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Implementation of Water-Food-Energy nexus using digital technologies for local communities in Mozambique

Technological benchmarking of international best practices

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This project has been proposed by Universidade Pedagógica de Maputo.

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This document is an output of the Technical Assistance Response in Mozambique. The present report is the output of the project 'Implementation of Water-Food-Energy nexus using digital technologies for local communities in Mozambique'. The views and information contained herein are a product of the international TA implementation team led by PRACTICA & HUB.

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1. Introduction

This report is part of the deliverables for the project *Implementation of Water-Food-Energy (WEF) nexus using digital technologies for local communities in Mozambiqu*e project implemented by the consortium PRACTICA and HUB. The overall objective of the project is to develop a fit-for-purpose system for one selected farm in the Zambezi Valley in Mozambique that will include aquaponics, biodigester, bio composting, and hydraulic management systems (including water storage and solar pumping integrated systems for drip irrigation).

This deliverable provides an overview of international best practices of smart-agriculture processes that include the four components to be included in the technical assistance. These are solar irrigation, aquaculture, bio composting and biogas production. The benchmarking was done with a particular focus on the practices and experiences of countries with similar socioeconomic, geographic, and climatic conditions. With a special emphasis on gathering valuable lessons learnt, present potential risks and barriers to be considered during the system's design phase.

2. Methodology

The methodology includes a comprehensive benchmarking exercise that specialises on Mozambique's socioeconomic, geographic, and climatic conditions. The steps involved are:

1. Literature review and data collection: Government publications, case studies, manuals and project reports were reviewed to gather relevant information.
2. Comparison of different types of technology: Different possibilities or arrays for each technology are presented and compared based on the advantages and disadvantages, taking as a baseline the socioeconomic conditions of rural Mozambique.
3. Identification of the design aspects for each technology: The key design aspects of implementing each technology highlight the important indicators that must be assessed during the following steps of the technical assistance.
4. Overview of different WEF initiatives in the region: Different projects and initiatives in South-Eastern Africa and Mozambique were identified to gather lessons learned, potential risks, and barriers encountered, as well as to define mitigation measures to be implemented during this technical assistance.

The expertise of each expert was used to tailor the search to accelerate and improve the quality of the research.

3. Benchmarking per technology

This chapter capitalizes on the information gathered during the data analysis phase from the literature review. Synthesizing key findings and insights focused on the different types of technologies, advantages, disadvantages, lessons learned and potential risks.

3.1 Aquaculture

3.1.1 Introduction

Aquaculture, also known as fish farming, is the practice of breeding, rearing, and harvesting aquatic species such as fish, crustaceans, molluscs, and aquatic plants for human consumption and other purposes[1]. Aquaculture can be practiced in fresh and salt water; therefore, applicability to the context of rural communities in Mozambique is high.

Worldwide, China is the leading country in Aquaculture, with a recorded production of 67 million tons of fish in 2021. In Africa, Nigeria is leading, followed by Egypt, which has 3.4 million and 2.8 million tons, respectively[2]. Mozambique is Africa's ninth largest fish producer, producing 0.5 million metric tons in 2021. Aquaculture development in Mozambique plays a vital role in the country's socioeconomic development: providing cheap protein, improving the population's diet, creating jobs, generating income and promoting regional development. The potential for aquaculture development in Mozambique is enormous. There is a favourable environment for investment, climatic conditions are favourable (tropical and sub-tropical climate), it is unpolluted, population pressure is low, and there are extensive resources[3]

The country's fisheries sector is dominated by small-scale fishers, who account for over 90% of total production. In 2016, 65,600 people were reported as engaged in fisheries. A significant number of women are involved in fishing with small seines, on foot, and picking seafood (specifically clams). Mozambique's main fish-producing regions are the Indian Ocean coast, the Zambezi River basin, and Lake Niassa. The country's most important fish species include shrimp, tuna, and tilapia. (Peter Yankson October 23, 2023).

