited community buy-in.

Business Models for Standalone System Powered Irrigation. There is also an array of business models for deploying SPIS through standalone solar system providers. Through stakeholder consultation and a literature review, the shared model with water-as-a-service appears to be the most common business model for standalone system powered irrigation in Nigeria. The three types of standalone solar system business models are supplier model, out-grower model, and shared model.

Supplier Model. Under this model, the solar irrigation equipment provider (also a service provider) supplies irrigation equipment to farmers in exchange for payment. The supplier model requires a facilitator to go into the rural off-grid communities to build awareness among farmers on the benefits of SPIS. Lease-to-own, equity cum subsidy, PAYG, and rental, are all examples of the repayment model of the supplier model.

Table 9: Advantages and Disadvantages of Supplier Model

Advantages	Disadvantages
• It is easier for smallholder farmers to pay because the payments are broken into installments.	• Smallholder farmers need to develop technical expertise to utilize the system. • The risk of default in payments exists if the farmers face challenges in operations.

Lease-to-own. This type of repayment approach helps mitigate the restrictive upfront costs that farmers face in purchasing a SPIS. By initially leasing, this model allows farmers to acquire and repay the asset through payment schedules suited to their income capabilities. It also permits the farmer to renew the lease on a periodic (e.g., weekly, or monthly) basis by making renewal payments, or to terminate the agreement with no further obligation by returning the SPIS. Although not necessary, the farmer can also choose to continue making interval payments on the SPIS for a pre-specified period, after which they would own the equipment.[84] Farmer cooperatives can also collaborate by identifying the interested farmers and collecting periodic payments on behalf of the supplier.

Table 10: Advantages and Disadvantages of the Lease-to-own Model

Advantages	Disadvantages
• Since it does not require collateral, unlike commercial banks and microfinance institutions (MFI), farmers do not face capital investment risk (loss of collateral with delayed payment) and it minimizes their upfront payment requirements. • Provides an easier payment structure that considers the farmers' income thereby easing the financial burden on the farmers.	• Farmers can potentially face paying more in the long run with lease-to-own contracts in comparison to traditional loans.[80] • There exists the risk of destruction of the SPIS by the farmers before the payment is complete and potentially stopping the payment for the system.

[84] Otoo, M.; Lefore, N.; Schmitter, P.; Barron, J.; Gebregziabher, G. 2018. Business model scenarios and suitability: smallholder solar pump-based irrigation in Ethiopia. Agricultural Water Management – Making a Business Case for Smallholders. Colombo, Sri Lanka: International Water Management Institute (IWMI). 67p. (IWMI Research Report 172). doi: 10.5337/2018.207

Equity-cum-subsidy Model. Under the equity cum subsidy model, suppliers provide SPIS at discounted rates to farmers and a portion of the cost is borne by the government or donors as a capital subsidy. Suppliers are required to meet prescribed technical standards and provide a multi-year service warranty. Many of the projects reported in Appendix A: Summary of Solar Irrigation Projects, by Country, benefitted from a capital subsidy from donors or the government.

Table 11: Advantages and Disadvantages of Equity-cum-subsidy Model

Advantages	Disadvantages
• Subsidized capital cost encourages smallholder farmers' patronage of SPIS.	• Subsidized capital period is temporary (usually 1 to 3 years) hence farmers may not be able to afford the unsubsidized rate after this period is over.

Pay-as-you-go (PAYG) Model. PAYG is a financing approach that allows farmers to pay for SPIS in weekly instalments or whenever they are financially liquid. Under the PAYG model, the supplier retains ownership of the SPIS in perpetuity. This credit system removes the initial financial barrier to solar energy access by allowing consumers to make a series of modest payments to purchase units of time using the SPIS instead of paying upfront for the entire system.[85] Suppliers provide individual SPIS to farmers, along with provisions of service warranty for 2 to 5 years.[82] In Nigeria, the majority of small-scale solar system suppliers (<10 kW) operate using a PAYG business model.[86] In addition, the majority of the solar irrigation projects reported in Appendix A, adopted a PAYG business model.

Table 12: Advantages and Disadvantages of PAYG Model

Advantages	Disadvantages
• Spreads the cost of purchasing the SPIS across a couple of months which aligns with the financial capabilities of the farmers thereby, allaying the financial strain on farmers.	• Inflation and currency devaluation can lead to a reduction in the potential profit or losses for the irrigation equipment contractor despite the interest incorporated in the cost. • Poses a financial risk to the supplier who bears the cost of maintenance and repairs even in cases of equipment misuse.

[85] Paul Winkel (2016). 'Startup Peru Winner | Powermundo. Source: http://www.powermundo.com/media-resources/news-events/startup-peru-winner/

[86] Africa Clean Energy Technical Assistance Facility (ACE TAF) Ifeoma Malo, Daramfon Bassey, Talatu Tarfa, John Atseye, Chibuikem Agbaegbu, Karin Sosis and Esther Kahinga, Stand Alone Solar (SAS) Market Update Nigeria (January 2021)

Out-grower Model. In this model, an out-grower (also known as an off-taker) enters binding arrangements with individuals or groups of farmers for the production and supply of agricultural products at some future time and meeting certain requirements. This model is largely dependent on the availability of a major off-taker requiring a constant supply of farm produce and is able to invest in SPIS on behalf of a group of farmers. However, this model is only commercially viable if the following criteria is met:

1. The price of the irrigation system must be low for the off-taking party to be willing to invest.
2. The deployment of the SPIS must meet the business needs of the off-taking company.
3. The price of the SPIS must be sufficiently high that the farmers cannot afford to pay for it at once.[80]
4. The farmer must be willing to own or operate the SPIS

The off-taking party can either choose to give the irrigation system to the farmers for free or develop a repayment structure that requires the farmers to pay back through a portion of their crops annually or in cash over a period of time. For this model there must be a facilitator to educate both the farmers and the out-grower on the benefits of investing in SPIS. The facilitator can be an SPIS supplier who ascertains the energy requirements of each farmer and recommends an appropriate SPIS based on their energy needs.

Table 13: Advantages and Disadvantages of Out-grower Model

Advantages	**Disadvantages**
• Provides an SPIS at no cost to the farmer or through a payment structure suitable for the farmers. • Reduces the risk of crop failure and enables a steadier supply of agricultural products for the off-taker.[80]	• The farmers may not value the SPIS, especially if acquired for free; this could lead to equipment neglect and inadequate maintenance. • Multiple individual contractual agreements associated with this model will mean transaction costs are higher, which can be a deterrent to the off-takers.

Shared Model. Under the shared model, the solar irrigation equipment provider (also a service provider) offers either irrigation equipment or service to a community of farmers in exchange for payment. Group sharing, water-as-a-service and renting are examples of a shared model. This type of model's design caters to the needs of a community of farmers, usually farmer cooperatives.

Table 14: Advantages and Disadvantages of Shared Model

Advantages	**Disadvantages**
• Reduced financial burden on each farmer. • Shared risk among the farmers. • Higher asset utilization of the SPIS	• Conflict can affect the relationship between farmers and the dynamics of tool sharing. • Potentially higher maintenance required for the SPIS

Group Sharing Model. Under the group sharing approach, farmers can form joint liability groups (JLGs) and secure collateral-free bank loans, to purchase SPIS for their irrigation needs.

Table 15: Advantages and Disadvantages of Group Sharing Model

Advantages	Disadvantages
• Farmers can secure low risk, collateral-free investments. • The cost is reduced since it is shared between the farmers in the JLG. • Higher asset utilization of the SPIS	• Disagreements within the group can affect the efficient repayment of loans. • A great deal of trust is required amongst farmers especially when loans are collateral-free. • Potentially higher maintenance required for the SPIS

Renting. Through renting, the supplier owns, maintains, and rents the SPIS to interested groups of farmers. The supplier could be an SPIS supplier, any private entity or a farmers' association. For example, Claro energy in Bihar (India) has the rental model at several locations. Portable trolley-mounted SPIS are offered on a fixed hourly rental to small farmers within a local area (see Appendix A).

Table 16: Advantages and Disadvantages of Renting Model

Advantages	Disadvantages
• Eliminates the burden associated with purchasing an SPIS. This way, the farmers make use of the system based on their income or needs (which determines their ability to rent). • When the irrigation system is not required and idle for extended periods of the year, the business case for purchasing the system for farmers is more tenuous. Therefore, renting the system allows the farmers to pay for the system only when required.	• The supplier could unexpectedly increase the rent, especially when demand is high. The most vulnerable farmers may not be able to pay the increased rental fee.

Water-as-a-service. Under this service, an SPIS is used to pump and sell water for a fee to a group of farmers. The system can be owned, operated, and maintained by a supplier, farmers association or any other third party. In Bangladesh, the water-as-a-service model has been used to deploy more than 600 SPIS. With the help of low-cost finance and partial grants, NGOs and MFIs own and operate SPISs to sell water for irrigation to farmers.[87] Similarly, in India, farmers' associations, such as Vaishali Area Small Farmers Association in Bihar, own and operate multiple SPISs providing irrigation water for a fixed fee to their members.[88]

Table 17: Advantages and Disadvantages of Water-as-a-service Model

Advantages	Disadvantages
• Faster to implement. • Water wastage is reduced because the farmers are motivated to efficiently utilize the water purchased. • Cost is saved because one irrigation system will be used to serve multiple farmers.	• Limited to a manual method of irrigation.

[87] Sarkar, M. N. I., & Ghosh, H. R. (2017). Techno-economic analysis and challenges of solar powered pumps dissemination in Bangladesh. Sustainable Energy Technologies and Assessments, 20, 33–46.

