Promoting Climate Adaptation by Upscaling Solar Irrigation Technology Options for Smallholder Farmers in Ghana through Innovative Financing Mechanisms, a Conductive Policy Framework for Technology Regulation and Tailored Training Modules

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Output 1 Deliverables Report

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Acronyms and Abbreviations

AfDB	African Development Bank
AIICO	Agriculture Infrastructure Investment Company
AWD	Alternate Wetting and Drying
CAC	County Agriculture Coordinator
CAO	County Agriculture Officer
CARI	Competitive African Rice Initiative
CHAP	Community of Hope Agriculture Project
CTCN	Climate Technology Centre and Network
DAO	District Agriculture Officer
DOA	Department of Agriculture
EIA	Environmental Impact Assessment
EPA	The Environmental Protection Agency of Liberia
FAO	Food and Agriculture Organization of the United Nations
FED	Food and Enterprise Development Programme
FUN	Farmer Union Network
GAP	Good Agricultural Practices
GIS	Geographic Information System
LIGIS	Liberia Institute of Geo-Information Services
M&E	Monitoring and Evaluation
MoA	Ministry of Agriculture
NDE	National Designated Entity
NGO	Non-Governmental Organisation
PV	Photovoltaic
RAC	Region Agriculture Coordinator
SPIS	Solar Powered Irrigation Systems
SRI	System of Rice Intensification
SWG	Stakeholder Working Group
TA	Technical Assistance
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization (UNIDO)
USAID	United States Agency for International Development
WAAPP	West Africa Agricultural Productivity Program
WARDA	West Africa Rice Development Association
WUA	Water User Association

1 INTRODUCTION

1.1 Background

The project “Promoting Climate Adaptation by Upscaling Appropriate Solar Irrigation Technology Options for Smallholder Farmers in Ghana through Innovative Funding Mechanisms, a Conductive Policy Framework for Technology Regulation and Tailored Training Modules” is a UN CTCN (Climate Technology Centre and Network) project. CARES Ghana, in association with INTEGRATION energy & environment (the Consultant) offered to provide Technical Assistance (TA) for the project and were awarded a Contract (UNEP- CTR-4700023676-CTCN Ghana) on 26th August 2022 to carry out the assignment.

1.2 Objective of Assignment

The objective of the TA is to promote smallholder farmers’ adaptation to climate change by providing a sustainable and efficient means of irrigation through the assessment of solar technology options, design of an appropriate and sustainable business model for the lowest income, and formulation of a policy framework for the use of Solar Powered Irrigation System (SPIS) in Ghana. This will include the following outputs:

I. **Output 1:** Benchmark Solar Powered Irrigation technologies suitable to smallholder farmers in Ghana and assess their respective cost-benefits.
II. **Output 2:** Define a business model targeting smallholder farmers for the use of Solar Powered Irrigation Systems in Ghana, with recommendations on financing structures to extend credit and reach the unbanked smallholder farmers
III. **Output 3:** National framework on Solar Powered Irrigation technology, to drive the setting of standards and certification that will support the deployment of a local market
IV. **Output 4:** Capacity training to raise awareness on the benefits of Solar Pumping Irrigation Systems for smallholder farmers in Ghana, targeted at the users and administrators of the technology across the supply chain to support its sustainable use and long-term maintenance.

The TA focusses on SPIS that builds on existing hard technology options in the country, and soft technology solutions that create an enabling environment for the uptake and dissemination of the technology (policy, training, and financing). The TA will ensure the involvement of financial institutions including micro finance institutions, rural banks and non- bank entities that could participate in the provision of financing services for smallholder farmers. The financing structures will consider appropriate risk mitigation instruments including insurance and guarantee structures aimed at crowding in private sector investments. Implicit for a successful financing structure is the aggregation of smallholder farmers to increase the scale of the opportunity.

1.3 Report Outline

This Report brings together all the deliverables for Output 1 of the TA, as follows:

I. Kick-off Meeting and Stakeholder Mapping Report, containing a complete stakeholder list as well as a description of the Stakeholder Working Group (SWG), with name, position, institution, gender and role of each member.

II. Inception Meeting Report, with materials, list of participants disaggregated by gender, bibliography and planning of bilateral meetings held by the international expert in Ghana.
III. Agricultural and Irrigation Practices Assessment, including minutes of interviews, names of participants, type of meeting, themes treated, questions raised.
IV. Minutes of the Stakeholder Working Group´s workshop, including materials, list of participants (disaggregated by gender), photos and conclusions.
V. Guide to the most appropriate Solar Powered Irrigation Systems that could be efficiently and sustainably implemented for smallholder farmers in remote areas of Ghana, including a list of accredited suppliers and distributors.
VI. Cost analysis of at least three of the technologies and system architectures presented.

2 KICK-OFF MEETING AND STAKEHOLDER MAPPING

The stakeholder mapping exercise commenced even before the Kick-off Meeting, held virtually on 15th September 2022, and continued after the meeting and throughout much of Output 1 activities. A complete Stakeholder List is attached in Appendix A, and a description of the Stakeholder Working Group (SWG) membership is as shown in Table 1 below.

Summary of key actions/decisions from minutes:

- Protection of water resources to ensure water availability for farmers to constantly use for irrigation, and determination of the required quantity per farmer are necessary.
- Terms of Reference (ToR) for the SWG must be developed, stakeholder mapping exercise completed, and detailed Work Plan updated.
- All communications should be circulated to all present from CTCN and EPA, including presentation with the minutes, drafts of the other mandatory deliverables, the Monitoring & Evaluation Plan and Impact Description Document.

Minutes of the Kick-off Meeting are attached as Appendix B, with the presentation materials in Appendix C.

Table 1 - Stakeholder Working Group (SWG)

S/N	STAKEHOLDER			CONTACT DETAILS		Gender	Role of Member
	Stakeholder Name / Organization	Contact Person	Position	Mobile No.	Email Address		
1	Environmental Protection Agency (EPA)	Dr. Daniel Benefoh	UNFCCC focal point	024 611 4652	dbenefor2000@gmail.com	Male	Chair
2	Ghana Irrigation Development Authority (GIDA)	Mr. Prosper Glitse	Senior Agro-Economist	020 378 3444	prosper.glitse@gida.gov.gh	Male	Co-Chair
3	Ministry of Food and Agriculture	Mr. Kingsley Amoako	Climate Change focal point	020 7411864	kingkwaw@yahoo.com	Male	Member
4	Agricultural Development Bank (ADB)	Kwame Asiedu Attrams	General Manager, Agribusiness	024 428 1927	kattrams@agricbank.com	Male	Member
5	Association of Rural Banks (ARB) Apex Bank	James Arko	Head of Credit	020 417 5911 024 475 5800	jarko@arbapexbank.com	Male	Member
6	Peasant Farmers Association of Ghana	Wepia Awal Adugwala	National Present	024 226 5313	wapiaawal@yahoo.com	Male	Member
7	Women in Agriculture Platform	Gilberta Akuka		024 629 7965	gilbertaakuka@gmail.com	Female	Member
8	Ghana Standards Authority (GSA)	Prof. Alex Dodoo	Director General	024 428 1927	gsanep@gsa.gov.gh	Male	Member
9	University of Energy and Natural Resources (UENR)	Ing. Prof. Eric Ofosu Antwi	Director, RCEES	020 881 2106 024 452 5974	ericofosuantwi@gmail.com	Male	Member

3 INCEPTION MEETING

The inception meeting was held on 22nd November 2022. Sixteen (16) persons attended physically, while six (6) participated virtually.

Summary of key actions/decisions from minutes:

- Proper needs assessment based on the farmers and end users should be done, and the real challenges of these users be assessed before proceeding further with the TA.
- Energy Commission should be part of the Stakeholder Working Group (SWG).
- Loans to farmers should not be linked to government nor politicians, so as to ensure repayment.
- Thresholds of existing financial packages for farmers at the banks and their repayment period must be reviewed to meet their capability.
- Value chain financing should be the way forward.
- Farmers should be re-oriented to change their attitude to help solve challenges in loan repayment.
- In-grower systems, where farmers with larger farms lease part of the farms to smallholder farmers to assist them expand their activities and be able to repay their loans, should be studied.
- Loans in the form of farm inputs and equipment instead of cash must be considered.
- The TA should identify medium term plans prepared by GIDA, MoFA, Energy Commission, etc.

Minutes of the inception meeting are attached as Appendix D, and the presentation as Appendix E.

4 AGRICULTURAL AND IRRIGATION PRACTICES ASSESSMENT

4.1 General

The Consultant carried out desk analysis of the agricultural and irrigation practices under a changing climate in Ghana, to assess smallholder farmers' needs, by desk studies and interviews with Stakeholders, as listed in Table 2 below. Minutes of meetings held with them are attached as Appendix F.

4.2 Agricultural and Irrigation Practices in Ghana

4.2.1 Findings of the Desk Study

A. *Source:* Baseline Study of Renewable Energy Technologies in Ghana, China-Ghana South-South Cooperation on Renewable Energy Technology Transfer (RETT), April 2018, Vol. 1

➢ **Solar Powered Irrigation Schemes – NewEnergy (Northern Savannah Zone)**

NewEnergy, a local-based NGO, with support from the Energy Commission and UNDP Ghana under the auspices of the SE4ALL (Solar Energy for All) initiative, has implemented four Solar Powered Irrigation Systems in Northern Ghana. The irrigations systems took three months to construct and was completed in December 2014 at a cost of USD 200,000. The goal of the project is to make sustainable energy for irrigation easily accessible and affordable to smallholder farmers. These systems are located in Datoyili, Fooshegu, Nankpanduri and Tamalugu.

Solar Irrigation System at Datoyili

Key findings and observations

- The irrigation system is equipped with a 2.3kW solar PV array and Lorentz DC pump together with accessories.
- Water is sourced from a nearby dam that is able to withstand the dry season.
- Furrow and drip irrigation techniques are used.
- About 12 farmers forming a cooperative are benefiting from the installed solar irrigation system. These farmers take shifts in watering their farms and payment is done only on days they use the system.
- Farmers pay GH¢5 daily to use the system per acre of land. Those with smaller farms are, however, grouped together to use the system on specific days at a different rate.
- The system is cheaper than operating a diesel-powered pump for irrigation.
- There is ready access to the system for irrigation. Farmers can also use the system on credit.
- Payments from utilisation goes to NewEnergy which is responsible for the maintenance of the system.
- The solar powered pump could do up to 30 acres of drip irrigation.

Challenges

Owners of neighbouring farms, especially the women, have expressed interest in using the facility. However, due to the limited capacity of the pump this has not been made possible.

Lessons learnt and recommendations

- In replicating such installations, a submersible pump should be employed as the area is known to flood during the rainy season.
- The capacity of the pump and the panels should be increased in similar projects to make room for expansion.
- Farmers should be trained on simple maintenance practices.

Solar Irrigation System at Fooshegu

Key findings and observations

- The irrigation system was equipped with a 1.5kW solar PV array and DC pump.
- Water for irrigation was sourced from a nearby lake, which usually dries up during the dry season.
- At the time of the visit, the DC pump for irrigation had been removed and the pipes were lying idly on the ground. The solar PV array was, however, present on site.
- It is difficult getting farmers to form cooperatives to operate and manage the facility. In view of this, New Energy has made plans of relocating the facility to another community.

Challenges

Due to decreasing water levels during the dry season the pump is not operated since the likelihood of drawing mud is high which could damage the system.

Lessons learnt and recommendations

- Farmers should be educated on how to put schemes in place that will enable them to pay for the use of the system and further take ownership.
- The use of underground water should be explored to address the situation when surface water dries out during the harmattan season.

Solar Irrigation System at Tamaligu

Key findings and observations

- The irrigation system at Tamaligu is equipped with a 15kW DC pump with advanced communication and monitoring capabilities which enables the user to monitor and control the operation of the pump remotely via the internet.
- The DC pump is capable of delivering 166,000 litres of water per hour with maximum torque.
- Irrigation technique is furrow. This is not very efficient, therefore, the farmers are being encouraged to purchase drip irrigations kits.
- The system is capable of doing two to eight (2-8) acres of furrow irrigation and about three (3) acres of drip irrigation.
- Water for irrigation is from a tributary of the White Volta, whose level reduces during the dry season.
- Among the maintenance practices are plumbing works and periodic cleaning of the panels.
- The farmers have formed a co-operative made up of 17 men and 20 women.
- Each farmer pays GHS100 per acre for the whole season.
- Prior to the installation farmers invested most of their earnings on purchasing diesel for their pumps.

"Iddrisu Abubakari could produce five (5) bags of onions from five (5) acres of land in the wet season, but with the solar irrigation system he is able to produce more than five (5) bags of onions from a quarter acre of land in the dry season".

Challenges

- The pumping pressure is low; therefore, the irrigation system is capable of doing only 1 hectare of drip irrigation.
- Owners of neighbouring farms had expressed interest in connecting to the system, but they had been denied due to the limited capacity of the pump.

Lessons learnt and recommendations

- For sites that are prone to flooding a submersible DC pump should be used.
- In replicating such solar powered irrigation systems, the capacity of the pump could be increased to make room for expansion.

➢ Aveyime Irrigation Scheme (coastal savannah zone)

The Aveyime Irrigation Scheme was started in 1962 at Aveyime, a village in the North Tongu District of the Volta Region of Ghana. The construction was done by Nippon Koei of Japan. It has a gross area of 760 hectares and a net irrigable area of 54 hectares. It is a project along the Volta River. Through a pumping system, water is lifted through a canal system to the paddy field. The main crop is rice and some okro.

Key findings and observations

- The project uses a combination of pumps and gravity flow system for water distribution from the Volta River. Three 38 kW asynchronous motors are used for water pumping to field.
- Before 2015, the pumping station relied solely on the grid for power for lifting water to the paddy field. A solar system has since been installed to power the pumps during the day by a Chinese company.
- The capacity of the solar system is 50 kW (200 solar modules with unit 250 W rating) without battery storage.
- The pumping station is managed and operated by GIDA. The Chinese company installed the solar system as part of their research into the viability of solar irrigation for the various irrigation schemes in Ghana.

Challenges

- A key challenge is developing a good business model to recoup investments.

Recommendations

- This solar system proves to be very viable for such irrigation schemes as water is mostly lifted for irrigation during the day, particularly in the dry season when the sun energy is abundant.
- A net metering scheme could be used to offset power consumed from the grid in order to cut out the idle time of the solar system.