3.1.2 Different types of aquaculture systems

Aquaculture systems range from extensive system stocking with no or little feeding. Ponds are maintained to provide fish with a closed ecosystem and natural food resources. This farming type has minimal environmental impact and allows good biodiversity management[4]. Intensive freshwater aquaculture involves creating water reservoirs and joining them to nearby rivers, either in a raceway or a closed or recirculation system. Fish, such as trout, eel, sturgeon and tilapia; live in the reservoirs until they grow big enough to be commercialized. If production is done through extensive farming, market size is not attained in time, making it not viable and taking time as the main factor. As an example, intensive fish farming takes 6 months to reach 550

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[1] www.oceanservice.com

[2] www.fisheriesindia.com

[3] https://firms.fao.org/fi/website/FIRetrieveAction.do?dom=countrysector&xml=naso_mozambique.xml&lang=en

[4] https://www.alimentarium.org/en/fact-sheet/aquaculture-techniques

grams (market size for the fish), whereas, in extensive farming, it can take up to 12 months to reach the same weight and size due to the lack of a balanced diet. Therefore, to maximize profit in aquaculture, an intensive approach is recommended. With the intensive system, there is a need for high levels of biosecurity, which is a challenge to most of the local communities, leading to low adoption of the system[5].

3.1.2.1 Open aquaculture systems

Open sea-cage aquaculture refers to rearing aquatic species within enclosures in natural waterways. Open systems are usually implemented in a wide range of environments, including freshwater rivers, brackish estuaries and coastal marine regions. Floating mesh cages are anchored to the seafloor and vary in size depending on the scale of operation and the species cultured. This type of system in Mozambique is found at Poe Lela Fisheries, an established and privately owned aquaculture company specializing in the sustainable production of Salt Water Bream. It is located in Inharrime District, Inhambane Province.

Figure 1. Open aquaculture-cage in a pond in Mozambique (Mapfumo, 2020).

3.1.2.2 Closed aquaculture systems

Closed system aquaculture refers to the land-based rearing of aquatic species in raceways, tanks and ponds. Recirculation technology is implemented, which cycles water through filtration processes and returns it back into the aquaculture system. This process aids in maintaining water quality whilst ensuring minimal exchange with natural waterways (Tidwell, 2012).

There are four main aquaculture grow-out systems/techniques (or combinations of these). These four aquaculture grow-out techniques are pond, cage, flow through, and RAS. Based upon the climate, availability of water, land and electricity, the decision of aquaculture grow-out systems is made.

[5] https://goodfishbadfish.com.au/aquaculture-methods/

Pond-based systems can be classified in several ways, including management intensity, salinity, and elevation or temperature. A typical pond should be located close to a reliable water source, on a soil type that can hold water. To reduce pumping costs, the farm should be sited on a gentle slope to allow water to flow into and out of the ponds by gravity. The average depth should be approximately 1.5 to provide adequate cover from predatory birds and hot surface water during the day.

Figure 2. Earth pond farm under construction, the plastic cover, reduces infiltration.

Cage-based systems refer to farming fish in culturing units consisting of a framed net that is open at the top and floating on the surface. A different option is to keep the cage below the water surface by adjusting buoyancy or suspending it from the surface (FAO, 1984). Given the relatively small size of cages, harvesting is simple, quick and cheap to perform. The investment per unit weight of fish produced is relatively low compared to pond-based systems.

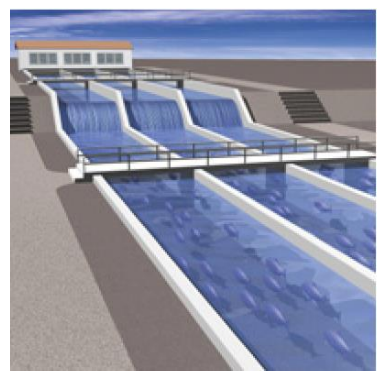

Figure 3. Flow-through system production scheme (Goodfish, 2024).

Flow-through system, also known as race away, can be described as an artificial channel. Water flows from a higher-located point down to a lower point and then flows back into rivers or the sea, with or without water treatment.

Recirculating Aquaculture Systems (RAS) is an almost completely closed circuit. The produced waste products, solid waste, ammonium and CO_2, are either removed or converted into non-toxic products by the system components. By recirculating the culture water, the water and energy requirements are limited to an absolute minimum.