[88] Kohler, F. (2014). Spread the word on solar pumping! Supporting farmers in Bihar to adopt clean technologies to improve agricultural outputs. Retrieved from http://igen-re-giz.blogspot.co.uk/2014/05/spread-word-on-solar-pumping-supporting.html

FINANCING OPTIONS AND PARTNERSHIPS FOR SOLAR IRRIGATION DEPLOYMENT

Business models that incorporate adequate financing, appropriate training on use and maintenance, and affordable payment options are most likely to succeed in the Nigerian market. This section summarizes possible financing structures and partnerships necessary for funding solar irrigation initiatives. Two or more of the financing structures identified in this section can be adopted together to enable successful deployment. Key actors (i.e. institutions, cooperatives, communities, developers, and suppliers) need to work together and where possible form partnerships or wear multiple figurative hats.

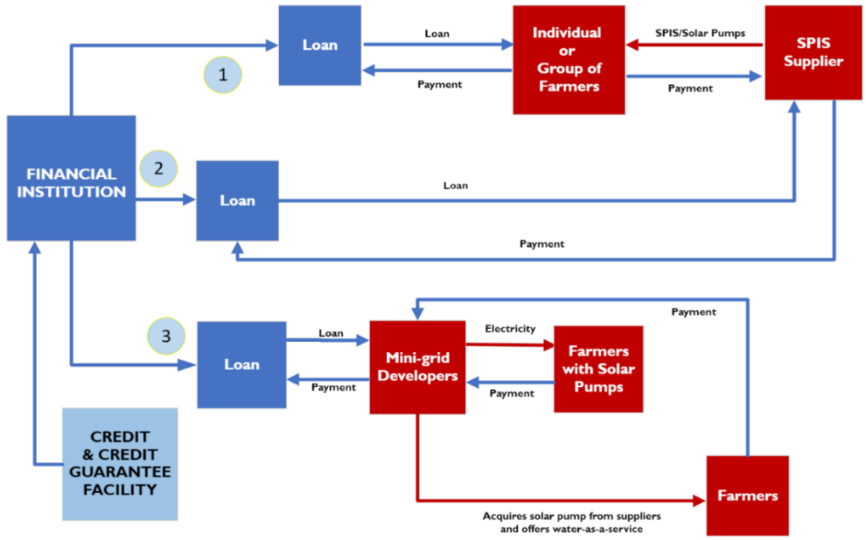
The following are examples of key actors necessary for each of the financing structures discussed:

- **Mini-grid Developer:** The mini-grid developer constructs and deploys the mini-grid that provides the electricity necessary for the SPIS. In the private-operator model, the mini-grid developer not only builds the mini-grid but also owns and maintains it. Therefore, the developer is responsible for collecting electricity tariffs from the smallholder farmers. Typically, mini-grid developers acquire grants from government and donor agencies, as well as debt financing from Private Financial Institutions (PFI). The electricity providers can offer a combined service (irrigation equipment rental and electricity) to the smallholder farmers. This is ideal for electricity providers operating a PAYG model.
- **Crop Off-takers**: The crop off-taker is an entity that requires a constant supply of one or multiple crops. As a result, the off-taker invests in a SPIS to increase the farmers' yield. In exchange, the farmers provide part of their harvest to the off-taker or make periodic payments to the off-taker.
- **Farmer Cooperatives**: Farmer cooperatives usually consist of a group of farmers who pool their resources together to provide services for the group which will, in turn, benefit the members. The farmer cooperatives can apply for loans from financial institutions to fund the purchase of a SPIS from an irrigation equipment provider or the development of a mini-grid to power an irrigation system.
- **SPIS Supplier:** The irrigation equipment provider supplies irrigation equipment to smallholder farmers or farmer cooperatives who are connected to the mini-grid, a standalone solar system provider, or an independent contractor. Alternatively, they collaborate with mini-grid developers/standalone system providers by supplying irrigation equipment directly to them. The standalone solar system provider can be the irrigation system provider, offering both the solar system (panel, inverter, battery) and the irrigation pumps as a complete package to potential customers.
- **Facilitator:** A facilitator is necessary to provide the required technical knowledge to farmers and could be a mini-grid developer, SPIS supplier, or an independent entity.

DEBT FINANCING

Debt financing for SPIS involves financial institutes such as MFIs, banks, and cooperatives providing direct loans to key actors (smallholder farmers and mini-grid developers) across the solar irrigation value chain. In debt financing, lenders look for returns on money lent in the form of interest payments and seek to minimize risks, while developers aim for profits to maintain their sustainable business operations . There are several potential agricultural sector loans that can be accessed by farmers, off-takers, and mini-grid developers for the productive use of electricity for agricultural productivity.

Figure 5: SPIS Debt Financing



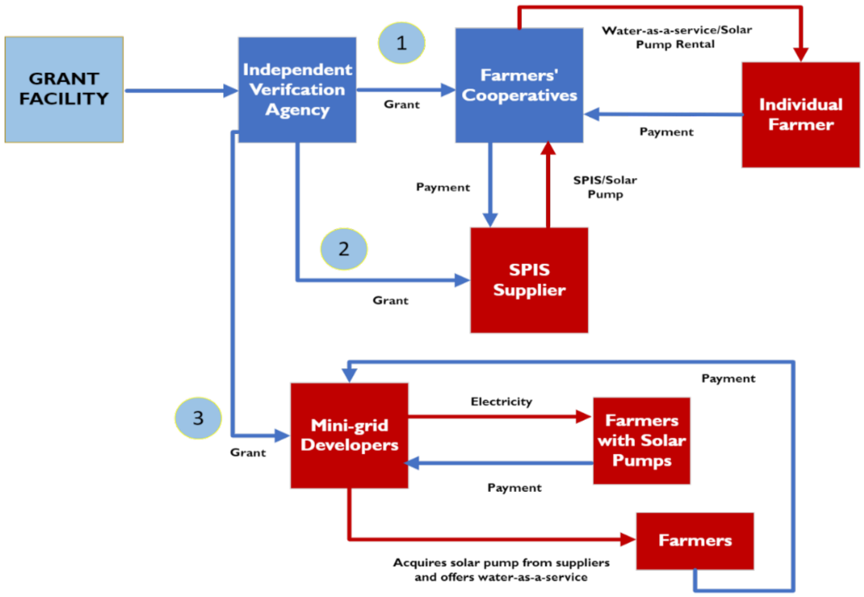
Actors well-suited to fulfill key roles in this financing structure include:

- **Credit and Credit Guarantee Facility:** The credit facility provides debt financing to Private Finance Institutions (PFIs) and is disbursed to mini-grid developers, standalone system providers, irrigation equipment suppliers or directly to smallholder farmers. The aim is to provide support while reducing risk because PFIs have adequate structures to reclaim the loan when due.[78] A credit guarantee facility, on the other hand, allows the government (potentially through donor agencies and international funding organizations) to provide guarantees to PFIs on loans, to reduce credit risk, thus enabling PFIs to offer loans.[80] Examples of credit and credit guarantee facilities are Agricultural Credit Support Scheme (ACSS, Solar Connection Facility, and Nigerian Infrastructure Credit Enhancement Facility (InfraCredit).
- **Private Financial Institutions (PFIs):** The PFIs typically receive funding from the credit facility to fund mini-grid developers, standalone system providers, irrigation equipment suppliers or smallholder farmers. They usually have adequate channels in place to provide funds to smallholder farmers and to make sure that it is used for the purpose for which it is sought. Furthermore, the credit facility can specify criteria that help tailor the direction to which the funds are disbursed to ensure it reaches the smallholder farmers. Examples of PFIs are LAPO MfB, Grooming Center and Sahel Capital.

GRANT FINANCING

Grants are free funds, typically provided by donor organizations such as USAID, UKAid as well as development finance institutions (DFIs) including the United States International Development Finance Corporation (US DFC), REPP, EnDev, AFD, and AfDB, through the country's government, that do not require payback. Grants reduce the capital costs associated with purchasing SPIS and usually include funds for technical support.[77] They are usually very competitive and limited in amounts, which is why other financing structures (debt financing and equity financing) are important. Furthermore, to monitor and ensure adequate utilization of the grant for its intended purpose, additional costs might be incurred through necessary involvement of an independent verification agency. Under this financing structure, the cooperative as a group can apply for grants which will enable the purchase of SPIS required by the members of the cooperative.

Figure 6: SPIS Grant Financing Structure



Actors well-suited to fulfill key roles in this financing structure include:

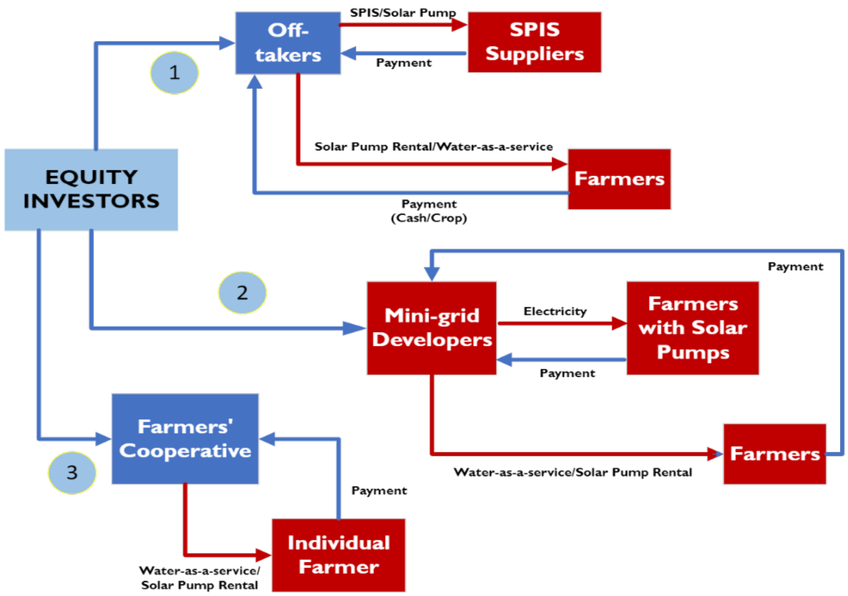
Independent Verification Agency: An independent grant verification agency is funded by a grant facility to verify grants are used for facilitating solar irrigation, directly or indirectly.