➢ Integrated Water Management and Agricultural Development – Centre Pivot Irrigation (Northern Savannah Zone)

The Integrated Water Management and Agricultural Development (IWAD) Ghana limited was created in 2011 as a department under Wienco Ghana Ltd to lead the implementation of the

Sisili-Kulpawn Irrigation project at Yagaba in the Upper East Region of the country. The core mission of this project is to expand the commercial viable irrigation practices in the Sisili-Kulpawn basin through the delivery of high quality irrigation support, new technology development, knowledge transfer, promotion of water use efficiency, sustainability and secure farmer revenues for both small holder and nucleus estates.

Key findings

- IWAD has acquired 800 hectares of land (leased for over 50 years) for the project.
- The Sisili-Kulpawn irrigation project was started in 2014.
- There are four centre pivot irrigation systems installed, each covering an area of 65 hectares.
- 3 X 75 kW pumps is used to lift water from the Sisili-Kulpawn river to an 18000 m3 reservoir from whence a similar pump house is set to pump water to the centre pivots. A 300 kVA genset is used to power the systems because of the high cost of running on grid power.
- There are also five sprinkler irrigation systems developed over an area of 90 hectares.
- The crops cultivated on the farms include onion, sugar cane, pepper and tomatoes.
- An 80 W solar future pump has been acquired by the project manager for demonstration purposes. This pump is portable and can operate on small holder farms. It has the capacity to lift water from a borehole into an overhead tank for drip irrigation at the nursery. The company however seeks a similar but more efficient technology as it proves to be very economical for small scale irrigation.
- A four-acre land has been allotted for the installation of solar PV to connect to the grid possibly through a net metering scheme to reduce the running cost of the irrigations.

➢ Solar-Powered Water Purification and Irrigation Facility (Northern Savannah Zone)

NewEnergy has implemented a Solar-Powered Water Purification and Irrigation Facility at Nabogu in the Northern Region of Ghana. The facility was constructed with funding from the United States African Development Foundation (USADF), under the Power Africa Off-Grid Energy Programme. The facility is intended to provide clean water for 1000 inhabitants who rely on a tributary of the White Volta for their water needs. A very efficient purification technology called Advanced Multi-Stage Filtration and Reverse Osmosis is employed for water purification.

Key findings and observations

- The facility runs on a 5kW roof mounted solar panel powering 2 DC pumps and equipment for purification.
- 3kW is used to power a pump that supplies 120,000 litres of water daily and 2kW to power the water filtration system.
- The water drawn is stored in a tank for irrigating 3.5 acres of farmland and for filtration.
- The irrigation component is owned and managed by four farmers.
- Purified water has been tested to be free of bacteria and has a higher shelf life.
- Purified water is sold at 10 pesewas per 25 litres.
- The facility has been running since August 2015.
- The project was sponsored by USADF at a cost of USD 125,000, with USD 25,000 going

into the irrigation component and the remaining for the water purification system.

- The installation of the facility also came with a significant training component where the attendants were trained on the maintenance of the system.

Challenges

Maintenance cost of the purification system is high due to the periodic replacement of the reverse osmosis.

Lessons learnt and recommendations

- Replicating this system would be very beneficial in rural communities in Ghana where access to clean water at an affordable cost is a huge problem.
- It is relatively easier to develop a scheme or business model that would cater for the maintenance of the system.

➢ **BXC SOLAR PROJECT 20MW SOLAR PROJECT (coastal savannah zone)**

BXC Ghana Limited is a subsidiary of Beijing Xiao-Cheng Electronic Technology Stock Company Ltd. BXC has established the largest utility scale solar project in Ghana. The installed capacity is 20MW and it has been feeding power to the grid since 2015. The project BXC is located at Gomoa Onyadze on a 150-acre land. The facility has installed 40,480pieces of PVs.

B. *Source:* Can solar pumps unlock Ghana's irrigation potential? – By Solomie Gebrezgabher, Researcher – Economics, IWMI, and Mansoor Leh, Researcher – Spatial Hydrology, IWMI, July 2021

New IWMI research indicates over 2 million hectares potentially suitable for solar photovoltaic (PV) pumping – and proposes sustainable business models for capturing the solar market opportunity.

Across Africa, governments are promoting small-scale irrigation as a climate adaptation measure. In addition, rising incomes and changing dietary patterns among middle-income urban consumers are making production of high-value irrigated crops an attractive market opportunity for small farmers. But a lack of an energy source to pump water is preventing many farmers from cashing in on this opportunity.

In Ghana, most small-scale irrigators do not have access to a consistent supply of electricity. Those who do may find it too unreliable and expensive for irrigation. Petrol and diesel pumps, which have high fuel and maintenance costs, are also expensive for smallholders. Companies serving small-scale irrigators, who have traditionally been perceived as high risk, can be profitable if the right business models are applied. However, use of solar irrigation systems remains limited. New approaches are needed to expand farmers' access to solar pumps that are appropriate in cost and scale.

Mapping the suitability of solar irrigation

The study assessed the feasibility of smallholder solar irrigation by integrating elements of business planning and business modelling with agricultural land suitability mapping. Suitability mapping takes into account land use, topography, soil, water availability and market information to assess the potential of expanding solar irrigation. Consideration of water availability is particularly important, as expansion of solar PV pumps in areas with limited resources or storage can lead to excess groundwater pumping and aquifer depletion.

Overall, the assessment showed that areas with groundwater are most suitable for solar PV pumps. A combined analysis of surface water and groundwater sources up to 25 meters deep indicated that 2.3 million hectares could be suitable for solar PV pumping. The largest potentially suitable area was found to be in northern Ghana, which has long, dry summers and high irrigation demand.

The study also analysed the policy and regulatory environment, financing mechanisms and technology supply chain, all of which are crucial to create a robust market for solar pumps and related equipment.

Finally, the study developed and evaluated three possible business models that could address the high up-front costs of buying a pump. They are:

Business model 1*: Individual ownership with multiple-use services*

In this model, a farmer purchases a solar PV pump to irrigate his/her own farm, meet other needs such as livestock water, home gardening and domestic uses, and sells water to neighbours.

Despite the economic benefits of solar pumps for irrigation, the high initial investment is a major limiting factor. In Ghana, uptake of the technology currently relies on donor subsidies, which have limited potential to reach many farmers. For this model to be successful, financing schemes such as pay-as-you-own, that spread the costs of a pump over time need to be explored.

Business model 2*: Cost-sharing*

An alternative to individual ownership is a shared model, where a group of farmers jointly own a solar PV irrigation system. Group members share the costs and risks as well as the benefits. For the model to work, the group must be cohesive, with clear rules on water-sharing mechanisms, maintenance responsibility, financial management and conflict resolution.

Business model 3*: Solar irrigation service provider*

Under this model, the solar PV system is owned, operated and maintained by a supplier or other third party. With the help of low-cost loans, partial grants and other financial incentives, entrepreneurs own and operate solar PV systems that provide irrigation water services to farmers for a fee. Entrepreneurs then use the fees from water sales to repay the loan.

In addition, instead of promoting individual ownership of solar pumps that might be underused, setting up young entrepreneurial farmers as solar irrigation service providers could help create a competitive water market by offering farmers irrigation services at an affordable price.

The study shows that potential for solar PV irrigation pumps is substantial. Achieving this potential will require strengthening the policy environment, monitoring water abstraction and use, and making finance available at a reasonable cost along with complementary inputs such as fertilizer and improved seed. Moreover, the proposed business models require strong farm and business management coupled with good links to markets for produce. This underscores the need for a comprehensive approach that involves and benefits all stakeholders. If effectively implemented, the impact on farmers' productivity and economic resilience could be immense.

C. *Source:* https://rcees.uenr.edu.gh

GiZ and the Ministry of Energy (MoEn) are jointly implementing a project dubbed "GreenPeople's Energy", a proposed country measure of a global project commissioned by the German Federal Ministry of Economic Cooperation and Development (BMZ).

The 'Green People's Energy (PGE)' Project has an overall objective to improve conditions for supplying rural regions in selected African countries, including Ghana, with decentralized renewable energy. The project supports the adoption of modern energy services through the introduction of alternative and sustainable renewable energy and energy-efficient technologies with the participation of citizens and businesses. Among other areas, the project focuses on these three areas:

1. The promotion and further development of the capacities of skilled workers, mainly for solar-powered irrigation systems (SPIS). These workers include SPIS installers, trainers, project development professionals of financial institutions, and users of SPIS.
2. Access to decentralized renewable energy (RE) system for enterprises and social institutions (solar PV systems for income-generating activities; school and health facilities) with incentives; and
3. The promotion of investment in decentralized RE systems (mobilization of financing by banks and crowdfunding companies).

Under this project, RCEES-UENR with technical support from Practica Foundation, Netherlands, is charged with the provision of competence-based training for installers, extension staff, and credit officers in the middle and southern belts of Ghana. This will ultimately reduce system downtime through enhanced technical skills and knowhow.

D. *Source:* Solar-powered irrigation systems for smallholder farmers in Ghana, SNV, February 2021 – Webinar

On 5 February 2021, SNV's Boosting Green Employment and Enterprise Opportunities in Ghana (GrEEn) hosted a webinar to commission a study to assess the opportunities and barriers smallholder farmers face in accessing Solar-Powered Irrigation Systems (SPISs) in Ghana.

About the GrEEn project

The Boosting Green Employment and Enterprise Opportunities in Ghana (GrEEn) project is a four-year action from the European Union, the Embassy of the Kingdom of the Netherlands in Ghana, SNV Netherlands Development Organisation and the United Nations Capital Development Fund (UNCDF). The project aims at creating greater economic and employment opportunities for youth, women and returning migrants by promoting and supporting sustainable, green businesses in two selected regions in Ghana: Ashanti and Western.

GrEEn is implemented under the European Union Emergency Trust Fund (EUTF) for Africa with a total contribution of EUR 20,600,000.

About the webinar

Solar-Powered Irrigation Systems (SPIS) have the potential to transform agricultural productivity, create jobs, improve livelihoods and provide resilience against the potential impacts of climate change. Evidence from early systems installed in Ghana and those from elsewhere have demonstrated that the benefits are immense and have led to greater yields, increased income for farmers, and a generally improved food security situation. The application of SPIS also launches the agricultural sector onto a greener pathway, by displacing options such as diesel/petrol pumps and in some instances, grid-powered irrigation pumps which tend to be more polluting.

In Ghana, solar-powered irrigation remains excessively expensive, far beyond the means of smallholder farmers. There is also limited demand due to lack of awareness of clean energy technology and its high cost. Within the context of the Boosting Green Employment and Enterprise Opportunities in Ghana (GrEEn) project, this study was undertaken to deepen the understanding of the barriers that militate against the uptake of SPIS and to provide insights into how these challenges may be addressed.

Objectives of the webinar

- Present the findings of the study to key stakeholders for feedback and validation.
- Discuss and exchange key lessons from the study with service providers and policymakers to improve service provision and access to SPISs for smallholder farmers.
- Introduce the GrEEn project to a broad range of relevant stakeholders and raise awareness on Ghana's green and circular economy.

Target audience

- Public sector/government institutions at the national and sub-national level
- Suppliers and installers of (solar-powered) irrigation facilities
- Financial service providers
- Incubation and acceleration hubs
- Farmer-based organisations and individual farmers
- Respondents/contributors to the study
- Business membership organisations
- Technical training service providers
- Individual/freelance consultants, coaches and mentors.

4.2.2 Agriculture and Irrigation

Agricultural Consideration:

The favourable climatic conditions in the past and the geo-physical characteristics of the coastal and northern savannah zones enable agriculture as the mainstay of the zones' economies, although predominantly engaged in subsistence crop farming (maize, yam, plantain, cassava, cocoyam, rice, grain legume, vegetables such as pepper, okra, garden eggs, etc., and tree crops; cashew, orange, banana and oil palm), with only a small proportion engaged in commercial agro-industries and mixed farming (Internet).

Agricultural productivity tends to be lower during insufficient rainfall and high temperatures, and this is worsened by poor farming practices, limited use of inputs and improved technologies (e.g., seed varieties, fertilisers, pesticides, and irrigation), small farm sizes, lack of knowledge and poor extension support services, limited access to agricultural credit and mechanization services, inadequate farmer-based organizations, and markets. In the past, the rainfall pattern allowed for two cropping seasons in the southern sector of the country, which includes the coastal savannah, depending on the crop duration, but with the early rains occasionally failing entirely and unexpectedly and most rain falling after the second quarter, until August, the climatic conditions have limited cropping to mainly rain-fed, single crops per year. Short duration crops, such as green maize, can be grown early in the year, sometimes with supplemental irrigation, but crops like yam, cassava okra and pepper can only be grown once without irrigation (GIDA NSSIP, 1991 and GCAP, 2016). Other external factors are also noted to contribute to low crop yields and production, including floods from Volta Lake, illegal mining of sand and gold, bush fires, alien herdsmen activities and the poor road network.

Agricultural development plans for irrigation schemes have been articulated in various GIDA project reports, considering factors such as crop selection, agricultural support services, sustainable market access, management of cattle herder activities and establishment of Water User Associations (as promulgated by GIDA LI 2230).