Figure 4. Recirculating Aquaculture Systems (Aquacultureeid, 2024).

Closed system aquaculture is considered one of the more environmentally benign methods of rearing aquatic species. Fishmeal (pellets comprising small schooling fish species) may be added to feed carnivorous aquaculture species and is a concern as it places continued demand on wild fish stocks.

A comparison of the different open and closed production systems is presented in the table below, highlighting advantages and disadvantages.

Table 1. Comparison of different production systems.

	Advantages	Disadvantages
Open Systems		
Open cage	• Natural environment for the fish remains the same, as fish are raised in their natural water environment. • Large-scale production, open cage accommodates a more significant number of fish, making it suitable for commercial-scale production. • Replicability based on production needs and site conditions is higher • Low investment needed	• Low control of diseases. • Site selection is key to ensure quality and depth, wind and wave action allow for production.
• **Closed Systems**		
Pond production	• Control of physical and chemical parameters of the prod	• Required availability of land on the farm to construct the ponds. • Soil needs to be able to retain water (not suitable for sandy soils)
Cage production	• Harvesting simple and quick to perform • Accessibility for harvesting is easy	• Low control of physical and chemical parameters of the production system.
Recirculating Aquaculture System (RAS)	• Fully controlled environment for the fish • Low water and energy use • Optimal feeding strategy • Full disease control	• Necessity for electricity 24/7 • Requirement for a good water source, preferably a borehole • Good fish feed quality, preferably high protein and fat • Requires medium-high skilled labour

3.1.3 Challenges and Risks for adoption of aquaculture in Mozambique.

As mentioned above, there is a considerable potential for expanding aquaculture activities in rural Mozambique. However, as with any new technological process, some challenges need to be overcome to support this introduction, such as :

- **Lack of Knowledge and trained personnel**—The major drawback in aquaculture is the lack of awareness of aquaculture products in the local communities. Most small-scale aquaculture producers lack properly designed models, making it difficult to achieve the targeted goals. For example, for a sustainable Aquaculture project in developing countries, a farmer should have at least four tanks to ensure four harvesting periods per year.

- **Lack of capital**—The initial setup capital for local communities tends to be high, so they do not adopt. Besides production in dams, rivers, and the ocean, it is also done in ponds. This requires capital to construct and purchase feed for the fish, becoming a challenge to the local communities.
- **Unavailability of proper feed**- to attain marketable size, there is a need for appropriate nutrients; since aquaculture is mainly practised at a large scale by large companies, they tend to import their feeds from countries like Zimbabwe and South Africa. With these imports, local feed production decreases. This results in the unavailability of the feed to the local farmers, or the feeds are available at high prices that the small-scale farmer cannot afford. The country faces a challenge with proper fish feed formulations.

Risks that small-scale fish farmers in Mozambique often face include:

- **Chemical poisoning**: Fertilizers and pesticides can contaminate the system, which can be done by spraying nearby fields. If the water source is from a flowing river there is a high risk of contamination from users upstream.

- **Water shortages**: due to climate change effects, river levels are getting lower during the dry season, directly affecting water availability for the aquaculture systems.

- **Shortage of high-quality fish seed**: this is due to a lack of breeding units for the production units of the small-scale farmers.

3.1.4 Design aspects to be considered for small scale aquaculture

Aquaculture farming comprises various steps, from pond construction, seed production and nursery, to grow-out, harvest and market. Knowing the carrying capacity and production factors for every single step in the process is important.

Carrying capacity is the fish's weight in a given unit of water where growth stops. This is recorded as kg/ha, kg/m^3. Carrying capacity measures the maximum biomass of a farmed species that can be supported without violating the maximum acceptable impacts on the farmed stock and its environment in a given unit.