Grant Facility: The grant facility provides matching grants to selected beneficiaries, through an independent verification agency, to reduce the capital cost associated with solar irrigation equipment purchase especially when projected cash flows indicate grant can improve business economic viability (discussed in further sections of the report). In addition to capital cost reduction, some grants are used to provide technical assistance through feasibility studies and capacity building programs. Grants can be administered in the form of result-based financing (RBF) or upfront payments. Examples of grants that can be leveraged for solar irrigation projects are the Nigeria Electrification Project (NEP), Rural Electrification Fund (REF) and Results Based Financing for Productive Appliances and Equipment.

EQUITY FINANCING

Under this financing structure, mini-grid developers, crop off-takers, or standalone solar irrigation equipment providers can raise capital from their balance sheet to finance solar irrigation projects. It is simpler to raise equity financing than to acquire grant or debt financing primarily because it is raised from internal funds (i.e., balance sheet).

Figure 7: Private Equity Financing Structure for SPIS Deployment



Equity Investors: Equity investors are individuals or organizations with keen interest in investing in a company or project. Mini-grid developers, crop off-takers, or standalone solar irrigation equipment providers can raise capital from their balance sheet to finance solar irrigation projects.[37] Furthermore, the members of farmer cooperatives can also provide equity financing for the provision of SPIS by pooling together their financial resources and owning percentages of the irrigation system. The main types are highlighted below[37]:

- Development Finance Institution (DFI): DFIs are quasi-governmental banks that deploy equity, debt, or other financial instruments, often at concessional rates, to achieve both development objectives and financial returns. Examples of DFIs in Nigeria are BOA, BOI, DBN, Nigerian Export-Import Bank (NEXIM), and the Infrastructure Bank.[89]
- Impact Investor: Impact investors are financiers who invest in projects or businesses that have the potential to provide financial and impact returns. Examples include Factor[e] Ventures, Acumen and All On Energy.
- Venture Capital: Venture capital is private equity which funds early-stage companies with significant growth potential in return for ownership in the business. Venture capitalists may invest in solar irrigation projects provided the return on investment (ROI) is significant and the project demonstrates potential for sustainability.
- Private Equity: Private equity investors, similar to venture capitalists, seek to purchase equity stakes in businesses or projects. Their main difference is that they target already established businesses who are seeking funds (whereas venture capitalists target startups). Private equity investors can invest in the business of mini-grid developers or stand-alone solar irrigation equipment providers to offer irrigation services (i.e. water-as-a-service, PAYG) to smallholder farmers.

[89] Central Bank of Nigeria. List of Development Finance Institutions. Source: Ref https://www.cbn.gov.ng/Supervision/Inst-DFI.asp

BUSINESS CASE SCENARIO ANALYSIS

In order to clearly delineate the economic viability of standalone solar and solar mini-grid powered irrigation projects across various business models, PA-NPSP conducted a scenario analysis examining and evaluating hypothetical applications of solar powered irrigation systems. These scenario models generate expected yield, profitability, and repayment outcomes and offer insight into potential business models for deployment. In order to identify the best solution for SPIS projects in Nigeria, PA-NPSP modeled financial outputs for various scenarios (Table 18) using different business model types—shared, PAYG, lease-to-own or equity cum subsidy— and financing structures.

VARIABLES

PA-NPSP used the following variables to develop scenarios for modeling solar irrigation systems and financing structures.

- **Crops.** Tomato and rice are used as test crops in Benue and Niger state respectively. In 2018, the annual rainfall in Niger and Benue state was 1,210mm and 1,196mm respectively. Niger, Benue, Nasarawa and Bauchi are states with similar rainfall patterns while states like Bayelsa, Cross river and Akwa Ibom had the heaviest rainfall[90]. Tomato and rice are used because they have the highest total addressable market among the six crops identified with high potential for improved yield by irrigation.[91] The average water requirements for tomato and rice are estimated and documented in Appendix A.
- **Irrigation Systems.** PA-NPSP modeled costs for drip and flood irrigation systems. Drip irrigation is used to irrigate tomatoes and flood irrigation is used to irrigate rice (e.g., paddies).
- **Size of system.** 0.4 kW, 4 kW, and 45 kW irrigation pump systems are tested in the scenarios. There is no difference in the pump capacity for drip or flood irrigation systems (i.e., both drip and flood in the base cases are the same system size).
- **Ownership Models.** Single farmer ownership, shared ownership (2 or more farmers), cooperative ownership (20 farmers), and mini-grid models are tested in the scenarios. In the mini-grid models, the farmers purchase the irrigation systems independently and these costs are not incorporated. Single, shared, and cooperative ownership models test the viability of standalone systems. The mini-grid models test the impact of solar irrigation demand on mini-grid viability.
- **Base Financing Structure.** Financing assumes a 22% interest rate for a local loan which covers 75% of the upfront cost of the irrigation system. The scenarios assume farmers or third parties such as donor organizations are able to fund the remaining 25% of the upfront cost of the system. Based on these assumptions the payback period is calculated using either 50% or 100% additional revenues earned by increased yield resulting from the application of the SPIS.

OUTPUTS

The outputs generated from the scenario analysis is as follows:

- **Profit increase from additional yield.** This is the annual increase in profit following the application of the solar powered irrigation system before operating costs from the system. Increased profit estimates are shown in Table 28.

[90] Statista (2019) Annual Rainfall in Nigeria in 2018 by State. Source: https://www.statista.com/statistics/1264326/annual-rainfall-in-nigeria-by-state/

[91] PA-NPSP used the FAO-GIZ Toolbox temperature and rainfall data for Benue and Niger state, where tomatoes and rice are grown, respectively, to estimate the amount of water necessary to irrigate a 0.5 ha of farmland in these geographies. A farmland size of 0.5 ha is used based on the assumption that the average smallholder farmer in Nigeria occupies 0.5 ha of land. Appendix B outlines further scenario assumptions and the methodology.

- **Payback of capital cost.** This output is the number of years of profit from increased yield that are required to pay back the upfront capital cost, before taking financing or debt into consideration. This output indicates the time required to recover the upfront cost if the farmer or another party were to fully fund the equipment investment up front.
- **Average debt service coverage ratio (DSCR).** DSCR is the ratio of cashflows available for debt service (increased yield profit minus capital and operating costs) to debt service. It indicates the coverage the cashflows provide against annual debt. The output calculated is the average DSCR for all financing years.
- **Net present value (NPV).** This is the present value of future cashflows from increased profit from additional yield over a 25-year project life, after the operating costs of the system and any debt service payments from financing (a NPV above zero is profitable).
- **Internal rate of return (IRR).** The IRR is the percent return on the upfront investment (capital cost) based on all future cashflows from increased profit from additional yield over a 25-year project life, after the operating costs of the system and any debt service payments from financing (an IRR below zero is not financially viable).

A detailed list of all assumptions is included in Appendix B.

SOLAR IRRIGATION SCENARIOS

PA-NPSP developed nine scenarios for testing the economic viability of different irrigation systems, ownership models, and financing structures.

- **Scenario 1. Tomato Scenario – Single Owner:** In Scenario 1, PA-NPSP modeled a single farmer's small-scale acquisition of a drip irrigation system (0.4 kW) for irrigating a tomato crop of 0.5 ha in Benue state. The farmer is able to use 100% of revenues earned from increased crop yields to pay back the loan required for system acquisition.
- **Scenario 2. Tomato Scenario – Shared Ownership:** In Scenario 2, PA-NPSP modeled two farmers' small-scale acquisition of a drip irrigation system (0.4 kW) for irrigating a tomato crop of 1 ha in Benue state. The farmers are then able to use 100% of revenues earned from increased crop yields to pay back the loan required for system acquisition.
- **Scenario 3. Rice Scenario – Single Owner:** In Scenario 3, PA-NPSP modeled a single farmer's small-scale acquisition of a flood irrigation system (0.4 kW) for irrigating a rice crop of 0.5 ha in Niger state. The farmer is then able to use 100% of revenues earned from increased crop yields to pay back the loan required for system acquisition.
- **Scenario 4. Rice Scenario – Shared Ownership:** In Scenario 4, PA-NPSP modeled three farmers' small-scale acquisition of a flood irrigation system (0.4 kW, See Appendix B) for irrigating a rice crop of 1.5 ha in Niger state. The farmers are then able to use 100% of revenues earned from increased crop yields to pay back the loan required for system acquisition.
- **Scenario 5. Tomato Scenario – Cooperative Ownership:** In Scenario 5, PA-NPSP modeled a cooperative of 20 farmers' acquisition of a 4kW drip irrigation system for irrigating a tomato crop of 10 ha in Benue state. Under this scenario PA-NPSP assumes that farmers are willing to pay 50% of the annual revenue realized from increased yield, on a lease-to-own basis, for joint ownership of the SPIS. This is an example of the community-based model described above.
- **Scenario 6. Mini-grid Scenario – Base:** In Scenario 6, PA-NPSP modeled a base case for mini-grid revenues at an initial tariff of US$0.49/kWh without any irrigation activities. Under this scenario, the mini-grid developer uses a 25% grant and a 75% loan, at 22% annual interest rate, to

fund the development of a 45kW mini-grid at a capital cost of US$140,000. Revenues from the sale of all electricity (minus operating costs) are used to pay back the loan.