Irrigation Practices:

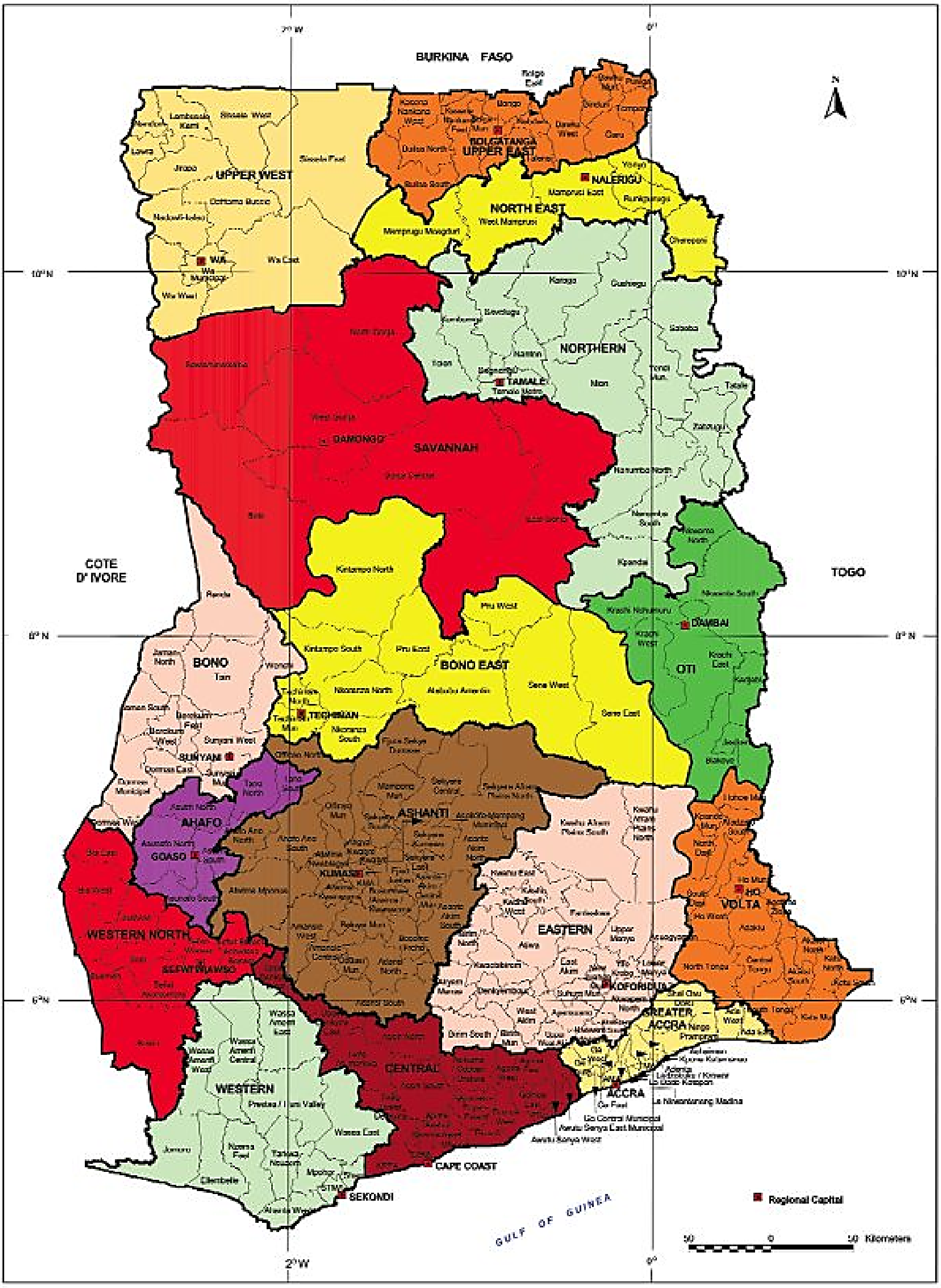
The Ghana Irrigation Development Authority (GIDA) initially managed formal irrigation projects in Ghana. However, a change occurred with the introduction of Irrigation Farmers Cooperatives (IFCo-ops) that began co-managing these projects. Currently, GIDA is forming Water Users Associations (WUAs) for all irrigation projects under Legislative Instrument (L.I.) 2230, which was passed in May 2016. According to the L.I., farmers on public irrigation schemes are required to form Water User Associations under the supervision of GIDA. The purpose of a WUA is to take responsibility for the operation, maintenance, and management of the irrigation infrastructure, as well as ensuring the efficient distribution of water to members within a designated service area.

Under the composition guidelines outlined in L.I. 2230, each Water Users Association is to be composed of 80% males and 20% females. This gender distribution aims to promote gender equality and inclusivity in the management of irrigation projects. GIDA's policy is to gradually rehabilitate the irrigation schemes and eventually transfer the management responsibilities to the farmer-based organizations, such as the Water Users Associations. This approach aims to empower farmers and ensure their active participation in the management of irrigation projects.

Small-scale, informal irrigators use various systems, predominantly along the fringes of Volta Lake, pumping water to irrigate vegetables, like okra, cabbage, peppers and rice; some have permanent structures, and it is likely this informal irrigation sector covers a larger area than the formal schemes (Afram Plains Agricultural Development Project, Appraisal Report, 2006). These irrigators mostly use mobile petrol/diesel pumps with high operating costs due to the cost of fuel and breakdown maintenance.

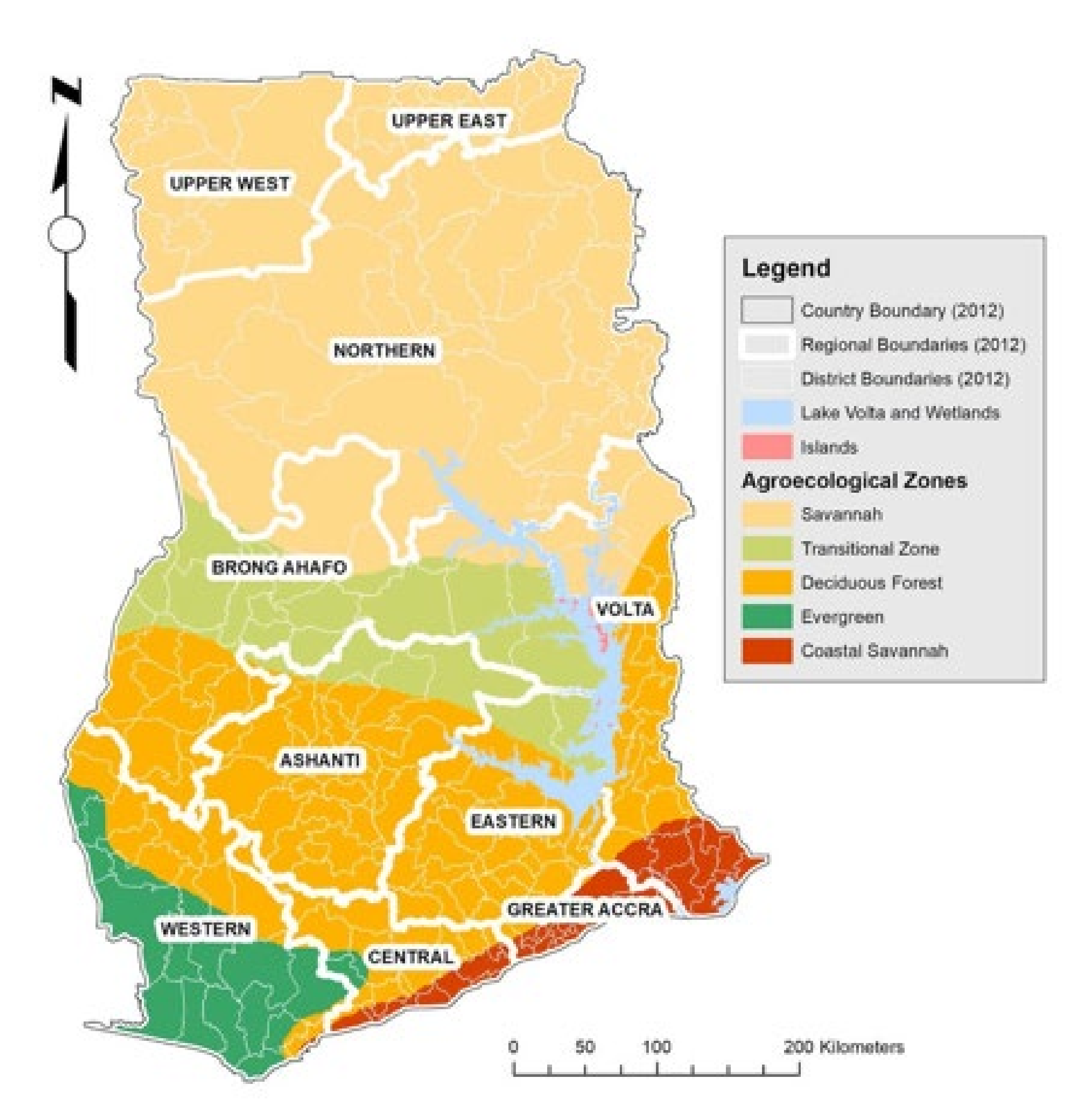
4.2.3 Maps

Below are some relevant maps of Ghana showing updated Regions, Agro-Ecological zones defining the northern and coastal savannahs, and Soils suitability for crops production.



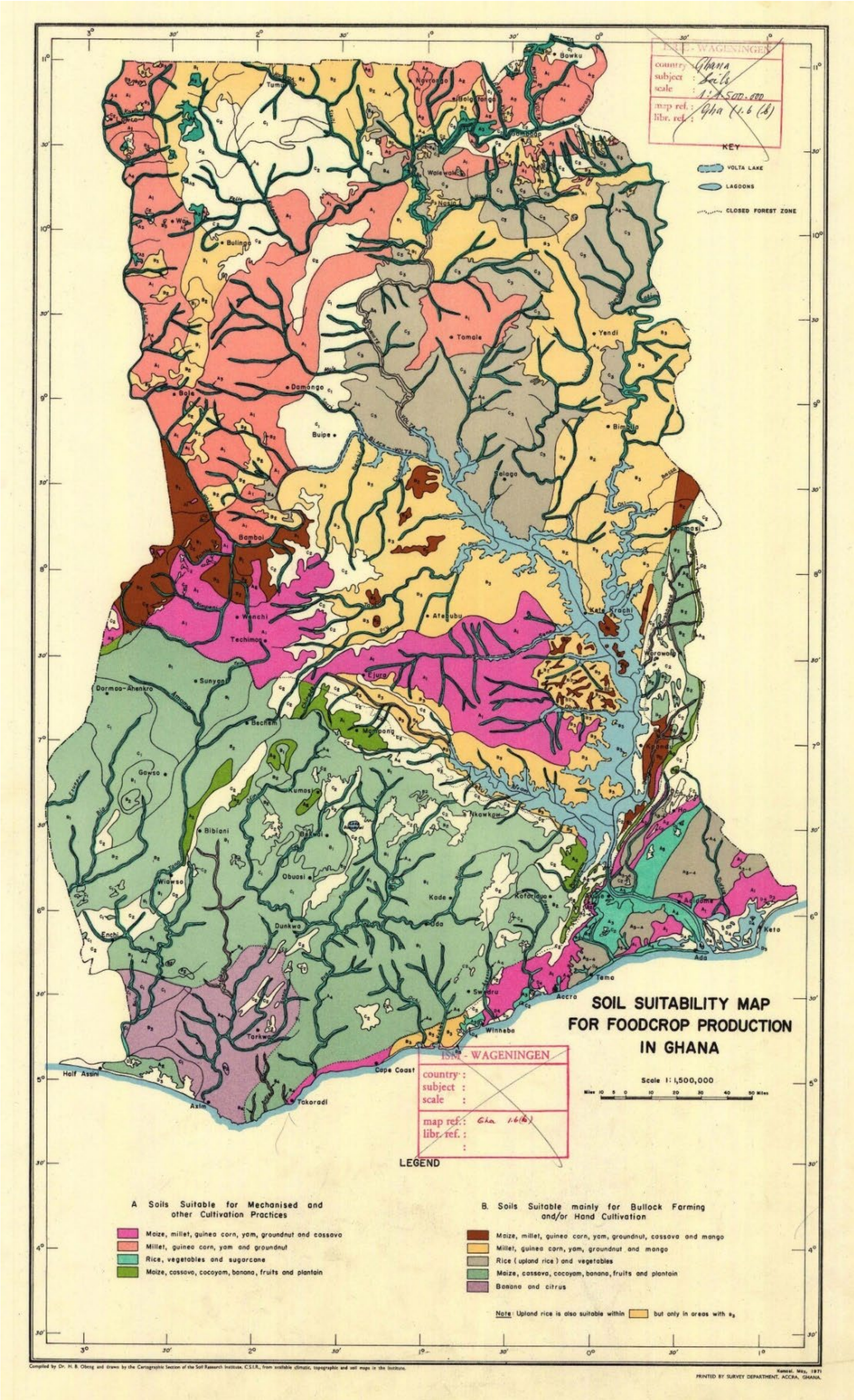
Source: Ghana Statistical Service, Geographical Information Systems (GIS)Section

Figure 1 - Regional Map of Ghana



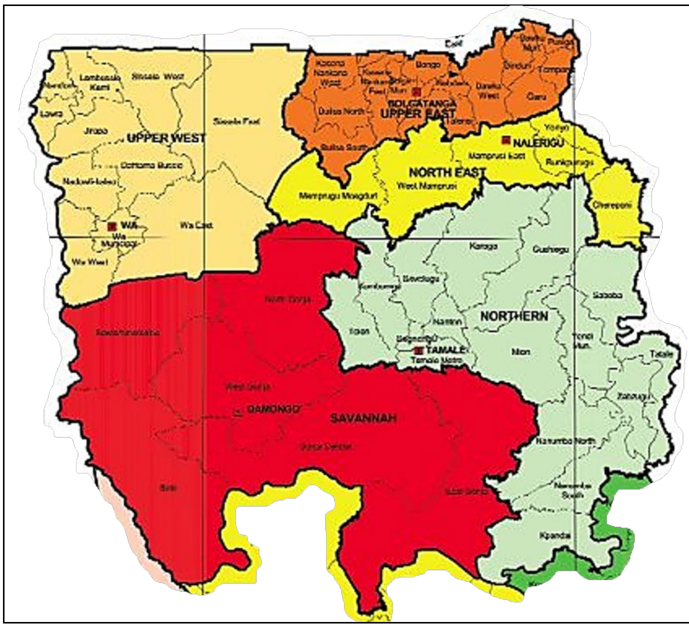
Source: Internet

Figure 2 - Agro-Ecological Zones of Ghana



Source: Internet

Figure 3 - Soil Suitability Map for Foodcrop Production in Ghana



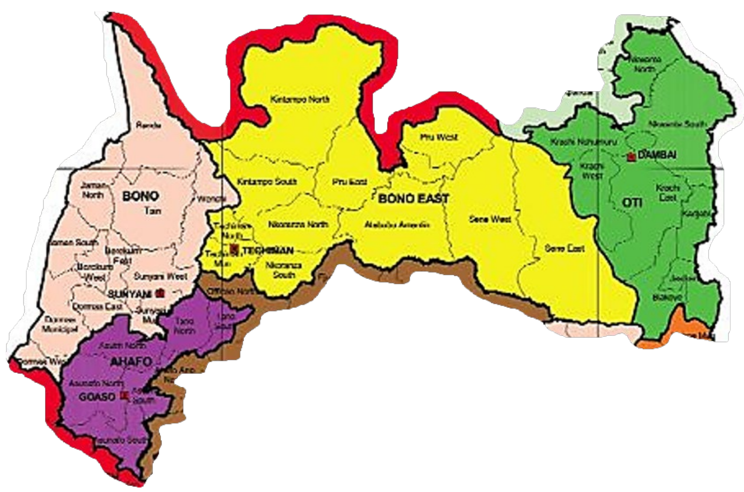
Crops cultivated in Northern Savannah Zone:

- Millet
- Guinea corn
- Maize
- Yam
- Groundnut
- Rice (paddy and upland)
- Vegetables

Irrigation practices:

- Fuel engine motorised pumps + sprinkler or furrow or basin or border irrigation, pumping from rivers, streams, or ponds
- Gravity dams and dugouts

Figure 4 - Typical Crops and Irrigation Practices in the Northern Savannah



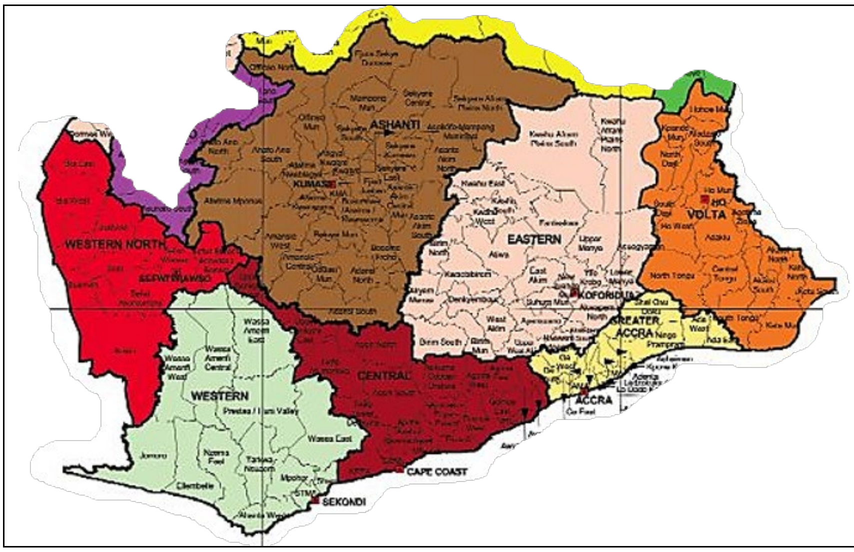
Crops grown in the Transition Zone:

- Maize
- Millet
- Guinea corn
- Yam
- Groundnut
- Cassava
- Mango
- Cashew

Irrigation practices:

Fuel engine motorised pumps + sprinkler or furrow or basin or border irrigation, pumping from rivers, streams, or ponds

Figure 5 - Typical Crops and Irrigation Practices in the Transition Zone



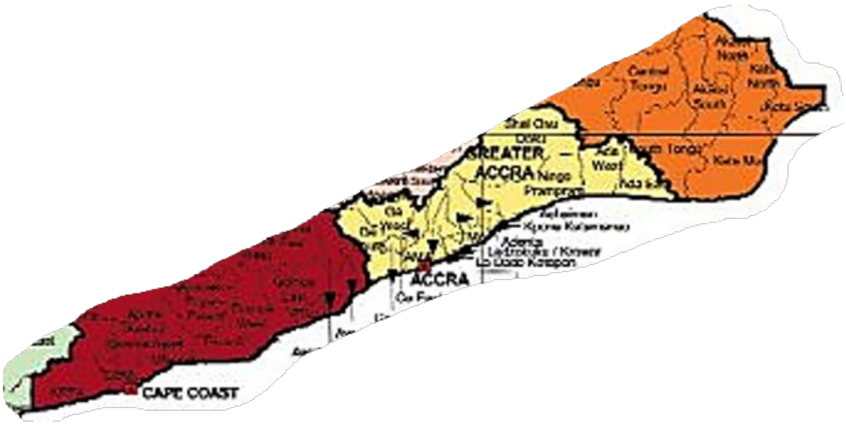
Crops cultivated in Deciduous and Evergreen Forest Zones:

- Maize
- Cassava
- Cocoyam
- Banana
- Plantain
- Fruits

Irrigation practices:

Fuel engine motorised pumps + sprinkler or furrow or basin or border irrigation, pumping from rivers, streams, or ponds

Figure 6 - Typical Crops and Irrigation Practices in the Deciduous and Evergreen Forest Zones



Crops cultivated in Coastal Savannah Zone:

- Maize
- Millet
- Guinea corn
- Yam
- Groundnut
- Cassava
- Mango
- Cashew
- Rice (paddy and upland)
- Vegetables
- Sugarcane

Irrigation practices:

- Fuel engine motorised pumps + sprinkler or furrow or basin or border irrigation, pumping from rivers, streams, or ponds
- Groundwater pumping with electric pumps for irrigation
- Gravity dams and dugouts

Figure 7 - Typical Crops and Irrigation Practices in the Coastal Savannah Zone

4.3 Stakeholder Engagement on SPIS

The Consultant carried out interviews with Stakeholders, as listed in Table 2 below. Minutes of meetings held with them are attached as Appendix F.

Table 2 - Stakeholder Engagement List

S/N	Stakeholder	Representatives(s) Met	Date	Key Issues Discussed
1	EPA (Environmental Protection Agency)	Dr. Antwi-Boasiako Amoah; Joseph Baffoe (Physical)	22 Nov 2022	• Key Stakeholders
2	Dizengoff Ghana Limited	Janus Van Der Westhuizen; Samuel Abbey (Physical)	23 Nov 2022	• Types of irrigation equipment sold • Projects delivered to smallholder farmers
3	GSA (Ghana Standards Authority)	Francis Akpaloo (Physical)	23 Nov 2022	• Standardisation of SPIS equipment
4	GIDA (Ghana Irrigation Development Authority	Richard Oppong Boateng (Physical)	24 Nov 2022	• Experience of GIDA in SPIS • Technical collaboration b/n GIDA and CARES
5	UENR (University of Energy & Natural Resources)	Prof Eric A. Ofosu (Physical)	24 Nov 2022	• Experience of UENR in SPIS • Technical collaboration b/n UENR and CARES
6	Dream Renewables	Barnaby; Samuel Yeboah (Physical)	17 Jan 2023	• Experience of DR in provision of solar power technology

S/N	Stakeholder	Representatives(s) Met	Date	Key Issues Discussed
7	GiZ (German Development Agency)	Rafael Wiese; Frank Lamptey (Virtual)	25 Jan 2023	• Green People´s Energy Project: • RBF (result-based financing) scheme - supporting installation of solar powered irrigation • Constraints in implementation: • Inflation • Sustainability of systems – due to poor maintenance
8	RDF (Rural Development Fund)	Emmanuel Sackey; Effie Appiah; Angela Klufio (Virtual)	26 Jan 2023	• Interest in investing in use of renewable energy in agricultural production, like solar powered irrigation • Financing farmers through the 'village savings and loans associations' (VSLA Concept); targeting women in agriculture in the northern sector of Ghana where water is scarce for farming
9	ADB (Agricultural Development Bank)	Lawrence Denkyi-Ansong; Edward Babalola; Kofi Nti Otoo; Samuel Arko (Virtual)	27 Jan 2023	• Outgrower (Smallholders – loan default, scattered nature of farms, etc. as challenges) • Ingrower system preferred (Technical operator with contiguous farms – allocates portions of farms to farmers) • MOWAC/Japanese funded project across Ghana – considered women in agriculture

Summary of the key issues:

- Constraints facing smallholders in the face of climate change:
    - Water storage facilities such as dams and dugouts that can provide enough water needs for dry season farming require high initial capital. High agricultural production require adequate water resources to meet solar powered irrigation system demands.
    - High fuel and electricity costs result in high operational costs in the use of diesel/petrol/electrical pumps to irrigate crops.
    - High machine hiring and/or maintenance costs to construct bunds for water management.
    - Scattered smallholder farms which discourage clustering of farmers to own a common solar pump.
    - Climate change impacts of increase in temperatures, shorter wet seasons, increase in number of dry days, heatwaves and evapotranspiration, will lead to increased risk of drought, and increase in rainfall intensity will result in risks of flooding and reduced crop production.
- Farmers adaptation to climate change:
    - Formation of cooperative groups, like the VSLA, to pool resources in acquiring loans and timely farm inputs.
    - Clustering to acquire solar pump and irrigation equipment.
- Forms of SPIS intervention:
    - Government assistance in provision of boreholes for groundwater exploitation to

supplement surface water availability.

- Lower lending rates to smallholder farmers by financial institutions.
- Subsidised cost of climate smart irrigation equipment for a smallholder farmer to enable farmers purchase PV panels, solar pumps and tanks.

4.4 End user / Smallholder Needs to adapt to use of SPIS

Table 3 below lists key points noted on farmers' present skills and knowledge in irrigation, and requirements to adapt to SPIS.

Table 3 - Smallholder farmer skills, knowledge and requirements

S/N	Traditional Skills & Knowledge in Irrigation	Requirements to Adapt to SPIS	Remarks
Northern Savannah Zone:			
1	**Natural water resources** include: – Rainfall, and – Rivers; the White Volta and Black Volta being the major rivers	• Existing natural water resources • Drilling of boreholes	Water extraction permit required
2	**Water storage facilities** prevalent include: – Dugouts, and – Gravity dams	• Existing facilities • Tank (e.g., 10,000 litres capacity Polytank)	Use of existing facilities require clustering of smallholder farmers, while individuals can own tanks
3	**Facilities to lift water** from lower to higher elevations include use of: – Diesel or petrol pumps, and – Electric pumps using electrical energy from the national grid	• PV panels • Solar pumps, complete with accessories (surface-mounted and submersible)	Cost of solar pumps higher, but with minimal operational cost
4	**Water conveyance methods** for irrigation mainly include: – Canals, and – Pipes	• Existing conveyance methods	
5	**Irrigation methods** are predominantly: – Flooding (surface) – Basin – Furrow, and – Border strip	• Existing irrigation methods • Drip	Drip irrigation system can include fertigation
Coastal Savannah Zone:			
1	**Natural water resources** include: – Rainfall – Groundwater – Rivers – Volta, Tordzie, Densu and Ayensu being the major rivers, and – Lagoons – Keta lagoon the largest	• Existing natural water resources • Drilling of boreholes	Water extraction permit required
2	**Water storage facilities** prevalent include: – Dugouts – Gravity dams, and – Tanks	• Existing facilities • Tank (e.g., 10,000 litres capacity Polytank)	Use of existing facilities require clustering of smallholder farmers, while individuals can own tanks

S/N	Traditional Skills & Knowledge in Irrigation	Requirements to Adapt to SPIS	Remarks
3	**Facilities to lift water** from lower to higher elevations include use of: – Diesel or petrol pumps, and – Electric pumps using electrical energy from the national grid	• PV panels • Solar pumps, complete with accessories (surface-mounted and submersible)	Cost of solar pumps higher, but with minimal operational cost
4	**Water conveyance methods** for irrigation mainly include: – Canals, and – Pipes	• Existing conveyance methods	
5	**Irrigation methods** are predominantly: – Flooding (surface) – Basin – Furrow – Border strip, and – Sprinkler	• Existing irrigation methods • Drip	Drip irrigation system can include fertigation
Transition and Deciduous/Evergreen Forest Zones:			
1	**Nature-based water resources** include: – Rainfall – Groundwater – Rivers – Volta, Ankobra, Pra and Tano being the major rivers, and – Lakes – Bosomtwi the largest	• Existing natural water resources • Drilling of boreholes	Water extraction permit required
2	**Water storage facilities** include: – Weirs – Dugouts, and – Tanks	• Existing facilities • Tank (e.g., 10,000 litres capacity Polytank)	Use of existing facilities require clustering of smallholder farmers, while individuals can own tanks
3	**Facilities to lift water** from lower to higher elevations include use of: – Diesel or petrol pumps, and – Electric pumps using electrical energy from the national grid	• PV panels • Solar pumps, complete with accessories (surface-mounted and submersible)	Cost of solar pumps higher, but with minimal operational cost
4	**Water conveyance methods** for irrigation mainly include: • Canals, and • Pipes	• Existing conveyance methods	
5	**Irrigation methods** are predominantly: – Water management (inland valleys) – Flooding (surface) – Basin – Furrow – Border strip, and – Sprinkler	• Existing irrigation methods • Drip	Drip irrigation system can include fertigation

5 STAKEHOLDER WORKSHOP

The Stakeholder Workshop was held on 1st February 2023. Minutes of the workshop meeting is attached as Appendix G, and the presentation as Appendix H.

Summary of key actions/decisions from minutes:

- High energy costs are affecting farmers on the pumped schemes.
- Engage organisations and projects that had previously installed solar powered irrigation pumps so as to learn from their experiences.
- Smallholder farmers need to form groups to enable them own and operate the SPIS.
- Farmers be given training to calculate crop water requirements in order to efficiently utilise the water resources available to them.
- Standardisation of locally manufactured as well as imported items are necessary.
- SPIS project must explore IFAD funding for smallholder farmers through GOG.
- Nucleus farmer training smallholder farmers, taking care of financing, and supplying them with the necessary inputs, including irrigation water, and in turn buy from the farmers, as the way forward.
- Initiatives such as the Ghana Smallholder E-Commerce Programme started by World Food Programme and MOFA must be studied for marketing of agricultural produce.
- Smallholder farmers forming groups to qualify for loans from the banks is important.
- Give inputs (cashless loans) directly to smallholders at government subsidized prices at the right time.
- The Outgrower Value Chain Fund currently being rolled out should be assessed and structured for SPIS.
- Land tenure issues must be resolved for farmers.

6 GUIDE OF MOST APPROPRIATE SOLAR IRRIGATION TECHNOLOGY SYSTEMS

The SPIS comprises two main components of infrastructure; the Irrigation System and the Electrical System. Different irrigation systems are more suitable to some situations than others and the choice will have an impact upon the overall irrigation efficiency. Irrigation infrastructure refers to the manner in which water is supplied and distributed to the fields (Conveyance) and how it is then applied to the crops (Application), each with particular infrastructure requirements. The choice of conveyance and application method depends on many factors, including the soil type, climate, crop and its physiological nature, the source and head of available water resources, land terrain, etc. The objective of selecting a particular irrigation system is to minimise water use and maximise yield. Similarly the Electrical System of PV panels, support structures, control electronics and pumps have a number of options that fit the particular situation and budget.