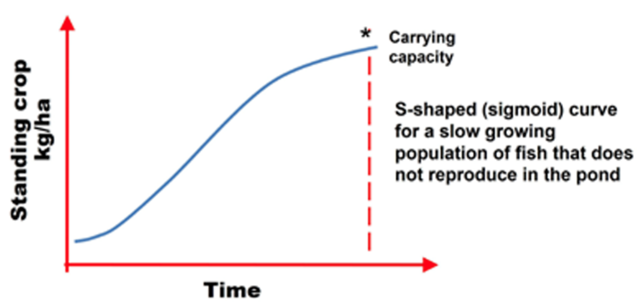

Figure 5. How carrying capacity works (FAO, 2022, pp-24).

Another critical factor is water quality, which determines the success or failure of any aquaculture operation. The different factors that must be monitored in the water are temperature, oxygen quantity, pH, and mineral concentration.

It is also vital to consider that different factors influence the tolerance of the farmed organisms, such as species, age, genetics, environmental interactions, rate of change, stocking density, and others.

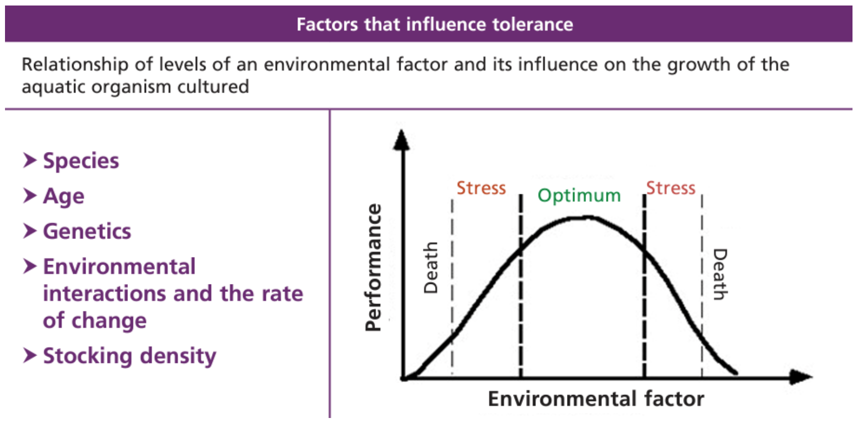

Figure 6. Environmental factors and performance (FAO, 2022-pp 27).

The steps that need to be considered when designing an aquaculture production system are described below:

1. Objective definition:
    a. Identify goals: determine the purpose of the aquaculture system (e.g., commercial production, research, upscaling, conservation).
    b. Target species: Define the species that will be cultured based on market demand, environmental conditions and resources availability.
2. Site selection:
    a. Environmental assessment: evaluate different parameters that affect the production system, such as water quality, temperature, salinity, etc.
    b. Accessibility: Consider the proximity to infrastructure, transportation and markets, and skilled labour.
3. System Design:
    a. Aquaculture type: Choose between open cage, point, recirculating or integrated systems based on species and site conditions.
    b. Layout and Construction: Plan the physical distribution of the infrastructure, including the size and placement of cages, tanks, ponds, warehouses, etc.
    c. Water Management: Design systems for water intake, circulation, filtration and waste management.
4. Infrastructure and Equipment:
    a. Aeration and Oxygenation: What mechanisms or systems will be incorporated to maintain dissolved oxygen levels?

    b. Monitoring Equipment: What equipment, sensors and tools will be used to monitor water quality, temperature, and fish health.

5. Health Management:
    a. Disease Prevention: What type of biosecurity measures are used to prevent disease outbreaks, health checks and water quality assessment.
    b. Treatment protocols: Define the protocols for disease identification, treatment, and practise control in the production system.
6. Operation, Economic and Financial Planning:
    a. Daily operations: Plan tasks such as feeding, cleaning, and monitoring, as well as keep records of water quality, growth rates, feed usage, and health status.
    b. Budgeting: Estimate detailed budgets covering capital expenditures and operational costs and estimate potential revenues based on production goals and market prices.

3.2 Biodigester

3.2.1 Introduction

In the rural landscape of Mozambique, access to sustainable and affordable energy sources remains a significant challenge. Traditional reliance on biomass, such as firewood and charcoal, for cooking contributes to deforestation and environmental degradation and poses health risks due to indoor air pollution. Biodigesters are innovative systems that convert organic waste materials -such as agricultural residues, animal manure, and household waste- into biogas and nutrient-rich slurry through anaerobic digestion. The biogas can be used as a clean and renewable energy source for cooking, heating, and lighting. At the same time, the slurry serves as a valuable organic fertilizer, enhancing soil fertility and agricultural productivity.