- **Scenario 7. Mini-grid Scenario – Base + Drip Irrigation:** In Scenario 7, PA-NPSP builds upon the 45kW mini-grid base case (Scenario 6) and adds additional revenue from electricity required to power a 16kW drip irrigation pump employed by a community of tomato farmers (i.e., the productive or anchor load from irrigation activities). The scenario assumes the cost of the irrigation system is borne by the end users or a third party (i.e. by the mini-grid developer). Electricity is assumed to be sold at a tariff of US$0.49/kWh and revenues from the sale of electricity (base + irrigation activities, minus operating costs) are used to pay back the loan.
- **Scenario 8. Mini-grid Scenario – Base + Drip Irrigation, Target IRR:** Scenario 8 is identical to Scenario 7 except rather than determining the IRR based on a fixed tariff, the IRR is fixed at 20% to determine the corresponding electricity tariff which achieves that rate of return.
- **Scenario 9. Mini-grid Scenario – Base + Flood Irrigation, Target IRR:** In Scenario 9, PA-NPSP modeled the 45kW mini-grid base case (Scenario 6) and adds additional revenue from electricity required to power a 16kW flood irrigation pump employed by a community of rice farmers. Similar to Scenario 8, rather than determining the IRR based on a fixed tariff, the IRR is fixed at 20% to determine the corresponding electricity tariff.

Scenarios 6-9 assumes the 45kW mini-grid is 50% underutilized with a daily load of 224 kWh and thus capable of powering a 16kW irrigation pump (up to 112 kWh/day for drip irrigation and flood irrigation, see Table 29). These scenarios also assume farmers are willing to pay between US$0.34–0.86/kWh for electricity to power their water pumps from the mini-grids and uses a baseline tariff of US$0.49/kWh.

Table 18: Financing Structure and Repayment Plan Scenarios

No.	System Size	Land Size (Ha)	Ownership	Irrigation Method	Crop
1	0.4 kW	0.5	Single	Drip Irrigation	Tomato
2	0.4 kW	1	Multiple (Two Farmers)	Drip Irrigation	Tomato
3	0.4 kW	0.5	Single	Flood Irrigation	Rice
4	0.4 kW	1.5	Multiple (Three Farmers)	Flood Irrigation	Rice
5	4 kW	10	Cooperative	Drip Irrigation	Tomato
6	45 kW	N/A	Mini-grid (Base)	None	N/A
7	45 kW	N/A	Mini-grid (Base + Drip Irrigation)	16 kW Drip Irrigation Load	Tomato
8	45 kW	N/A	Mini-grid (Base + Drip Irrigation)	16 kW Drip Irrigation Load	Tomato
9	45 kW	N/A	Mini-grid (Base + Flood Irrigation)	16 kW Flood Irrigation Load	Rice

The findings from this analysis reveal the economic viability of solar irrigation of crops using standalone solar systems and solar powered mini-grids. More specifically, it sheds light on the thresholds of underlying assumptions and suitability of different types of SPIS business models for key stakeholders in the solar irrigation value chain such as farmers, solar mini-grid developers, and entrepreneurs seeking to enter the market.

It is critically important to note that these scenarios simplify many elements of farming, irrigation, and mini-grid operations including farming and mini-grid operational costs, mini-grid capital cost components, mini-grid component replacement costs (not included), and costs associated with back-up power systems (e.g., battery or diesel powered back-up generation systems). These models are meant to be high level and illustrative to demonstrate and compare cashflows benefits from irrigation activities to the upfront capital cost of systems. Scenarios 1-5 results and feasibility are further constrained by the high capital costs in later schedule years required to cover replacement costs of irrigation systems. Additionally, scenarios assume a constant figure for increased yield from irrigation activities, with a profit escalator to account for increased prices and efficiencies.

SCENARIO ANALYSIS RESULTS

As evidenced below, the economic viability of solar irrigation investment by farmers varies by ownership model and financing structure. Solar irrigation investment is more attractive when using shared and lease-to-own models (Scenario 2, 4, 5) than under single-owner models given the additional revenues from multiple farmers.

Table 19: Summary of Scenario Cash Flow Results (NPV, IRR and Payback)

No.	CAPEX (USD)	Annual Revenue from Irrigation Activities (USD)	IRR (%)	Payback of Capital cost (Years)	DSCR	NPV (USD)
1	2,390	909	19.1%	3	1.40	5,830
2	2,390	1,817	53.2%	2	2.94	25,326
3	1,840	567	9.2%	4	1.10	806
4	1,840	1,700	68.5%	2	3.60	25,121
5	13,477	18,170	21.2%	3	1.49	36,540
6	140,000	0	20.2%	4	1.16	784,150
7	140,000	8,232	24.7%	3	1.42	1,035,207
8	140,000	6,905	20.0%*	4	1.15	770,346
9	140,000	3,084	20.0%*	4	1.15	770,342

**Fixed IRR*

Results from Scenarios 1 through 5 (Table 19) show positive NPVs for all scenarios, demonstrating a strong case for potential investment. Scenarios 1, 3, and 5 have average DSCRs below 1.5 which presents a risk to the farmer's ability to repay the loan in financing years (e.g., if there is any significant variation in the forecasted yield increase resulting from irrigation activities). Farmers may be unable to obtain local bank loans with forecasted DSCRs below 1.5. This demonstrates the need for grant funding not only for the 25% grant modeled in the scenarios but perhaps even greater amounts in Scenarios 1, 3, and 5 (see Table 20 for sensitivity analysis).

Under Scenarios 2 and 4 farmers jointly invest in solar irrigation systems with positive returns and recover the full capital cost investment within two years. These scenarios assume the capital cost is the same for one farmer to acquire as for two or three farmers and use and yield outcomes are the same if a farmer is the only user of the system or if the system is being shared. A critical assumption here is that farmers need to be located in close proximity to one another to maintain yield outcomes with the same investment cost as in the single farmer scenario. In these scenarios, PA-NPSP assumed farmers are willing to contribute up to 100% of profits from increased yield for financing repayment and validation of these outcomes necessitates obtaining a deeper understanding of farmers' ability to contribute yield revenues to loan repayment, share equipment with other farmers in close proximity, and obtain grant funding for or self-fund the portion the capital cost not covered by the loan. That said, the high rates of return under these scenarios presents a business opportunity for enterprising farmers to acquire SPIS and provide water-as-as service to other farmers.

Table 20: Impact of Variation in Yield on IRR (Scenarios 1-5)

Yield Variation	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
-70%	<0%	<0%	<0%	<0%	<0%
-60%	<0%	10.8%	<0%	17.1%	<0%
-50%	<0%	19.1%	<0%	26.0%	<0%
-40%	<0%	26.0%	<0%	34.4%	<0%
-30%	3.9%	32.7%	<0%	42.7%	5.7%
-20%	10.8%	39.4%	<0%	51.1%	12.7%
-10%	15.3%	46.2%	<0%	59.7%	17.3%
Baseline	19.1%	53.2%	9.2%	68.5%	21.2%
10%	22.6%	60.2%	13.6%	77.3%	25.0%
20%	26.0%	67.4%	17.1%	86.2%	28.6%

Table 21: Impact of Increased Grant on Average DSCR, Sensitivity Analysis

Grant Size	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
20%	1.308	2.753	1.034	3.375	1.401
25%	1.395	2.936	1.103	3.600	1.494
30%	1.495	3.146	1.182	3.857	1.601
35%	1.610	3.388	1.272	4.153	1.724

40%	1.744	3.670	1.379	4.499	1.868
45%	1.903	4.004	1.504	4.909	2.038
50%	2.093	4.405	1.654	5.399	2.241

The crop water requirement analysis documented in Appendix B illustrates the dependency of the shared ownership model on the type of crop being irrigated, seasonal conditions at the irrigation location, and farm size. As shown in Table 18, it is possible for two farmers to share a 0.4 kW SPIS for drip irrigation whereas three farmers are necessary to share an SPIS of the same capacity for flood irrigation.

Scenario 5 demonstrates that it is profitable for cooperatives in farming communities, where tomatoes are predominantly grown, to invest in SPIS for their members. According to our scenario analysis, 20 farmers benefit using just 30% of their annual profit from increased yield to pay back financing. Results from Scenario 5 indicate that the out-grower or insurer model (whereby the off-taker invests in an SPIS for a large number of farmers) is a potentially economically viable model.

Results from Scenarios 6-9 illustrate the economic impact of irrigation system load pairing with solar mini-grids. The base case is a 45 kW mini-grid which is 50% underutilized and capable of meeting an additional 112 kWh/day for drip irrigation five months of the year and for flood irrigation two months of the year. Scenario 7 results illustrate that by incorporating the added irrigation load using a pay-as-you-go approach to electricity sales, a mini-grid developer can recover costs more quickly and achieve a higher IRR while maintaining the same tariff of US$0.49/kWh for customers.

Furthermore, results from the scenario analysis show that relative to a base case (without added productive use), mini-grid electricity tariffs can be 8-18% lower while still earning a high IRR (20%) for mini-grid investors with the addition of the productive use load from irrigation. Drip irrigation methods are more favorable than flood irrigation with greater tariff reduction potential given the higher energy demand from drip irrigation as compared to flood irrigation.