This Chapter considers which of these choices are most suitable for irrigation in different conditions in southern and northern regions of Ghana, and explores the options for solar energy generation, pumping and control that will interact with these systems to provide the farmers with a sustainable and effective scheme.

6.1 Electrical Systems (PV and Pumping Configurations)

6.1.1 Direct Pumping / Standalone System

In direct pumping, the system includes the PV panels, a pump controller that can have DC or AC motor, potentially a water storage elevated tank and the irrigation system (flood, sprinkler, micro-irrigation). Usually a maximum power point tracking (MPPT) device is used to improve the efficiency of the system. This system leads to variable motor speed and pump volume during the hours of sunlight, especially during cloud interfaces. The solar irrigation controller uses volume meter, instead of timer. The advantages of this configuration are that it is relatively simple and that it is adaptable to all sizes and irrigation methods. Additionally, fertigation can also be easily integrated, as well as other water treatments or chemical cleanings. It is the most widely used configuration, and water to wire efficiencies of more than 50% can be achieved with efficient systems. Usage can easily be monitored and charged to the farmer on a volume basis.

The schematic below is a simplified diagram of how this configuration could look like.

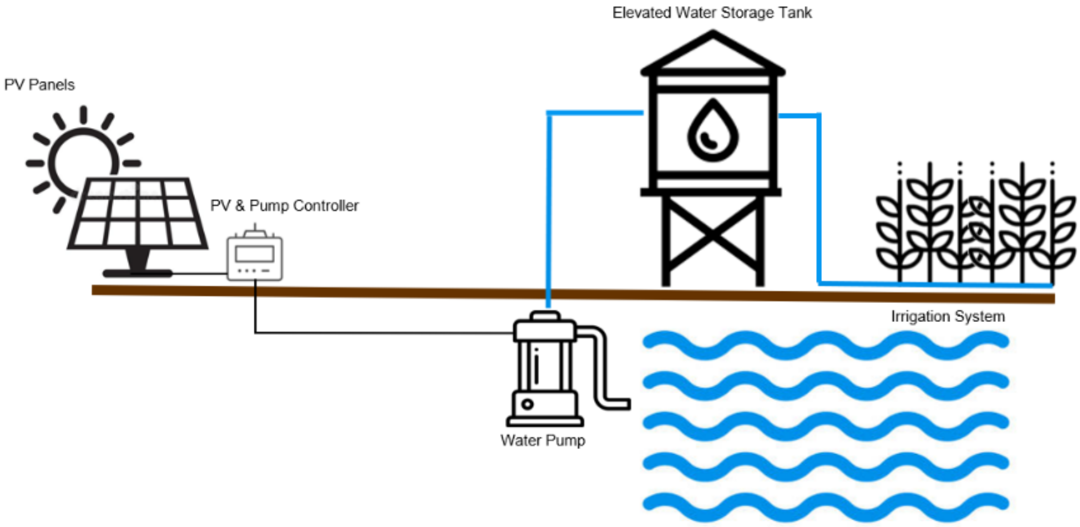


Figure 8 - Schematic of Direct Pumping Configuration

6.1.2 Multi-Use System

The Multi-Use System is essentially a Direct Pumping configuration, with the difference that when no pumping is required, excess energy can be used for other productive uses such as grinding, sawing, food processing, cooling, etc. It entails a higher level of complexity than simple direct pumping, and the controller is usually optimized for the pumping system. The energy needs of any other use must follow the pump, so the motors should have the same voltage as the pump motor and the same AC/DC configuration. For this system, use of batteries is only recommended with separate systems.

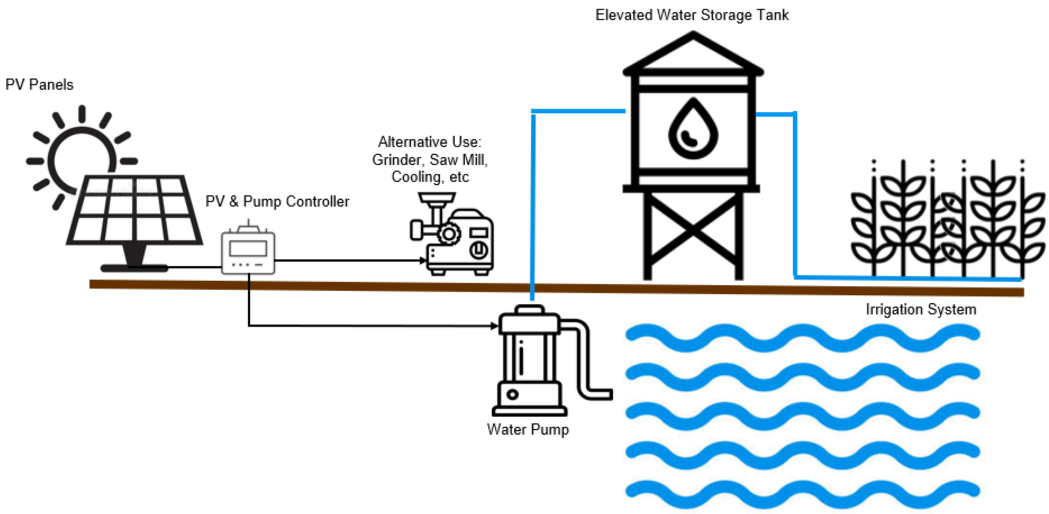


Figure 9 - Schematic of Multi-Use Configuration

6.1.3 Mini Grid

In this configuration, PV panels supply the power to various different uses, such as pumping, but also solar home systems, etc. It is a more complex solution, but technological solutions are being developed. Different uses can be accounted for, but important compromises on efficiency are necessary. A key consideration in Mini-Grid based pumping systems is the distance of the pump from the powerhouse. Within a low voltage (LV) network, it is recommended that the electrical load (pump in this case) is located no more than 1-1.5 km away from the powerhouse otherwise the voltage and power losses in the network are too high. In case the pump is located much further away, an alternative could be to supply power via a medium voltage (MV) network but this would come at higher distribution network costs and needs to be compared for financial viability of the entire system.

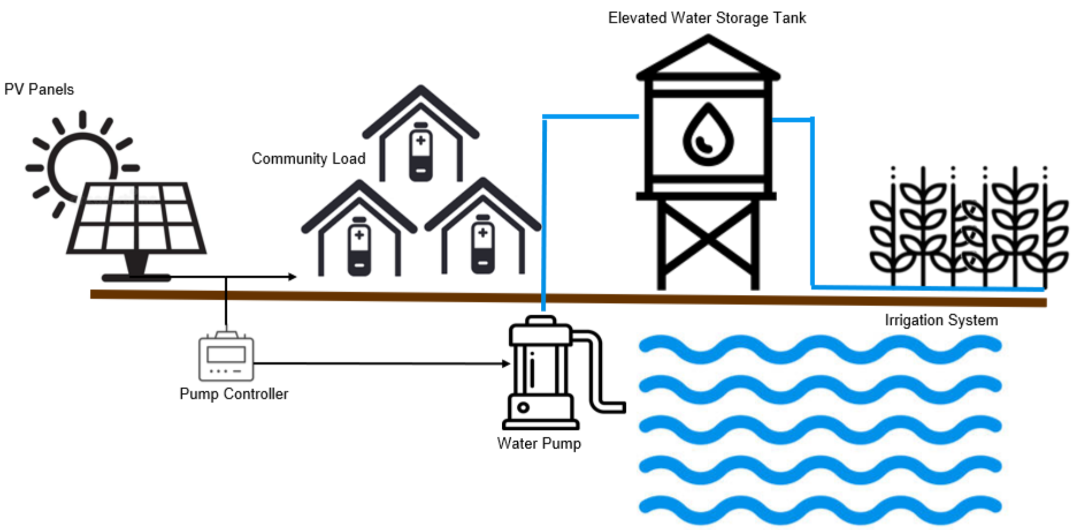


Figure *10* - Schematic of Mini Grid Configuration

6.1.4 Hybrid System

Another possible configuration are hybrid systems where the pump can be supplied electricity from the PV panels or from the grid directly. This would require use of special purpose hybrid inverters that allow switching of source power supply either based on time of the day or other pre-determined switching criteria (e.g., PV first, voltage stability, etc.). The switching can also be controlled manually in simpler systems but this would require an operator to physically approach the inverter and activate the switch. Hybrid systems are mostly suitable in cases where the pump is located close to the electrical grid and a fairly stable grid supply can be expected. If the grid supply is very poor (either in terms of hours of availability or power quality), the system would anyway need to run primarily on the PV panel's power generation. However, if grid supply is reliable, then significant benefits can be derived as a much smaller PV system can be used, battery requirements can be minimized and the pump can run even beyond sun-shine hours. Increasing the flexibility for the farmers and improving crop yields.

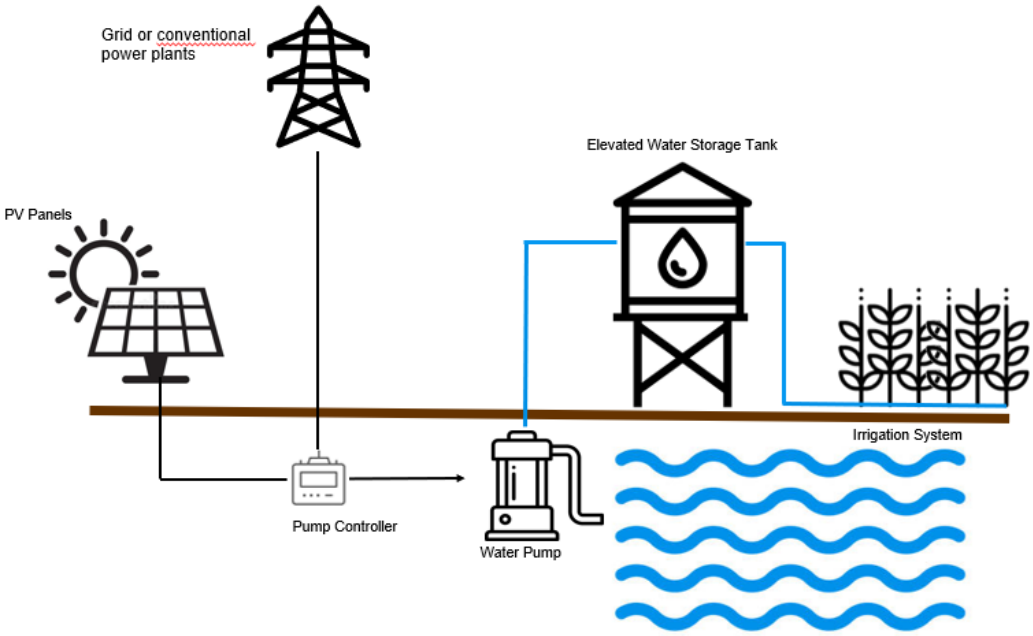


Figure 11 - Schematic of Hybrid Configuration

The advantages and disadvantages of the different PV and pumping infrastructure options are summarised in Table 4.

Table 4 - Advantages and Disadvantages of Potential Electrical System Configurations

Type of system	Advantages	Disadvantages
Direct pumping / Standalone	- Low price point - Easy installation and maintenance	- No energy storage - No energy in times of no sunshine
Multi-use system	- Enables other productive uses	- Higher complex system - More expensive initial investment
Mini grid	- Includes battery storage for a low additional price - Enables other productive uses	- More expensive initial investment - More difficult in maintenance - Control of the excess use of the battery outside sunshine hours
Hybrid System	- Bridging the time with no sunshine - Minimum battery requirements	- Access to the main grid - Main grid stability - Price of electricity from the grid

Suggested system type (by application):

After analysing the available technological solutions and barriers to uptake SPIS by smallholder farmers in Ghana, it is recommended to consider only the **direct pumping / standalone systems** because of their simplicity and low costs. These systems would respond well to issues of difficult financing of the investment and insufficient knowledge on operation and maintenance of the systems. Accordingly, water storage options and water application methods of standalone solar pump irrigation systems are considered going forward.

6.2 Pumping Systems

In the solar pumping irrigation system, a pump is powered by solar panels and used to extract water from an underground or a surface source. Various types of pumps are available and include surface-mounted and submersible pumps. Advantages of these pumps, in comparison to those powered by fossil fuels, is in lower operational cost and reduced negative environmental impact.

6.2.1 Surface-mounted pumps

Surface-mounted pumps are generally used when the source of water for irrigation is a lake, pond, river, dugout or a dam. They are relatively easy to instal and maintain as well as less costly than submersible pumps. Surface pumps are easy to access, which makes maintenance simple but also makes the pump sensitive to harsh weather conditions, theft, and vandalism.

6.2.2 Submersible pumps

Submersible pumps are the best choice with water sources deep underground, since they can lift water from greater depths. These pumps are suitable for larger irrigation areas since they can deliver a high flow of water. In comparison to the surface-mounted pumps, these pumps are generally less noisy and more efficient since there is less friction loss. Challenges that arise when using these pumps are higher investment and operational costs and issues with accessibility when there is a need for maintenance. A level of caution has to be exercised with using these pumps as they can take in soil if the well dries out.

Suggested pump solution

Given the fact that small-holder farmers in Ghana use different sources of water for irrigation, both pump types are recommended. More specifically, the surface-mounted pumps are generally more suitable for usage in northern regions of Ghana where water is sourced from rivers, lakes and dams. In the coastal regions of Ghana, where water is sourced from ground dug wells, usage of submersible pumps is more suited.

6.3 Storage Systems

A water storage tank allows farmers to irrigate at different times, such as at night or when there is no sunshine, ensuring a constant water supply. The water is pumped from the water source during sunshine hours and stored in a tank. The type and the capacity of a tank vary depending on water demand and risk of drought periods. The installation of a tank increases the capital and operational costs of a SPIS, but not significantly. It is an essential component of the system, especially in rural areas with unreliable electricity supply. Three options for water storage tanks are presented below:

6.3.1 Elevated tank

The most affordable and easy to install option of storage is an elevated tank. The tank is filled with water during the sunshine period and the stored potential energy can be used to supply water when needed by using gravity. These kinds of water storage tanks are suitable for areas where lack of available space is an issue. Irrigation directly from an elevated water tank only provides low pressure supply and is not suitable for overhead irrigation but only for surface or drip water application methods. However, this water pressure provides improved water distribution. A disadvantage of an elevated tank comes with its sensitivity to extreme weather conditions and installation costs.