Even though it has been widely communicated that biogas production technology has a large potential for poverty reduction, waste management, energy provision, etc., but Kalina et al. (2022) state that little is known about what is happening on the ground. In literature, Kalina states there is a tendency to focus on limited successes while ignoring failures, and there remains a lack of critical reflection towards a technology that, on the African continent, has failed to live up to expectations.

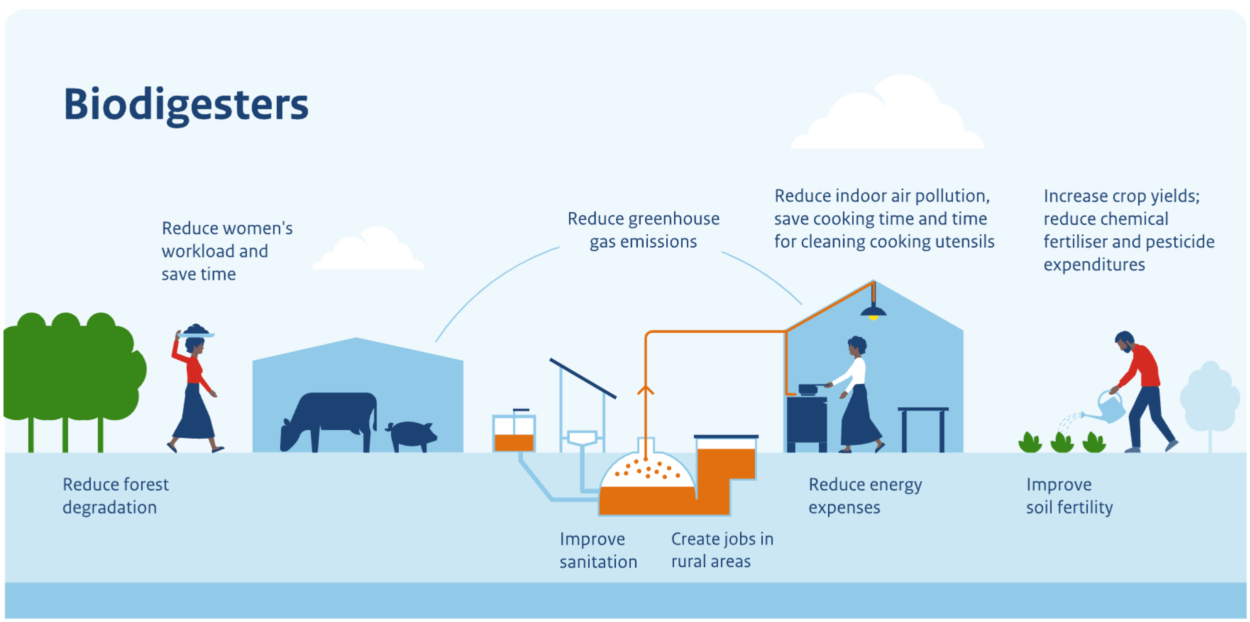

Figure 7. Biodigester technology and its contribution to the SDG (rvo.nl)

3.2.2 Different types of biodigester

Two types of digester designs are mostly installed for small-scale plants in developing countries: fixed-roof biogas installation and tubular flexible roof biogas installation.

3.2.2.1 Fixed roof biogas installation

Fixed dome biodigesters are built with cement and brick and have an estimated lifespan up to 20 years. The fixed some is usually made with two tanks: one with a completely buried vault and a second, half buried tank.

Figure 8. Fixed-roof biogas installation (greenempowerment, 2023).

The first tank is where the anaerobic digestion occurs, and the biogas is produced and captured. When buried, the temperature at which anaerobic digestion occurs is similar to the temperature of the soil. The second tank is open and serves as a compensation tank for the produced biogas.

3.2.2.2 Tubular flexible roof biogas installation

Figure 9. Tubular flexible roof biogas.