System utilization rates and electricity sales further improve mini-grid economics, but the timing of additional load is critical to system optimization. As noted above, solar irrigation pumps are potential anchor loads that can be powered by mini-grids whenever surplus power is available. Mini-grid pairings with solar irrigation pumps are most likely to be successful when the mini-grid design and load profile are compatible with anchor loads. Based on crop water requirements, while irrigation loads vary seasonally, the variation is predictable and mini-grid developers can be made aware well in advance which months will have increased energy demand due to irrigation activities. Farmers debate the best time of day for irrigation. Scenarios 7-9 assume daytime irrigation sufficiently meets users' needs. Mini-grid developers can encourage customers to change their behavior to shift loads during irrigating hours through time-of-use tariffs to prevent excessive peak demand that would require additional PV panels investment.

Based on the results from the scenario analysis and the ability for farmers to raise funds from additional crop yields, PA-NPSP recommends the following for potential deployment models under Scenarios 1-5. Fundraising can take place at the farmer level or at the level of an entity that is aggregating funds to achieve sufficient volume for a fundraise. In case of the latter, there must be sufficient overall returns (as is the case in Scenarios 2 and 4) so that cashflows can be spread across the multiple entities involved (i.e., the aggregator and the farmer).

Table 22: Deployment Models Most Relevant to Business Case Scenarios

Deployment Model	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
1. DISCO SPV-Led Model		x		x	
2. Community-based Model					x

3. Private Operator Model		x		x	
4. Collaborative SPV-led Model					x
5. Supplier Model		x		x	
6. Lease-to-own		x		x	
7. Equity-cum-subsidy Model	x		x		
8. Pay-as-you-go (PAYG) Model		x		x	
9. Out-grower Model	x		x		
10. Shared Model	x		x		
11. Group Sharing Model					x
12. Renting		x		x	
13. Water-as-a-service		x		x	

While this analysis provides some insight into the potential economic impacts of standalone solar powered irrigation systems and solar irrigation as productive use anchor loads for solar powered mini-grids in Nigeria, additional study is critical to understanding these impacts in greater depth and in various unique contexts across the country. The scope of this business case is limited to drip and flood irrigation applied to tomatoes and rice grown in specific states in Nigeria. As revealed from the crop water requirement analysis, different states will require distinct methods of irrigation depending on the type of crop grown and the rainfall patterns in the state. In addition, further study to understand and test the assumptions for these analyses is necessary to determine the real-time impact of additional load on a specific mini-grid system before implementation.

CONCLUSIONS AND RECOMMENDATIONS

Irrigation is essential to improving agricultural productivity in Nigeria and highly dependent on access to electricity. Standalone solar irrigation systems and solar powered mini-grids may be used by farmers to irrigate crops where there is otherwise limited or no access to reliable grid electricity. Such solutions require financing – both affordable debt as well as grants – to facilitate uptake due to the high initial capital cost.

PA-NPSP's scenario analysis highlights shared and lease-to-own models as superior in terms of profitability. PA-NPSP's mini-grid scenarios indicate that irrigation pump anchor loads have the potential to improve mini-grid economics by increasing mini-grid system utilization rates and thus increasing electricity sales. For sustainable deployment of solar irrigation system in Nigeria, PA-NPSP recommends the following interventions:

- **System Quality and After-sales Services:** Regulating the quality of solar irrigation pumps equipment and suppliers available to consumers, as well as technician certifications and supplier service warranties is important to ensuring cost estimates and forecasts are in line with economic feasibility and profitability outcomes. Adopting best practices for system quality and after-sales services will help ensure the availability of quality solar pumps and reliable after-sales service. Regulating system quality requires stringent oversight, periodic training, and assistance to local actors in identifying authentic products and maintaining timely maintenance of SPIS.
- **Utilization Factor and Water Management:** End-users and mini-grid developers can increase profits on solar investments and water management through pump optimization. The off-grid stakeholder community should encourage use of optimally sized solar pumps through training and policy advocacy. Adoption of SPIS under shared or service-based business models promotes more efficient water use, compared to individually owned systems. The promotion of shared or service-based business models requires higher financial, organizational, and training support from the government or donor organizations.
- **Facilitator-led Awareness Campaigns:** The research conducted by PA-NPSP in this report suggests the need for a facilitator to equip farmers with relevant knowledge for financial decision making when procuring and operating solar-powered irrigation systems. A facilitator who champions awareness campaigns leveraging local knowledge networks, such as farmers' cooperatives, to spread information and increase acceptance of SPIS among farmers can meaningfully impact the effectiveness of these solutions. Existing extension services programs like USAID's Feed the Future (FTF) Nigeria Agricultural Extension and Advisory Services (AEAS) Activity can also be incorporated in campaigns to increase adoption of this technology.
- **Targeted Financing for Marginalized Farming Communities:** Scenario analysis results reveal low DSCRs for individually purchased solar irrigation systems by smallholder farmers and a need for subsidies greater than 25% of capital cost to ensure farmers are able to both obtain and pay back bank loans. The off-grid stakeholder community and FGN can support marginalized end-users – such as women, youths and other marginalized farming communities – as well as mini-grid developers in capturing the benefits of solar powered irrigation by facilitating access to targeted loan schemes with low concessional interest rates as well as grant facilities to encourage adoption of solar irrigation by marginalized farmers. Such subsidies can be particularly valuable for assisting women given restrictions on women's land ownership and farming activities – and therefore higher costs of operation.
- **Further Analysis of Location-specific Business Models:** There is an opportunity for the off-grid stakeholder community to further develop location specific, data-driven business models for solar irrigation given different states require different methods of irrigation, based on the type of crop grown and rainfall patterns in the region.

APPENDICES

APPENDIX A: SUMMARY OF SOLAR IRRIGATION PROJECTS BY COUNTRY

State, Country	Capacity	Developer	Funding Institution	Impact	Business/Payment Model
Nile Delta, Egypt	100 kW mini-grid	SunEdison	Italian Cooperation.	Reduced negative environmental impact.[92]	**System quality and after-sales services**: trained 196 farmers and their Water User Associations on the use and maintenance of the solar-powered irrigation system
Bihar state, India	Mobile standalone system Mini-grids; ranging from 17 to 40 kW	Claro Energy India	Smart Power India (SPI), an initiative established by The Rockefeller Foundation, Husk Power Systems, and other SPI partner developers.	Farmers saved up to 50 percent of irrigation costs by displacing diesel.[93]	**Renting:** irrigation as a service (Pay-per-use). on-demand irrigation without requiring capital investment. **System quality and after-sales services:** Claro's IoT and power electronics allow for remote monitoring of the mini-grids and mobile standalone systems and the company has developed a mobile app allowing farmers to schedule and pay for irrigation from their smartphones.
Burkina Faso	Two 60 W solar panels, motor pump with a capacity of 3600 liters/hour	Buy-Us Solar	The African Enterprise Challenge Fund (AECF)	Capable of irrigating 0.5 to 1 ha depending on the crop and the watering plan to increase crop yield.[94]	**Individual ownership model**: Burkinabe farmer purchased the motor pump for an average cost of 475,000 CFA francs (US$862)
Jharkhand, India	3.73 kW AC Solar pump		40 percent Syngenta Foundation India (SFI) 35 percent Schneider Electric India Foundation (SEIF)	Farmers can save around INR 60,000 (US$807.47) per season on their fuel expenditures.[95] Reduced operational cost from US$181 to US$113.	**Group sharing model:** the farmers invested 40 percent of the capital cost. Ownership of the installed solar pump rests with all the farmers who paid for the pump. **System quality and after-sales services:** SFI provided technical support to the farmers.

[92] Water Scarcity Initiative. Solar Powered Water Lifting for Irrigation in The Nile Delta. Source: http://www.fao.org/3/i9204en/I9204EN.pdf

[93] William Brent (2018, June 27). Agro-centric mini-grids and solar trolleys could transform Indian farming. Source: https://www.pv-tech.org/agro-centric-mini-grids-and-solar-trolleys-could-transform-indian-farming/

[94] Afrik 21 (2021). Buy Us Solar launches a solar-powered irrigation system. Source: https://www.afrik21.africa/en/burkina-faso-buy-us-solar-launches-solar-powered-irrigation-project/

[95] Syngenta Foundation (2020). Solar-powered irrigation system. Source: https://www.syngentafoundation.org/agriservices/whatwedo/irrigation/solarpoweredliftirrigationsystem

			25 percent farmers	Increased productivity of vegetables from 4.58MT to 8.45MT.[96] Increased net income per farmer from US$131 to US$243. **Crops:** strawberry, watermelon, broccoli, etc.	
Lajolo Village, Kwara, Nigeria	8.5 kW solar microgrid	Shaybis Nigeria Limited	Institute of Electrical and Electronics Engineers (IEEE) Smart Village (ISV)	Prolonged food storage, better water supply and cleaner rice processing.[97]	**Pay-as-you-go (PAYG) model**: prepaid metering system.
Nairobi, Kenya	310W solar panel, 215feet Irrigation head, 3,000 Liters per hour Submersible pump	SunCulture	The farmers	Increased monthly income from 12,000 Ksh (US$111) to 37,000-40,000 Ksh (US$343 - US$370) per month.[98] **Fruit crop**: oranges, mangoes, bananas, guava, and papaya	Pay-as-you-go (PAYG) model **System quality and after-sales services:** free delivery and installation, smart notification

[96] Syngenta Foundation (2020). Compendium on Solar-powered Irrigation System in India. Source: https://www.syngentafoundation.org/sites/g/files/zhg576/f/2020/10/13/ccafs_-_compendium_solar_final.pdf

[97] Smart Village (2017). Shaybis Nigeria Limited. Source: https://smartvillage.ieee.org/project/shaybis-nigeria-ltd-nigeria/

[98] Sun Culture (2021, January 1). Japhet Muthami - SunCulture. Source: https://sunculture.com/index.php/japhet-muthami/

APPENDIX B: BUSINESS CASE ANALYSIS ASSUMPTIONS

This appendix presents an overview of the methodology used to assess the economic feasibility of solar irrigation investment for farmers and mini-grid developers.