6.3.2 Portable tank

The main advantage of a portable water storage tank is in its flexibility and possibility to move it easily to different locations, which makes it useful for large farming areas. The tank comes with low to no installation costs as no construction is needed. These tanks provide only a limited storage capacity since they are made of light plastic materials and of smaller size, while at the same time raising water quality concerns when not maintained properly or made out of poor materials.

6.3.3 Civil tank

A civil water storage tank is usually used in civil engineering projects and are known for their durability, being highly resistant to extreme weather conditions. These tanks can be installed above or under the ground level. The complexity of installation and maintenance, together with a relatively high costs, makes this water storage solution unfavourable for rural context and smallholder farming.

Suggested water storage option

Given the conditions in Ghana, it is recommended that solar irrigation systems include an elevated tank. This type of tank comes at a relatively low price and much higher quality than the portable tank. An elevated tank can provide enough water supply for small farms and has an advantage of sufficient water pressure for irrigation.

6.4 Irrigation Systems

6.4.1 Conveyance Infrastructure

There are two main forms of supply and distribution infrastructure used in irrigation; Gravity-fed open channels or Pressurised pipes (closed conduits).

Gravity-fed open channels (canals) can either be lined or unlined, depending on soil conditions and the need to minimise seepage losses, or to improve the hydraulic characteristics of the cross-section and profile to carry the required flow, or to a lesser extent to minimise maintenance operations[1]. They are generally used wherever the water source is higher than the point of delivery, so the water flows naturally under gravity. In some situations, gravity channels may be covered or run in closed culverts or pipelines to minimise evaporation losses or to negotiate difficult features in the terrain. Open channels can convey large volumes of water over significant distances for minimal capital and almost zero running costs and are most usually combined with surface/flood methods of irrigation.

[1] Cost is a major factor in deciding whether to line open channels.

Pressurised pipes are used when the water source is lower than the point of delivery and pumps are required to raise it to the level of the field and/or provide a residual pressure at the field to be applied via overhead methods more suited for smaller volumes. Pressurised pipes are more expensive both in terms of capital and recurrent operating costs, they are suited to smaller volumes of water and should be sized to optimise the capital cost of the pipe material, which rises with increasing diameters, and the pump size and recurrent energy costs, which falls with increasing diameters.

Hybrid systems combine the benefits of open channels with pipelines in different ways, either raising water through a short supply pipeline, from where it is conveyed by gravity in an open channel to the fields, or supplying water via canal to the fields, but at level below ground, such that it has to be pumped to the fields.

6.4.2 Application Methods

The various methods of irrigation can be categorised as surface/flood, overhead/sprinkler, drip and sub-surface irrigation.

Surface/Flood irrigation

In the surface/flood method of irrigation, water flows by gravity either through furrows, basins or borders that are integral to the layout of the fields and the type of crop. This method is the simplest system that has been used for many years by farmers, but also water losses in conveyance and deep percolation are usually high, with the efficiency of irrigation only 40-50% at field level. It is usually employed where water is in abundance and inexpensive, and where the fields are well levelled. There are limited controls over the rate of flow or distribution in the field and the wastage of water can be high; such uncontrolled or wild flooding is frequently the method used in lowland river valleys for rice crop. Efficiency can be improved by lining the field canals and by improved levelling of the field, and by the following adaptations:

Check basin method – in this method, the field is divided into number of plots and levelled. It is also known as bed method. This method is most suitable for levelled fields with low permeability and where water is not a constraint. In this method, water doesn't stand at a uniform depth over the entire check resulting in uneven distribution of water within the plot. Normally, the field channels and bunds occupy about 30% of the area.

Basin method – it is a modified check method adopted particularly in orchards. Basin is formed for each plant or for a number of plants and connected by ditches. Basins allow more water to be impounded as the root zone of orchard crops is very deep. The size of the basin is adjusted to soil permeability and size of streams. Each basin is flooded in turn and water is allowed to soak into the soil. Basin method has the advantage that unskilled labour can be used as there is no danger of erosion. However, it has the disadvantage of high labour requirement and restriction in the use of modern machinery in the field.

Border strip method - in this method, the field is divided into narrow strips by small parallel ridges on the sides. The border strip is formed by levelling and grading the land between the ridges. Each border is irrigated by allowing the water to flow from the upper end of the border in a thin sheet. Water moves towards the lower end at non-erosive velocities covering the entire width of the border. This method can be used on all types of soil but it is best suited to soils having moderately low to moderately high infiltration rates. However, it is not suited to coarse sandy soils to clay type of soils.

Furrow methods - in furrow irrigation, water is applied in small streams between the rows of the crops, grown on ridges or furrow sides. The size and shape of the furrows depends upon the soil, crop spacing and the equipment used for the furrow forming. Water is applied into a small furrow and infiltrates into the soil and spreads laterally to wet the area between the furrows. This method of irrigation is generally used to irrigate row crops and vegetables. Furrow method is not recommended for very light soils with high infiltration capacity as water is wasted at the upper end of the furrow due to deep percolation.

Overhead/Sprinkler Irrigation

In this system, water is applied to simulate natural rainfall, with water conveyed through pipes and sprayed through sprinkler, usually rotating to cover a circular area. Water is applied to the crop above the ground surface in the form of spray developed by orifices or nozzles. Overhead/Sprinkler irrigation generally requires a pump to develop the desired operating pressure in the main supply lines, laterals and risers, to convey water to the sprinkler head or nozzle, where it discharges in spray form. The selection of the sprinkler head and spacing of sprinklers is the key to the efficient operation and even distribution of water and depends on the topography, head and climate conditions, such as temperature and wind, which can adversely affect the spray pattern and increase losses to evaporation. The rate of water application through the sprinkler should be less than the infiltration rate of the soil to prevent run off wastage. The advantage of this method is uniform and efficient distribution of water, particularly in uneven or sloping topography, and sandy soils.

Centre pivot, moving lateral or rain gun systems are derivations of overhead/sprinkler irrigation where the sprinklers are mounted on a movable structure that rotates around a central pivot point or moves in a straight motion, electrically or hydraulically powered, while remaining connected to the water supply by a flexible couple or pipe. These systems are popular because of their high efficiency, uniformity and ability to be automated by remote control. Centre pivot equipment is costly, but this is more than balanced by the significant savings in reduced land levelling and less labour than many other irrigation methods. The system can also reduce the need for soil tillage, helps to reduce runoff and soil erosion, and reduces soil compaction.

Drip Irrigation

Drip irrigation is often termed as micro-irrigation as the approach involves controlled supply of water in small amounts, discharged at the root zone of a plant. It is frequently adopted in water scarce areas to conserve limited water resources. The water supply is measured by flow meter before it runs through distribution pipes to lateral drip lines, where the equally spaced drippers/emitters deliver the water to the plants.

Typical drip irrigation systems consist of a pumping unit to create a pressure, a filter unit to remove suspended impurities in the water, which might clog the drippers, and sometimes a system to dose dissolved fertilisers and herbicides. There is little water loss due to evaporation, therefore it is frequently used in arid and semi-arid regions, where the limited availability of water and high evaporative demands are the constraint to other cheaper methods. The method is best suited for wide spaced crops and is also very effective where only saline water is available for irrigation because the precise control of water enables the salinity to be controlled.

The disadvantages of the method are the capital and recurrent costs, which can be considerable, and the delicate nature of the drip lines and emitters, which can be easily damaged and blocked. It is also unsuitable to provide flooded conditions or large quantities of water to crops with high demands, such as rice and sugarcane.

Sub-surface Irrigation

In this method, the moisture in the root zone is controlled by maintaining an artificial water table at a shallow depth (0.3 - 1.0 m) depending upon the soil texture and rooting depth of crops. As such it is highly dependent on crop and location and is not widely implemented except in areas of reclaimed land (i.e., Dutch polders or English fens).

Suggested irrigation system(s)

Out of four application systems presented (surface, overhead, drip and sub-surface irrigation), two systems can be suggested for small-holder farmers in Ghana – **surface/flood and drip** applications. The reason is that simple pumps don`t have the capacity to produce high enough pressure for overhead irrigation and, as mentioned already, the sub-surface application method is still not in wide use and suitable only in very specific conditions. The choice between surface or drip application of water will further depend on the crops grown by each farmer and is analysed further in this report.

6.5 Systems suitable for Smallholder Farmers in Ghana

From the analysis of available technologies and conditions for adopting SPIS by smallholder farmers in Ghana there are eight (8) possible combinations of water sourcing, storage and application for solar pump irrigation systems farmers could consider:

System 1: Surface-mounted water pump + no water storage + drip irrigation method

System 2: Surface-mounted water pump + no water storage + flood irrigation method

System 3: Surface-mounted water pump + water storage + drip irrigation method

System 4: Surface-mounted water pump + water storage + flood irrigation method

System 5: Submersible water pump + no water storage + drip irrigation method

System 6: Submersible water pump + no water storage + flood irrigation method

System 7: Submersible water pump + water storage + drip irrigation method

System 8: Submersible water pump + water storage + flood irrigation method

Corresponding to the eight systems, the following table illustrates possible combinations of solar pumping irrigation systems:

Table 5 - Summary of Potential SPIS Configurations

	Pump type		Water storage		Irrigation method	
	Surface	Submersible	Yes	No	Flood	Drip
System 1	✓			✓		✓
System 2	✓			✓	✓	
System 3	✓		✓			✓
System 4	✓		✓		✓	
System 5		✓		✓		✓
System 6		✓		✓	✓	
System 7		✓	✓			✓
System 8		✓	✓		✓	

From the eight systems presented in this chapter, four are most suitable for use in northern and southern regions of Ghana. All four systems include a water storage solution in a form of an elevated tank since irrigation during sunshine is unfavourable for the crop and results in higher degree of water evaporation.

6.5.1 Systems appropriate for Northern Regions of Ghana

System 3: Surface-mounted water pump + water storage + drip:
Surface-mounted water pumps are appropriate for use in the northern savannah regions of Ghana, which include 5 regions – Upper East, Upper West, North East, Savannah and Northern, where agriculture mainly depends on gravity dams, dugouts and pumping from the White and Black Volta rivers to farm during the dry season. Typical crops grown in the region are staple crops such as: millet, guinea corn, yam, groundnut, vegetables. A drip water delivery method is appropriate for cultivation of these crops and can be executed by an elevated tank providing enough pressure for the water to reach the root zone of the plant. The drip method will minimize water evaporation, which is of high importance during the dry season.

System 4: Surface-mounted water pump + water storage + flood:
A system with a Surface-mounted water delivery method is also appropriate for the northern savannah of Ghana to cater for the needs of farmers growing upland rice and leafy vegetables in this region.

6.5.2 Systems appropriate for southern / coastal regions of Ghana:

System 7: Submersible water pump + water storage + drip:
Shallow groundwater sources are typically used for farming along the Coastal Areas of the Volta Region (VR). The traditional irrigation system involves fetching water from hand-dug wells along the coastal areas of the VR, making submersible water pumps the most appropriate solution. Typical crops grown along the coastline of the VR include vegetables, shallot / onion, maize, cassava, with agricultural activities being oriented towards sale in the market or even export.

Farmers also lift water from shallow boreholes using diesel, petrol or electric pumps for distribution. Although these farmers prefer sprinkler irrigation system for water application as the soils are mostly sandy, it will be very important to promote a storage tank with drip irrigation method for more efficient water application. The farmers normally improve the structure of the soil by mulching.

System 8: Surface-mounted water pump + water storage + flood:
Other parts of southern Ghana, covering the coastal savannah zone and stretching from the coastline towards the transition zone, also have many river basins including rivers Volta (with parts of its lake), Tordzi, Densu, Ankobra, Pra and Tano. Farmers traditionally pump from these rivers, ponds, dugouts and dams with diesel/petrol pumps for surface/flood irrigation. Crops commonly grown include vegetables, paddy and upland rice, cassava, maize, and various tree crops.

The table below shows relevant criteria to consider when deciding on the most suitable solar pumping and irrigation system for different water resources and crops.

Table 6 - Key Water Source and Crop Considerations for SPIS Design

WATER PUMPS DEPENDING ON WATER SOURCE	
Groundwater	Submersible pump
Wells	
Rivers	Surface-mounted Pump
Lakes	
Dams	
WATER DELIVIERY SYSTEM DEPENDING ON THE CROP	
Millet	Drip
Guinea corn	Drip
Yam	Drip
Groundnut	Drip
Vegetables	Drip
Rice	Surface
Leafy vegetables	Drip
Onion	Surface
Maize	Drip
Cassava	Drip

6.6 List of accredited suppliers and distributors

Below is a table of suppliers and distributors of SPIS related equipment, as utilised in Ghana, particularly by the Green People's Energy Project.

Table 7 - Accredited SPIS Suppliers and Distributors (Ghana Green People's Energy Project)

S/N	Name	Address	Contact(s)
1.	Dizengoff Ghana Limited	No. 2 Feo Eyeo Road North Industrial Area P.O. Box 3403 Accra, Ghana	• Janus Van Der Westhuizen (027 756 5403) • Samuel Abbey (024 214 4821)
2.	DENG Limited	P.O. Box AN 19996 Accra, Ghana www.dengltd.com info@deng.com	024 431 3261
3.	Jahan Engineering Services	No.2 Walantu Street, Kasoa http://www.jahanengineeringservices.com/	020 811 7420
4.	Pump Tech Limited	C5C5+R6J, Tamale http://www.pumptechgh.com/	050 545 8400
5.	Foundries and Agricultural Machinery (Gh) Ltd	10 Steel Works Rd, Tema	0302 304113/306403
6.	Agaabi Plumbing Services	Doblo Gonnor, Amasaman, Ga East, Accra	Gabriel Asare (024 647 7929)

7 COST ANALYSIS

7.1 Cost of system components

SPIS systems costs can generally be broken-down in the following components categories:

- Generation system (solar panels, pump, controller)
- Water storage system (tank, etc)
- Irrigation network (canals, piping, etc.)
- Balance of system costs (transport, civil works, etc.)