The tubular biodigesters are constructed of plastic and usually have cylindrical and elongated forms. They are half-buried, leaving the biogas dome visible. The plastic used to build these biodigesters is usually greenhouse polyethene (double layer) in most economic cases (with durability between 5-7 years) and geomembranes (10-15 years of durability).

These biodigesters operate at temperatures similar to soil temperatures because the manure and water mixture is contained in the ditch the biodigesters sit in. Tubular biodigesters work at lower pressures of biogas, between 5 and 15 cm of water column. The required ratio of manure to water is 1:3, increasing the water usage and the needed volume of the biodigester.

Both technologies are compared by GreenEmpowerment in the document and presented in Table 2.

Table 2. Advantages and disadvantages of fixed dome biodigesters amd tubular biodigesters (GreenEmpowerment, 2019, pp-6[6]).

	Fixed Dome	Tubular
Advantag	• Has a life expectancy of 20 years • Uses little water (manure: water 1:1)	• Can be installed in warm and cold regions (colder climates require passive solar heating) • Quick installation (1 or 2 days) after the ditch is dug • Easy training to become a tubular biodigester installer

[6] https://greenempowerment.org/wp-content/uploads/2021/04/Biogas-Manual_English.pdf.

<table>
<tr><td rowspan="3"></td><td rowspan="3">with respect to tubular biodigesters
• Does not occupy space on the farm when buried, and there is no need for a protection system
• Achieves much higher biogas pressures (1m water column)
• It is a technology widely used in Asia and Africa</td><td colspan="2">• The cost of transporting materials is low because of lightweight pieces
• Widely used in Latin America</td></tr>
<tr><td>Using Plastic</td><td>Using Geomembrane</td></tr>
<tr><td>• The cost/ durability ratio (5-7 years) is in line with smallholder farmers
• Materials available at hardware stores in the local market</td><td>• Comes prefabricated
• It can be made in any size
• Lifetime of 15 years
• PVC geomembrane is very easy to repair</td></tr>
<tr><td rowspan="3">Disadvantage</td><td rowspan="3">• Its cost is greater than plastic tubular biodigesters
• They are not adapted to work in cold climates
• Transport of materials to communities can increase the costs
• Intense training is required to install biodigesters</td><td colspan="2">• It is necessary to protect the biodigester
• They use more water in the load (manure: water, 1:3 to 1:5) than the fixed dome biodigesters
• Achieve lower biogas pressures (up to 15 cm of water column) than fixed dome pressures</td></tr>
<tr><td>Using Plastic</td><td>Using Geomembrane</td></tr>
<tr><td>• Limiting in terms of the size of plastics available
• Can repair holes up to 20 cm long</td><td>• PVC geomembrane: if it is not reinforced, it reaches biogas pressures around 5 cm of water column
• Polyethylene geomembrane: repairable up to 20 cm hole</td></tr>
</table>

An advantage of the flexible roof design not mentioned by GreenEmpowerment, is that the flexible roof design invites to inspect and engage in the making of biogas, as you can visually see the (creation of) gas pressure.

3.2.2 Challenges & Risk associated to small-scale biogas installations

Empirical findings show that the success of a biogas installation is mainly dependent on the owner's motivational drive, irrespective of the system design. This is formulated by *Kalina* as follows:

"Our own, preliminary, on-the-ground, engagement with projects in both Malawi and South Africa suggests that owners who had better outcomes with biogas were the ones, who largely, sought it out for themselves, while owners who were more passive 'beneficiaries' within the intervention, generally experienced poor outcomes."

Alternatively, or perhaps in extension of this vision, large-scale data collection on biogas plant failure has shown that the primary causes are technical challenges and the operator's inability to deal with them. Below, three reports on this are discussed.

1. Mahdi et al. (2012) used a mixed methodological approach to examine 85 digesters in Bangladesh’s Pabna District, finding that 65% were not operating or operating poorly, with most failure owing to technical complications linked to the digester or the associated appliances.
2. In a survey of 141 digester owners in central Vietnam, Roubík et al. (2016) found that one-third of owners had experienced severe problems with technical challenges, such as leaks in the reactor or piping, malfunctioning of the stove, or breakdowns in anaerobic digestion featuring prominently.
3. Wamwea (2017), writing about Kenya, generally observed better outcomes but also found that technical issues were the leading cause of failure among sampled owners.