Methodology for Assessing Economic Viability

Economic viability is determined for rice (paddy) and tomato irrigation using flood and drip irrigation methods respectively. PA-NPSP modeled scenarios which assumed a single farmland size of 0.5 ha as that is the average smallholder farmer land size in Nigeria.

Crop Water Requirement

Solar pump capital cost depends on the peak daily water needs of a crop. It is important that daily water needs of a crop is established using rainfall and temperature data as some locations may not be suitable for irrigation investment. Using FAO-GIZ Toolbox and the temperature and rainfall data for Benue, Niger and Ebonyi states where tomatoes and rice are grown respectively, PA-NPSP estimated the amount of water needed to irrigate a 0.5-ha farm.

As shown in Figure 11, irrigation is not necessary for growing rice (paddy) in Ebonyi state due to the adequate levels of monthly effective rainfall. Based on annual rainfall data, states in the Southern region have higher rainfall days in Nigeria. Compared to the Northern regions (with lower rainfall days), farmers in the Southern regions of Nigeria need not invest in solar irrigation to improve their crop yield.[99] In Northern Nigeria, farmers can use irrigation to supplement rainfall two months out of the year. The estimated water requirement (Figure 12) for using flood irrigation to irrigate a rice paddy is 198,000 Liters/0.5Ha/year.

The estimated water requirement (Figure 13) for drip irrigation of tomatoes is 905,000 Liters/0.5Ha/year. Drip irrigation is required 5 months out of the year.

[99] Interview with the president of the Nigerian Association of Soybeans Farmers.

Figure 8: Effective Rainfall and Irrigation Water Need for Paddy Cultivation in Ebonyi State

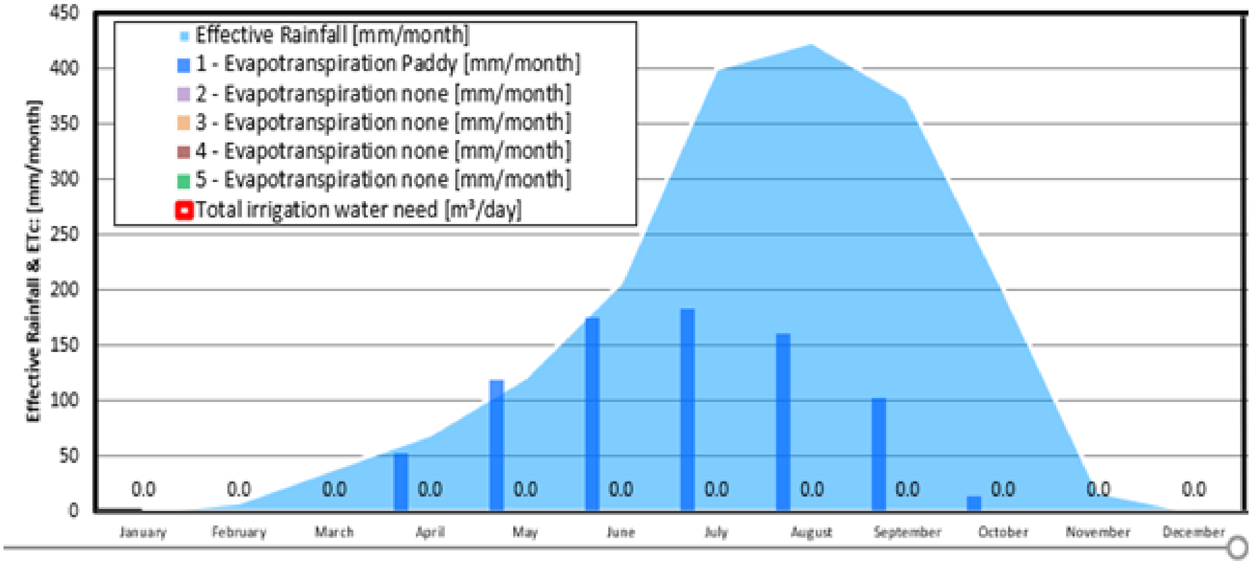


Figure 9: Effective Rainfall and Irrigation Water Need for Paddy Cultivation in Niger State

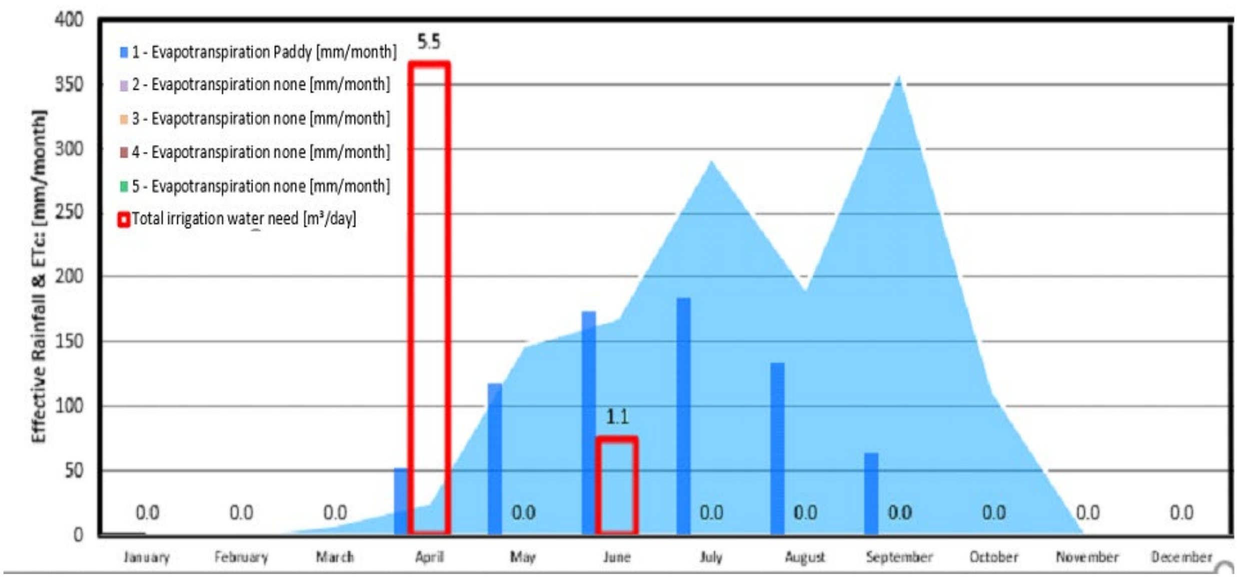
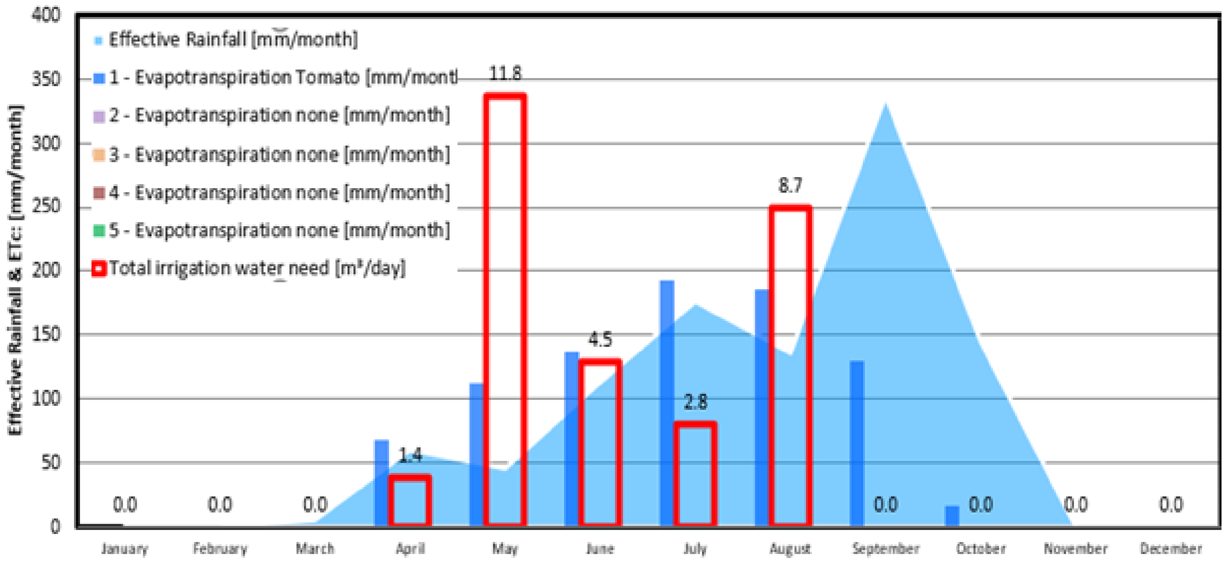


Figure 10: Effective Rainfall and Irrigation Water Need for Tomato Cultivation in Benue State



Capital and Operating Cost Estimates for Scenario Analysis. The initial capital cost, operating and maintenance running cost associated with SPIS investment is estimated and used to determine NPV, IRR, Payback, and Average DSCR over a period of 25-year project life.