Overall system assumptions:

- As the target groups are small holder farmers, areas of 1, 5, 10, 15, 20 and 25 ha are considered for the cost analysis in this section
- Typical SPIS would be less than 10 kW pump systems (in fact in majority cases, 1-3 kW pump systems are prevalent).
- Water requirement of 1 litre / sec / ha is assumed for purposes of simplicity and standardization.
- Irrigation period is considered to be of 3 months.
- Total dynamic head is assumed to be 5 m, again for purposes of standardization and ease of comparison. Actual TDH may influence the pump capacity required.
- PV panels are oversized to 150% of pump capacity to allow adequate power generation during early morning and evening hours as well (this is generally more cost effective compared to installing electrical batteries)
- Boreholes and other source improvements (e.g. River diversions, weirs or dams) would be an additional cost.

Generation system:

- Solar panels whose price is normally proportional to the system size. An average cost of 600 $/kW is considered typical for the cost analysis.
- Pumps and corresponding controllers can be DC or AC, depending on the brand. It is worth noting that smaller pumps have a higher cost per kW and economies of scale can be leveraged if multiple farmers were to combine and available a larger pump for combined usage. For the cost analysis, Grundfos submersible pumps (Orange Line) are compared to Lorentz pumps (Green Line), as shown in Figure 8 below.

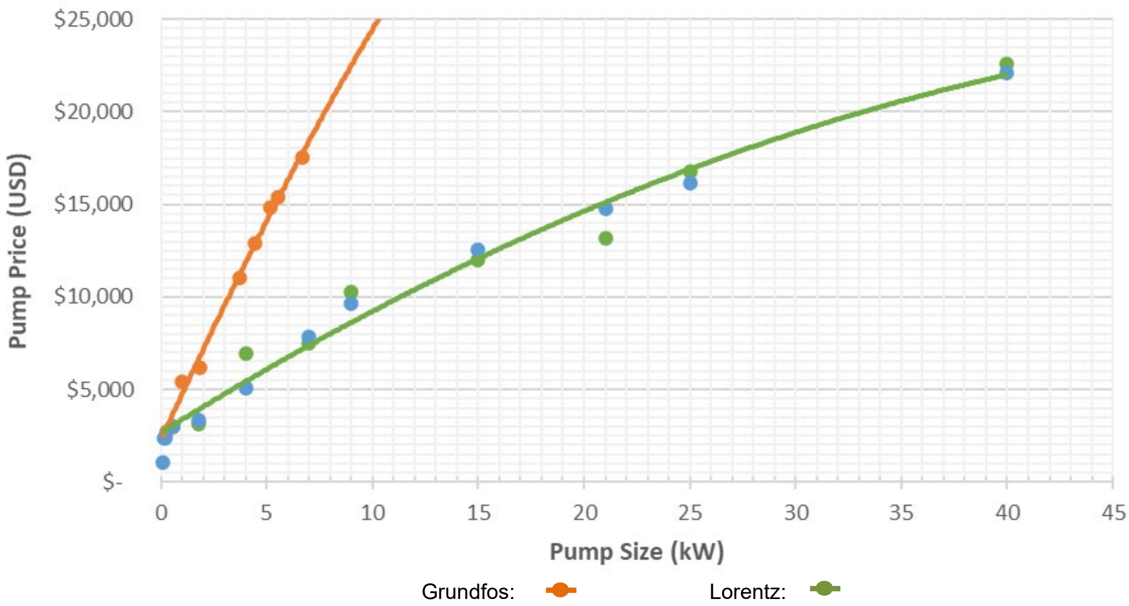


Figure 12 - Solar Pump and Controller Costs (US$) Depending on Size (kW)

Water storage:

- Elevated tanks with capacity of 10,000 litres are considered with a cost of approximately $ 2,000 including the cost of a concrete platform. Depending on water requirements, multiple such tanks are used for larger schemes or for less efficient systems, such as flood application. For actual installations, larger capacity tanks may be used, if available in the local market, and if suitable transportation means are available.

Irrigation network:

- While the costs are largely proportional to the irrigated area, costs per ha for surface/flood irrigation are generally higher than for drip irrigation by approximately 40%. This is because the spacing of lateral pipes and risers has been assumed to be every 20m to avoid the need for costly land levelling for gravity application of irrigation to larger plots. An overview of the costs for increasing area is shown in Figure 9 below.

Areas (ha)	Drip Irrigation	Surface/Flood Irrigation (Pipe & Riser)
1	$3,460	$5,710
5	$17,300	$24,920
10	$34,600	$48,025
15	$51,900	$72,340
20	$69,200	$96,050
25	$86,500	$118,550

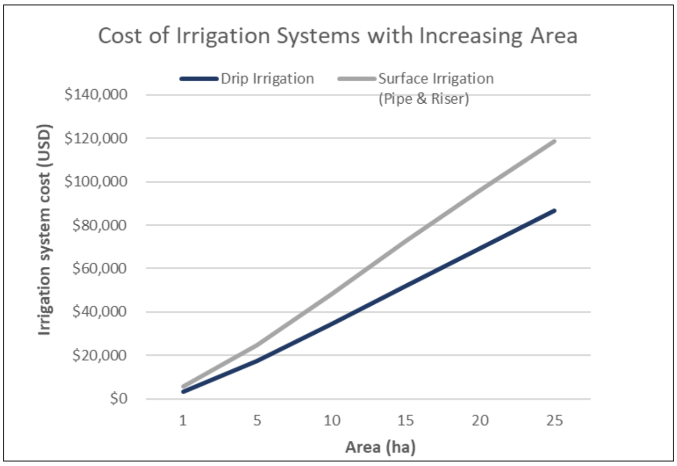


Figure 13 - Costs of Irrigation Systems (US$) with Increasing Area (ha)

Balance of system costs:

- Transport, civil works and other items (e.g., fencing, earthing) account for roughly 15-20%

of the overall cost. Again, economies of scale can be expected for larger systems where these costs per kW are reduced.

7.2 Overview of SPIS Capital Costs

Table 4 provides an overview of costs categorized by CAPEX components for some typical small SPIS. The total system costs varies most significantly by the type of irrigation application method (i.e. Drip or Flood), with the majority of the CAPEX costs relating to water storage, which are significantly higher (~25%) for methods with lower water-use efficiency. There are minimal differences in CAPEX costs for different pump types, assuming the water sources are fully developed.

Table 8 - Capex for Key Components of SPIS

Specifications		**Price (USD)**	**Price %**
Surface-Mounted Pump and Drip Irrigation			
Solar PV	1.1 kW	1,650	10%
Pump	Surface-mounted Pump (0.6 kW)	3,029	18%
Water Storage	4 x 10.000 litres elevated tanks	6,000	36%
Irrigation Network	Drip Irrigation, 1 ha	3,460	21%
Balance of System Costs	Transport, civil works, fencing etc	2,700	16%
	TOTAL:	**20,160**	**100%**
Surface-Mounted Pump and Flood Irrigation			
Solar PV	1.1 kW	1,650	7%
Pump	Surface-mounted Pump (0.6 kW)	3,029	12%
Water Storage	8 x 10.000 litres elevated tanks	12,000	48%
Irrigation Network	Pipe & Riser Irrigation, 1 ha	5,710	23%
Balance of System Costs	Transport, civil works, fencing etc	2,700	11%
	TOTAL:	**25,089**	**100%**
Submersible Pump and Drip Irrigation			
Solar PV	0.9 kW	1,350	8%
Pump	Submersible Pump (0.28-0.6 kW)	2,869	18%
Water Storage	4 x 10.000 litres elevated tanks	6,000	37%
Irrigation Network	Drip Irrigation, 1 ha	3,460	21%
Balance of System Costs	Transport, civil works, fencing etc	2,700	16%
	TOTAL:	**16,379**	**100%**
Submersible Pump and Flood Irrigation			
Solar PV	0.9 kW	1,350	5%
Pump	Submersible Pump (0.6-1.0 kW)	4,230	16%
Water Storage	8 x 10.000 litres elevated tanks	12,000	46%
Irrigation Network	Pipe & Riser Irrigation, 1 ha	5,710	22%
Balance of System Costs	Transport, civil works, fencing etc	2,700	10%
	TOTAL:	**25,990**	**100%**

Table 5 and the figures on the next page(s) summarises the CAPEX components for different sizes of the irrigation developments, from 1ha to 20ha systems. While the cost per ha doesn't change much for larger systems, there is a 16-30% reduction in costs comparing 1 ha and 5 ha, indicating potential benefits of pooling farmers into a larger system.

Table 9 - Comparison of SPIS CAPEX with Increasing System Area

System Area	1 ha			5 ha			10 ha			15 ha			20 ha		
	Specification	Price (US$)	Price %	Specification	Price (US$)	Price%	Specification	Price (US$)	Price%	Specification	Price (US$)	Price%	Specification	Price (US$)	Price%
Surface Mounted Pump and Drip Irrigation															
PV	0.9 kW	1,350	8%	2.7 kW	4,374	7%	6.0 kW	9,720	8%	6.0 kW	9,720	5%	10.5 kW	17,010	8%
Pump	0.6 kW	3,024	18%	1.8 kW	3,245	6%	4.0 kW	5,995	5%	4.0 kW	5,995	3%	7.0 kW	7,530	3%
Water Storage	40k litre	6,000	36%	200k litre	30,000	51%	400k litre	60,000	52%	600k litre	90,000	48%	800k litre	120,000	54%
Drip Irrigation	1	3,460	21%	1	17,300	29%	1	34,600	30%	1	51,900	25%	1	69,200	31%
Other	1	2,700	16%	1	4,050	7%	1	5,400	5%	1	6,750	19%	1	8,100	4%
Total		**16,534**	**100%**		**58,969**	**100%**		**115,715**	**100%**		**164,365**	**100%**		**221,840**	**100%**
US$/ha	**16,534**			**11,794**			**11,571**			**10,958**			**11,092**		
Surface Mounted Pump and Flood Irrigation															
PV	0.9 kW	1,350	5%	6.0 kW	9,000	9%	10.5 kW	15,750	8%	13.5 kW	20,250	7%	22.5 kW	33,750	9%
Pump	0.6 kW	3,024	12%	4.0 kW	5,995	6%	7.0 kW	7,690	4%	9.0 kW	9,939	3%	15.0 kW	12,267	3%
Water Storage	80k litre	12,000	48%	400k litre	60,000	58%	800k litre	120,000	61%	1,200k litre	180,000	62%	1,600k litre	240,000	62%
Flood Irrigation	1	5,710	23%	1	24,920	24%	1	48,025	24%	1	72,340	25%	1	96,050	25%
Other	1	2,700	11%	1	4,050	4%	1	5,400	3%	1	6,750	2%	1	8,100	2%
Total		**24,784**	**100%**		**103,965**	**100%**		**196,865**	**100%**		**289,279**	**100%**		**390,167**	**100%**
US$/ha	**24,784**			**20,793**			**19,686**			**19,285**			**19,508**		
Submersible Pump and Drip Irrigation															
PV	0.9 kW	1,350	8%	2.7 kW	4,374	7%	6.0 kW	9,720	8%	6.0 kW	9,720	6%	10.5 kW	17,010	8%
Pump	0.6 kW	3,024	18%	1.8 kW	3,245	6%	4.0 kW	5,995	5%	4.0 kW	5,995	4%	7.0 kW	7,690	3%
Water Storage	40k litre	6,000	36%	200k litre	30,000	51%	400k litre	60,000	52%	600k litre	90,000	55%	800k litre	120,000	54%
Drip Irrigation	1	3,460	21%	1	17,300	29%	1	34,600	30%	1	51,900	32%	1	69,200	31%
Other	1	2,700	16%	1	4,050	7%	1	5,400	5%	1	6,750	4%	1	8,100	4%
Total		**16,534**	**100%**		**58,969**	**100%**		**115,715**	**100%**		**164,365**	**100%**		**222,000**	**100%**
US$/ha	**16,534**			**11,794**			**11,571**			**10,958**			**11,100**		
Submersible Pump and Flood Irrigation															
PV	0.9 kW	1,350	5%	6.0 kW	9,000	9%	10.5 kW	15,750	8%	13.5 kW	20,250	7%	22.5 kW	33,750	9%
Pump	0.6 kW	3,024	12%	4.0 kW	5,995	6%	7.0 kW	7,690	4%	9.0 kW	9,939	3%	15.0 kW	12,267	3%
Water Storage	80k litre	12,000	48%	400k litre	60,000	58%	800k litre	120,000	61%	1,200k litre	180,000	62%	1,600k litre	240,000	62%
Flood Irrigation	1	5,710	23%	1	24,920	24%	1	48,025	24%	1	72,340	25%	1	96,050	25%
Other	1	2,700	11%	1	4,050	4%	1	5,400	3%	1	6,750	2%	1	8,100	2%
Total		**24,784**	**100%**		**103,965**	**100%**		**196,865**	**100%**		**289,279**	**100%**		**390,167**	**100%**
US$/ha	**24,784**			**20,793**			**19,686**			**19,285**			**19,508**		