In the above text, we speak of the ‘failure’ of biogas plants, whether it be a financial failure or lack of biogas production. In reality, four negative outcomes can be distinguished: production failure, adverse greenhouse impact, adverse health effects, and explosion or fatal toxicity. These four adverse outcomes result from two significant risks known for biogas plants: unsafety or abandonment (Figure 10). Both of these risks have their causes, and to identify the causes for both unsafety and abandonment, we delve into literature.

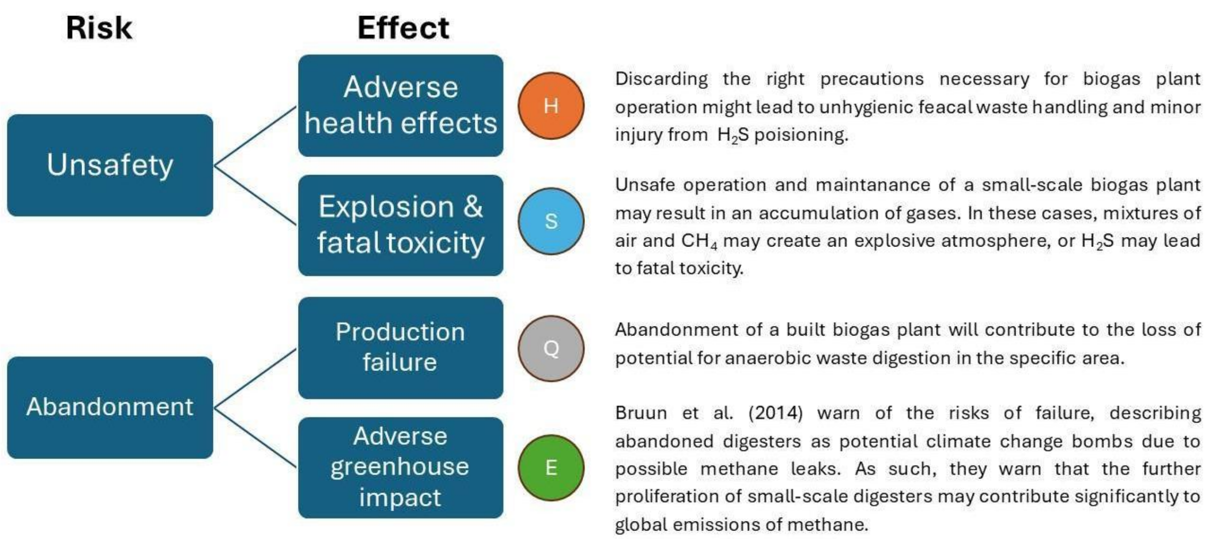

Figure 10. Risks in small-scale biogas plants located in rural areas of developing countries.

Causes of unsafety are, in arbitrary order:

1. **Lack of Training**: Insufficient knowledge and training of operators.
2. **Poor Ventilation**: Gas leaks in anaerobic segments and insufficient ventilation of aerobic areas.

Causes for abandonment are, from most to least significance:

1. **Technical** (*Bangladesh, Vietnam, Kenya*): technical difficulties that cannot be addressed by the operator (Mahdi et al. (2012), Roubík et al. (2016), Wamwea (2017),
2. **Financial** (*universal*): Too high investment and constant maintenance costs (Bekchanov et al., 2019; Chen et al., 2017; Dyah, 2019; E. U. Khan and Martin, 2016; Landi et al., 2013; Mittal et al., 2018; Puzzolo et al., 2016; Rupf et al., 2015; Taylor et al., 2019)),
3. **Farm/farmer selection** (*China, South Africa*): problems in securing feedstock (Jian (2009)), emotional adversity ('yuck-factor') against biogas (Dumont et al. (2021)) and low biogas use rates (Huanyun et al. (2013)).