Table 23: Capital and Operating Cost Estimates for Scenarios 1-4

Standalone Solar-Powered Drip Irrigation		
Capital cost for 0.5ha irrigation	**Cost (USD)**	**Source/Assumption**
Solar panel, 450W	240	Panel sizing is typically slightly higher than the capacity of a system. Source: Konga
Solar pump (submersible) with controller, 0.4 kW, up to 13,000L/day	400	Source: Konga
Drip line, 10,000m (0.5ha with 1m spacing)	600	Source: Afrimash Drip Irrigation Tape, 1500m/Roll
Drip Irrigation header with filter	400	Source: UN Food and Agriculture Organization
Pump Installation and Drilling	500	Source: UN Food and Agriculture Organization
Water storage, 5000L	250	Source: Jiji Reservoir Water Tank
Total	***2,390***	

Standalone Solar-Powered Flood Irrigation		
Capital cost for 0.5ha irrigation	**Cost (USD)**	**Source/Assumption**
Solar panel, 450W	240	Panel sizing is typically slightly higher than the capacity of a system. Source: Konga
Solar pump (submersible) with controller, 0.4 kW up to 13,000L/day	400	Source: Konga
Irrigation header with filter	400	Source: UN Food and Agriculture Organization
Pump installation and drilling	500	Source: UN Food and Agriculture Organization
Irrigation line, 150m	50	Market price observations
Water storage, 5000L	250	Source: Jiji Reservoir Water Tank
Total	***1,840***	
Operating Cost for 0.5ha irrigation	**Cost (USD)**	**Source/Assumption**
Annual maintenance cost (0.4 kW Drip)	71.9	Assumed annual maintenance costs 3% of capital cost, Source: UN FAO Economics of Irrigation
Annual maintenance cost (0.4 kW Flood)	55.2	Assumed annual maintenance costs 3% of capital cost, Source: UN FAO Economics of Irrigation

Table 24: Capital and Operating Cost Estimates for Scenario 5

Standalone Solar-Powered Drip Irrigation		
Capital cost 5ha irrigation	**Cost (USD)**	**Source/Assumption**
Solar panel, 4.5 kW	2400	Panel sizing is typically slightly higher than the capacity of a system. Source: Konga
Solar pump (submersible) with controller, 4 kW up to 52,000L/day	2,077	Scaled from Table 23 using formula: New Cost = (Base Cost) *(New Size/ Base Size)^n Where n= 0.72 (for pumps)
Drip line, 50,000m (5ha with 1m spacing)	6,000	Scaled by quantity

Drip irrigation header with filter	2,000	Scaled by size, Source: UN Food and Agriculture Organization
Pump installation and drilling	1,000	Scaled by size, Source: UN Food and Agriculture Organization
Water storage, 5000L	-	
Total	***13,477***	
Operating cost for 5ha irrigation	**Cost (USD)**	
Annual maintenance cost (4 kW Drip)	404.3	Assumed annual maintenance costs 3% of capital cost, Source: UN FAO Economics of Irrigation

Table 25: Capital and Operating Cost Estimates for Scenarios 6-9

45 kW Mini-grid Powered Irrigation		
Capital and Operating Cost		**Source**
Simplified mini-grid capital cost (USD)	140,000	RMI Nigeria Mini-grid Investment Report (2018)
Operating cost (USD/year)	2,000	RMI Nigeria Mini-grid Investment Report (2018)

Table 26: Cost and Capacity of Solar and Fuel-powered Irrigation Appliances*

Item	Description	Current Price Range (USD, 2021)[100]
Individual pump system components		
PV panel		US$1.30 - 2.08/Watt[36]
Water pump	Submersible pump, max energy 0.5HP – 3HP	US$73.17 to 634.15[101]

[100] Current value of equipment in calculated using the formula; Present cost = (Original cost * ratio of equipment index 2021 / equipment index 2017). Equipment index is available at https://ycharts.com/indicators/us_producer_price_index_machinery_and_equipment_electrical. Naira is converted to US$ using the official exchange rate in June 2021

[101] Nigerian Guide. Cost of submersible pumping machines in Nigeria. Source: https://nigerianguide.com.ng/cost-of-submersible-pumping-machines-in-nigeria/

Item	Description	Current Price Range (USD, 2021)[100]
Solar pump	4 kW	US$1,038.67[36]
Pump controller	4 kW	US$1,038.67[36]
Electric cables	Depending on pump depth and distance to PV panels	US$5.19 to 14.54[36]
Pump installation	Manual up to 30m	US$207.74 to 415.48[36]
Pump installation	With crane	US$779.02 to 1,038.67
Solar water pump and controller	DC submersible solar water pump ranging between 1HP – 3HP (water pump and controller)	US$536.59 to 1,097.56[102]
Complete System		
Solar Pump System	Submersible DC/AC pump, 2HP, up to 150m, with a flow rate of 5,000 liters/day (Grundfos MSF 3 Motor (motor) – 1.4 KW, Grundfos SQF 1.2-3 Pump & Motor, Grundfos IO-50 DC Switch, 270-Watts Solar Panels (6))	US$4,268.29[97]
Fuel-powered water pump	With 2" hose and ranging from 4.0HP – 6.5HP (with a flow rate of 36,000 – 60,000 liters/hr.)	US$134.15 to 214.63[97]
Fuel-powered water pump	With 3" hose and 5.5HP – 6.5HP (with a flow rate of 36,000 – 60,000 liters/hr.)	US$132.44 to 207.31[97]

**Not direct assumption in models but provided as context and for future analysis.*

Table 25: Cash Flow Input Assumptions

Variable	Input	Notes
Inflation rate	12%	Assumed based on inflation rate 2020-2021 in Nigeria. While the cash flow is presented in dollars, the Naira inflation rate is used to capture the impact of inflation in Nigeria. PA-NPSP used an initial exchange rate conversion of NGN 410 to US$1.
Discount rate	4%	Assumed based on interest rate range (2-6%) for bank savings in Nigeria

[102] Konga. https://www.konga.com/

Variable	Input	Notes
Tariff escalator	6%	Estimated annual increase in tariff charged by the mini-grid developer over the life of the project.
Water levy (USD)	0	Water levy is set to zero. Groundwater is assumed to be free as observed in rural communities.
Annual profit margin Increase	3%	Annual escalation from price increases and efficiencies on assumed profit from additional yield of crop sale.
Profit increase from additional yield (USD/0.5ha) – Drip Irrigation	909	Profit increase from additional crop sales based on increased yield with irrigation (Table 28)
Profit increase from additional yield (USD/0.5ha) – Flood Irrigation	566	Profit increase from additional crop sales based on increased yield with irrigation (Table 28)
Solar panel lifespan on drip and flood irrigation systems(years)	20	Assumes solar panel on irrigation systems requires replacement after 20 years.
Pump and controller lifespan (years)	10	Lifespan of submersible pump ranges from 10-15 years.
Pumping time (hours/day)	7	Assumed hours per day for pumping to determine energy demand.
Pump utilization rate (drip)*	21%	Based on water utilization rate estimate for irrigating 0.5ha of tomatoes in Benue state, Nigeria
Pump utilization rate (flood)*	10%	Based on water utilization rate estimate for irrigating 0.5ha of paddy in Niger state, Nigeria
45 kW mini-grid load utilization factor	50%	Assumed utilization of mini-grid allowing for excess capacity to power a 16kW pump (112 kWh/day).
45 kW mini-grid initial tariff (USD/kWh)	0.49	Assumed estimate based on tariff range of US$0.34–0.86/ kWh for mini-grids in Nigeria
Irrigation labor cost	-	Irrigation labor cost was assumed zero and not considered as part of the operating cost in this analysis.

Variable	Input	Notes
Interest rate	22%	Based on interest rates for observed agricultural bank loans ranging from 5% to 40%.[103]
Loan tenor (years)	5	Based on observed average loan tenors for agricultural loans in Nigeria.
Project life (years)	25	Assumed to be greater than the lifespan of PV panels to capture project return more accurately on investment.

**Not direct assumption in models but provided as context and for future analysis.*

Table 26: Profit Increase Generated by Additional Yield from Irrigated Crops

No.	Assumption / Calculation	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
I	Land size (ha)	0.5	1.0	0.5	1.5	10
II	Rainfed yield (metric tons/ha)	6.41	6.41	2.51	2.51	6.41
III	Irrigated yield (metric tons/ha)	8.42	8.42	3.58	3.58	8.42
IV	Increased yield by irrigation (metric tons/ha) = III – II	2.01	2.01	1.07	1.07	2.01
V	Market rate of crop (USD/metric ton)	904	904	1,059	1,059	904
VI	***Profit increase from additional yield (USD) = IV * V***	***909***	***1,817***	***567***	***1,700***	***18,170***

103 Start credit (2021). https://startcredits.com/free-loan-search/?swoof=1&product_cat=micro-finance&product_tag=group_loan-nigeria

Table 27: Energy Demand Estimates for Pumping Systems (Scenarios 7-9)

No.	Assumption / Calculation	Scenario 7	Scenario 8	Scenario 9
I	Water requirement (m^3/year/0.5 ha)	905	905	198
II	Hectare irrigated by 16kW optimized pump	40	40	60
III	Pump power demand (kW)	16	16	16
IV	Number of irrigation days (days/year)	150	150	60
V	Water requirement (m^3/day) = (I * II) / IV	241	241	198
VI	Number of pumping hours	7	7	7
VII	Volume flow (m^3/hour) = V / VI	34.5	34.5	28.3
VIII	Daily demand (kWh) = (III * VI)	112	112	112
IX	Annual energy demand for pumping (kWh/year) = VIII * IV	16,800	16,800	6,720

APPENDIX C: DETAILED DESCRIPTION OF DEBT AND GRANT FINANCING

This appendix provides detailed examples of possible debt and grant financiers for the deployment of solar irrigation systems

Debt Financing

Potential Credit Guarantee Facilities include:

- *The Nigerian Infrastructure Credit Enhancement Facility (InfraCredit)* is a US$75 million NSIA-backed project aimed at providing guarantees to infrastructure projects to enable debt financing from the domestic market.[104] InfraCredit can provide a guarantee for infrastructure projects, including energy supply and distribution infrastructure; mini-grid projects fall under this category.
- *The Development Bank of Nigeria (DBN)* provides partial credit guarantees to financial intermediaries which aid in providing financial support to micro, small and medium scale enterprises. Agricultural off-takers/agribusinesses fall under these categories.