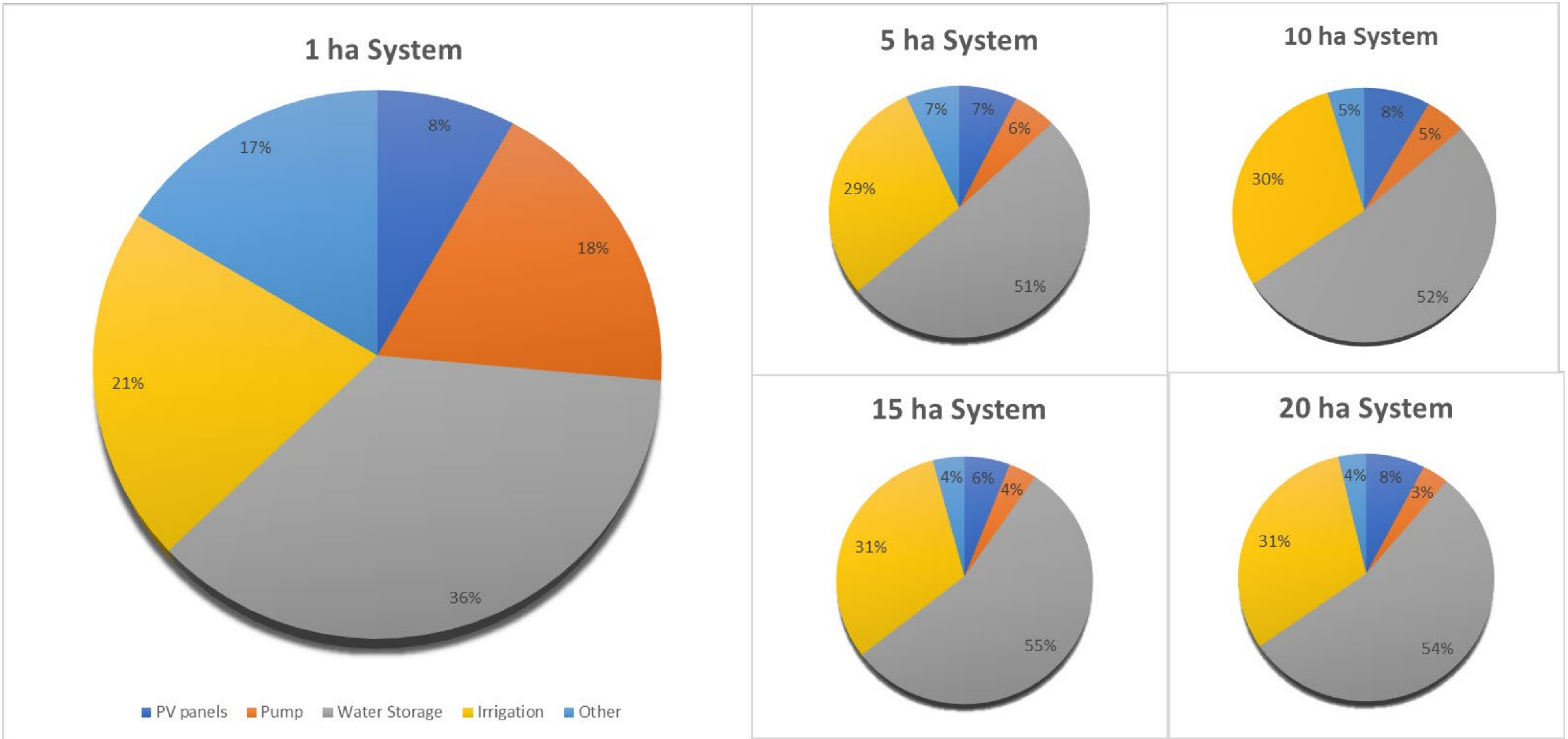


Figure 14 - CAPEX Components for Surface-Mounted Pump and Drip Irrigation

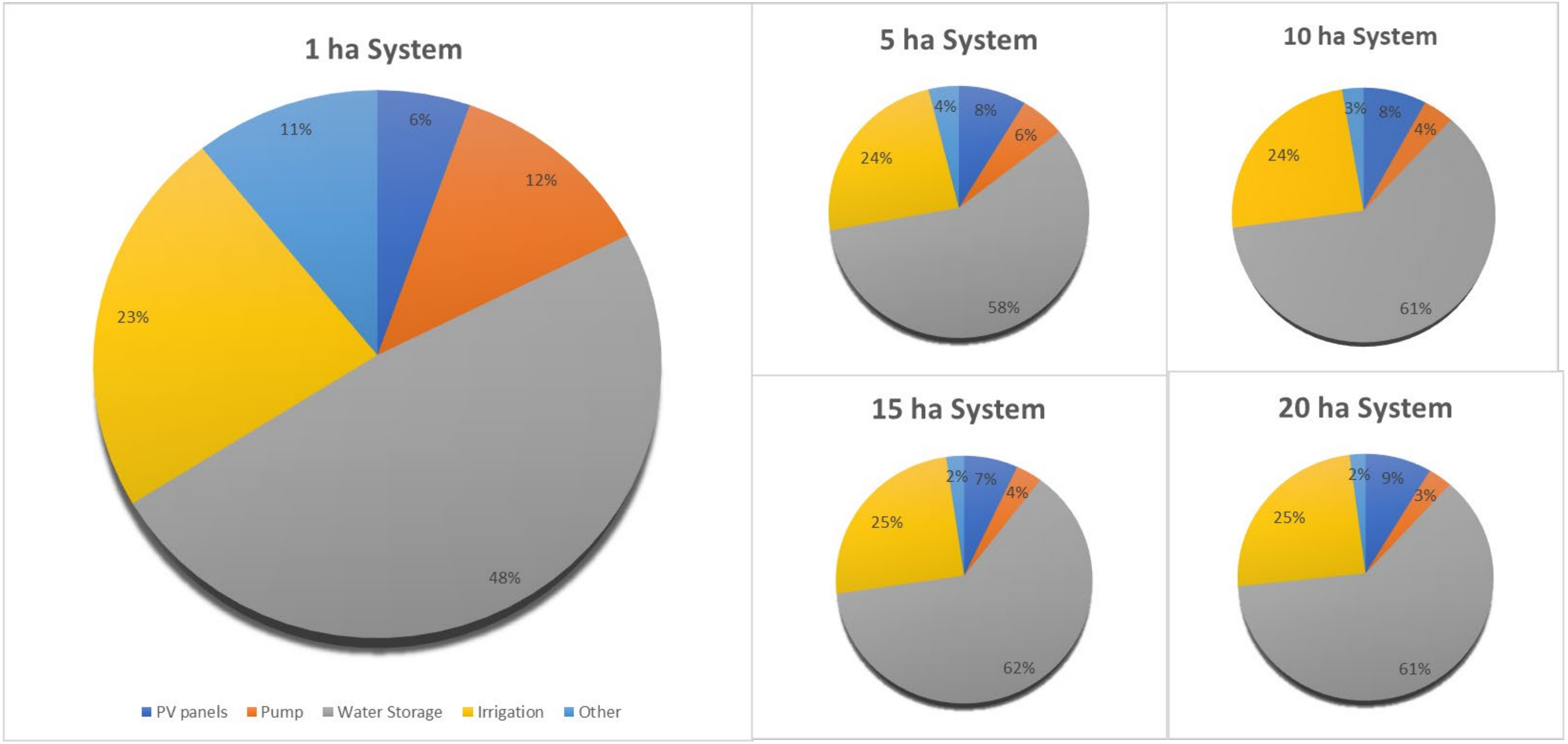


Figure 15 - CAPEX Components for Surface-Mounted Pump and Flood Irrigation

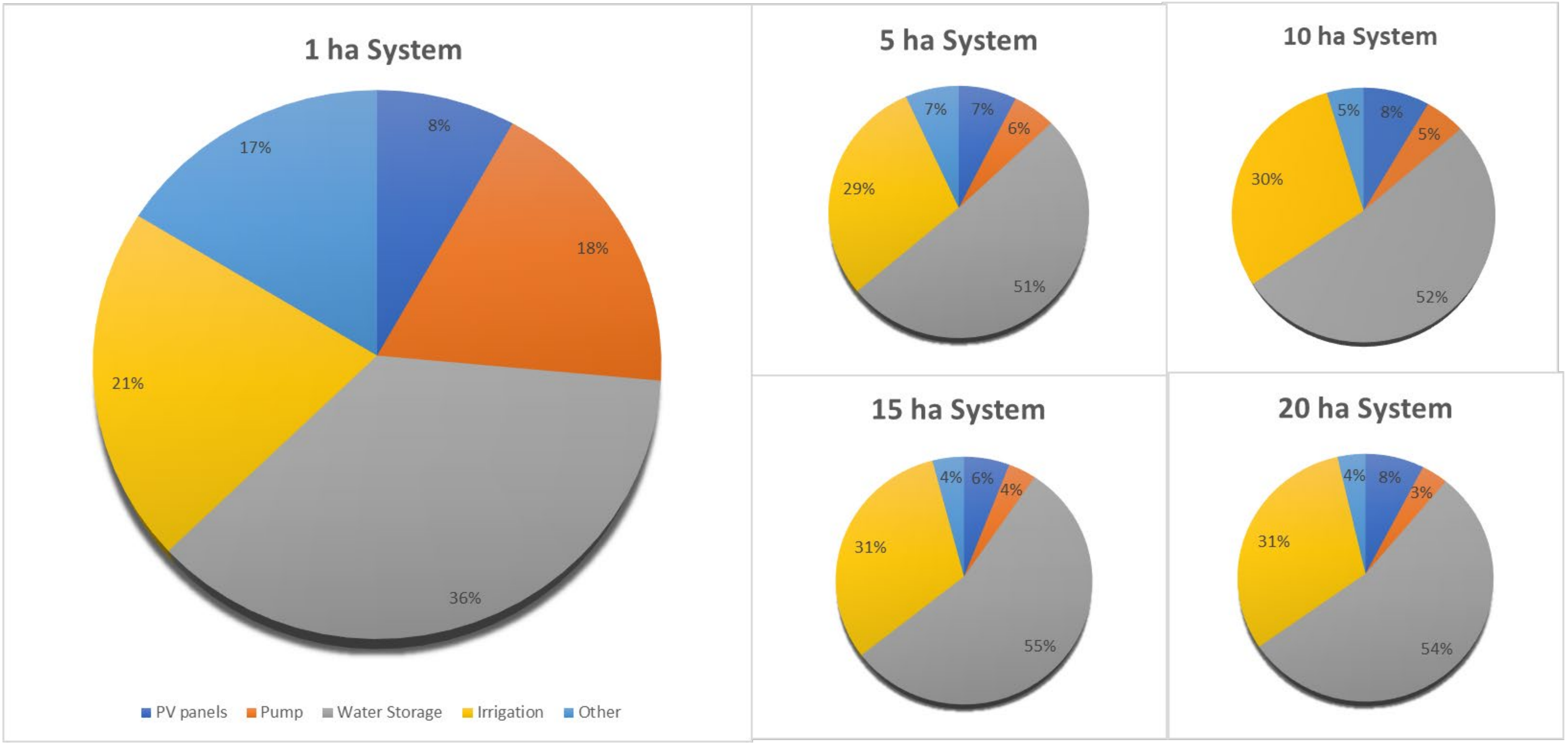


Figure 16 - CAPEX Components for Submersible Pump and Drip Irrigation

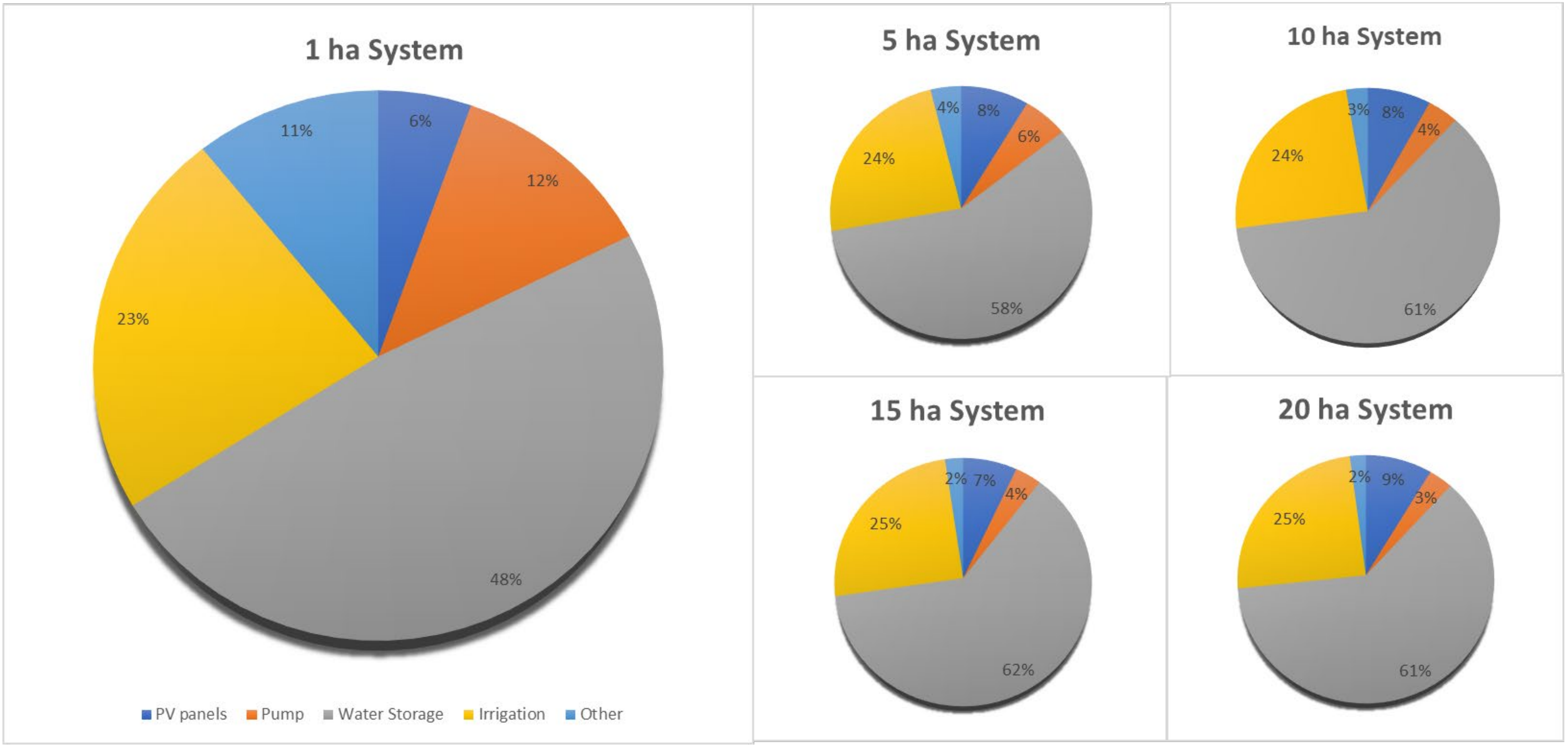


Figure 17 - CAPEX Components for Submersible Pump and Flood Irrigation

APPENDICES

APPENDIX A: Stakeholder List

APPENDIX B: Kick-off Meeting Minutes_20220915

APPENDIX C: Kick-off Meeting Presentation_20220915

APPENDIX D: Inception Meeting Minutes_20221122

APPENDIX E: Inception Meeting Presentation_20221122

APPENDIX F: Individual Stakeholder Engagement Minutes

APPENDIX G: Stakeholder Workshop Minutes_20230201

APPENDIX H: Stakeholder Workshop Presentation_20230201

APPENDIX I: Stakeholder Workshop Minutes_20230413

APPENDIX J: Stakeholder Workshop Presentation_20230413

APPENDIX K: Bibliography