Potential Credit Facilities include:

- *The Central Bank of Nigeria* acts as a credit facility through its Solar Connection Facility launched as part of the Economic Sustainability Plan (ESP) to roll out 5 million new solar-based connections in communities that are not grid-connected. It provides long term, low-interest credit facilities to manufacturers and assemblers of solar components and off-grid energy retailers in the country.
- *SUNREF Nigeria* provides a credit facility of US$70 million (approx. EUR 60 million) to Nigerian banks (Access Bank and UBA), that offers attractive terms (concessional rate loans, long tenors, grace period) to advance green financing. SUNREF provides technical assistance to local actors (developers and banks) in the development and financing of projects.
- *The Bank of Industry (BOI)* through its NGN 6 billion (US$150,000,000) solar energy fund aims to provide financial support to commercial and residential end-users including smallholder farmers, in the development or acquisition of reliable solar solutions. The funds will be disbursed directly through the BOI or Deposit Money Banks (DMBs) or Microfinance Banks (MFBs).[105] Mini-grid developers can leverage the fund in the development of mini-grids in rural communities to enable the energizing of solar irrigation systems to be used by smallholder farmers.
- *The Agricultural Credit Support Scheme (ACSS)* is an initiative of the Federal Government and the Central Bank of Nigeria aimed at equipping farmers with the capacity to maximize the untapped potential of the agricultural sector.[106] To access loans under ACSS, applicants (practicing farmers and off-takers with means) are encouraged to approach their banks for a loan through the respective state chapters of Farmers Associations and State Implementation Committees. Large-scale farmers are allowed to apply directly to the banks in accordance with the guidelines. ACSS funds are disbursed to farmers and off-takers at an interest rate of 8 percent. At the commencement of the project support, banks will grant loans to qualified applicants at 14 percent interest rate.[100]
- *All On Energy and BOI* invested NGN 1 billion (US$2.4 million) in the *Niger Delta Off-grid Clean Energy Fund*, which aims to provide debt financing for the provision of clean energy solutions in the Niger Delta region. The financing will be provided at a 10 percent interest rate per annum as

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104 ACE-TAF (2021). Stand-alone Solar Investment Map Nigeria. Source: https://www.ace-taf.org/wp-content/uploads/2021/03/Stand-Alone-Solar-Investment-Map-Nigeria.pdf

105 Bank of Industry. The N6 Billion BOI Solar Energy Fund. Source: https://www.boi.ng/solar-energy/

106 Central Bank of Nigeria (2018). Guidelines for Commercial Agriculture Credit Scheme (CACS). Source: https://www.cbn.gov.ng/devfin/acgsf.asp

well as a 1-year moratorium and tenor of up to 7 years.[107] The fund will enable the provision of electrification within rural communities to support household and commercial activities. It can be further utilized by mini-grid developers to finance the development of a mini-grid which provides the energy needed by a water pump for irrigation, as well as by standalone irrigation equipment provider in the sale and distribution of standalone solar irrigation equipment needed by farmers.

Potential Private Financial Institutions are:

- *LAPO Microfinance Bank* is also suited to serve within the role of the PFI as it currently offers an agricultural loan between NGN 50,000 to NGN 500,000 (US$122 to US$1,220) to smallholder farmers. The loan is a low-interest loan that requires no collateral. It is targeted at individual and group farmers which makes it a great fit for the shared model. However, the repayment period, while flexible in terms of its structure, is short - ranging between 12 months to 14 months.[108]
- *Grooming Center*, through its IFDC loan, provides smallholder farmers with NGN 250,000 to NGN 750,000 (US$500 to US$1,500) at an interest rate of 14 percent to be repaid after 6 months. Grooming Center can receive credit facilities and loans to smallholder farmers with the loan structures already in place within the organization. The IFDC loan can be utilized together with other financing options to fund the purchase of SPIS. However, the repayment period is too short and needs to be longer if it is to serve the purpose.[109]
- The Small and Medium Enterprise Development Agency of Nigeria (SMEDAN) in collaboration with the Bank of Agriculture (BOA) aims at improving the output of Micro and Small Enterprises (MSEs) in Nigeria.[110] It provides loans between NGN 1.2 million (US$2,900) and NGN 5 million (US$12,200) at an interest rate of 9 percent per annum for a tenor of 30 months.
- *Bank of Agriculture* (BOA) is a development finance institution focused on providing loan credit facilities in agriculture. They accept loan applications from cooperative societies. Its mission is to stimulate agriculture, improve lives and grow communities. As part of the eligibility criteria, applicants must own or operate an existing farm. One of the BOA loans is the Direct Credit Product loan. Loan ranges from about NGN 250,000 (US$609.76) to a maximum of NGN 50 million (US$122,000) with a loan tenor of a maximum of 5 years. There is a limit of NGN 5 million (US$12,200) to individual persons. There is an interest rate of 14 percent for agricultural production and agro-processing, and a 20 percent interest rate for commodity marketing. In order to access this loan, a deposit of 20 percent of the required loan amount must be made into the account. Securities are an acceptable form of collateral under this loan option.

Grant Financing

Result-based Financing is a mechanism that disburses the grant upon confirmation of specific results or achievements of pre-agreed milestones. For example, if a developer is funded to deploy a mini-grid in a community for agricultural productive use, a grant is paid after the developer proves that the mini-grid is functional and that the farmers are connected to the grid. Additionally, an irrigation equipment provider receives grants based on the number of standalone solar irrigation systems distributed.

The examples below highlight some RBF available to support the deployment of solar irrigation systems in rural communities in Nigeria:

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[107] All On Energy. The Bank of Industry (BOI) And All on Announce the Establishment of The Niger Delta Off Grid Energy Fund. Source: https://www.all-on.com/media/media-releases/boi-and-all-on-announce-niger-delta-off-grid-energy-fund.html

[108] LAPO Microfinance Bank. Agric Loans. https://www.lapo-nigeria.org/loans/agric

[109] Grooming Centre. https://groomingcentre.org/products/

[110] SMEDAN (2021, March 31). SMEDAN, BOA Target MSMEs with Matching Fund Programme. Source: https://smedan.gov.ng/smedan-boa-target-msmes-with-matching-fund-programme/

- The *Nigeria Electrification Project* (NEP) is an initiative of the REA supported by the World Bank and AfDB. It seeks to provide electricity access to households, micro, small and medium enterprises in the off-grid communities across the country through the adoption of renewable energy sources.[111] The initiative provides grant facilities to private and public sector organizations which will enable the electrification of rural communities. The grant is performance-based and provides support to mini-grid developers for the deployment of mini-grids within rural communities. The electricity generated by the mini-grid can be utilized productively by farmers through the use of solar irrigation systems.
- *The Results Based Financing for Productive Appliances and Equipment,* managed by the REA, is aimed at increasing the productive use of electricity through the provision of productive use appliances (including solar irrigation equipment) to 24,500 MSMEs in Nigeria. The total fund available under this program is NGN 8.2 billion (US$20 million) targeted towards mini-grid developers with existing mini-grids in rural communities.[112] Standalone irrigation equipment providers are also eligible.

Upfront Grants are grants disbursed to the recipient (mini-grid developer, standalone irrigation equipment provider, or farmer cooperative) prior to the launch of the project. Unlike the RBF, these grants are not dependent on the achievement of particular milestones. In most cases, for mini-grid projects to be commercially viable (in the case of the mini-grid model), some form of grant funding is necessary.[37]

The examples below highlight some upfront grant opportunities that can be leveraged for the provision of mini-grid to power irrigation systems in rural communities:

- The *Rural Electrification Fund (REF)* administered by REA provides upfront capital grants to mini-grid developers and solar home systems companies to electrify unserved and underserved rural communities, and is financed through budgetary allocations from the Nigerian Government.[113] The REF grants between US$10,000 to US$300,000, or 75 percent of the total capital costs of the project to the mini-grid developers and solar home system companies.[114]
- The *U.S. African Development Foundation (USADF) and All On* Energy in an attempt to provide funding to businesses looking to increase energy access to communities, launched the *Nigerian Off-grid Energy Challenge Fund*. The fund provides US$50,000 in convertible debt and US$50,000 in grant capital to businesses including mini-grid developers and can be used to provide off-grid energy to rural communities and most importantly smallholder farmers, for productive use (i.e., solar irrigation).

[111] Rural Electrification Agency (REA). Source: https://rea.gov.ng/nigeria-electrification-project-nep/

[112] Rural Electrification Agency (REA) https://nep.rea.gov.ng/result-based-financing-for-productive-appliances-equipment/#plan

[113] The Rural Electrification Fund (REF). https://rea.gov.ng/download/rural-electrification-fund-ref/

[114] Ashley Wearne and Bhoomika Tiwari. 2021. Financing Instruments for the Mini-Grid Market – Nigeria. *Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, https://www.get-transform.eu/wp-content/uploads/2021/08/Success-in-Rural-Electrification-Case-Study_Nigeria.pdf*