3.2.4 Design aspects to be considered for small scale bio digester

A review article by Issahaku et al. (2024) has found numerous articles on design considerations for the operation and maintenance of small-scale biogas digesters (Table 3). In the articles, four themes are deemed essential topics for design. These four themes are reactor design and monitoring of critical parameters (temperature, stirring, biogas quality).

Table 3. Number of articles for each theme discussed in the literature from Issahaku et al. (2024)

Subheadings -themes	**Number of documents**
1. Reactor design consideration for small-scale biogas digester	23
2. Stirring mechanisms for small-scale biogas digesters	15
3. Monitoring systems of small-scale digesters	7
4. Small-scale biogas temperature regulation strategies	10
Total	**55**

However, extensive engineering and the option to monitor key parameters resulted in high financial investment and high maintenance costs. Furthermore, automated control and moving parts such as stirring mechanisms will quickly break down and jeopardize digester safety. Issahaku et al. (2024) also mention that poorly designed digesters can result in numerous issues, including decreased biogas production, toxic gas accumulation, and system failures:

> *"key design considerations such as the safety of designs, generated biogas quality, and the safety of discharge or use of effluent from small-scale biodigesters were rarely considered in the literature. Furthermore, there were no reports of guidelines or standards in the design of small-scale biogas digesters."*

The step-by-step process to design a biodigester tailored to the Mozambican context would be as follows:

1. Objective definition:

    a. Identify goals: Determine the primary purpose of the biodigester (e.g., providing biogas for cooking, generating fertilizer, waste management).

    b. Identify target group: Identify the composition of households or small communities that will operate and benefit from the biodigester.

2. Site selection:

    a. Environmental Assessment: Evaluate the site's proximity to organic waste sources (e.g., livestock, agricultural residues) and access to water.

b. Accessibility: Choose a location that is easily accessible for maintenance and waste input; also, the site should be assessed as safe from any risk.

3. System Design:

a. Biodigester Type: Define what type of biodigester is the most appropriate (e.g., fixed dome, floating drum, plastic tubular) based on the access to local materials, expertise and values and beliefs system in the community.

b. Capacity and Construction Materials: Determine the size and capacity of the biodigester based on the amount of available organic waste and the users' energy needs.

4. Operation:

a. Inlet and outlet design, storage and safety design: Incorporate the inlet for feeding organic waste and the outlet for slurry removal, and define the storage facilities for the produced biogas and the piping systems required for transporting the gas. And define safety features to be installed, such as pressure relief valves and flame arrestors.

b.Waste collection and feeding: Determine the logistics for regular organic waste collection from households and farms to feed the biodigesters. Built capacities within the team to ensure consistent input of organic material into the biodigester.

c.Maintenance schedule and training: Establish a regular maintenance schedule to check and repair any parts of the biodigester system and train community members on the proper use of the technology.

3.3 Bio fertilizer

3.3.1 Introduction

In Mozambique, the agricultural sector faces significant challenges, including low soil fertility, limited access to conventional fertilizers, and the growing impacts of climate change. As climate variability increases, so does the urgency to adopt sustainable agricultural practices that enhance soil health, improve crop yields, and build resilience against climatic threats.

Biofertilizers offer a promising solution to these challenges. Produced from natural materials such as compost, manure and microbial inoculants, biofertilizers enrich the soil with essential nutrients and beneficial microorganisms. Unlike synthetic fertilizers, they promote sustainable agriculture by enhancing soil fertility without depleting the soil's natural resources or harming the environment.

In this sense, biofertilizer technology is gaining attention due to its considerable benefits, especially in sustainable agriculture, and its global market is growing (Suyal et al., 2016; Markets & Markets, 2019). However, strategies such as input subsidies, financial support and market development must be created to support the development of biofertilizers (Chianu et al., 2011).

Biofertilizers can be divided into two main categories: biofertilizers based on organic waste and biofertilizers based on microorganisms as a raw material source. Being an economical and safe technology, biofertilizers are suitable for African countries where cheap labour is abundant and agrochemical inputs are expensive and not readily available (Rami et al., 2018). However, an often overlooked aspect of biofertilizer application is field implementation. Therefore, it is advisable to facilitate farmers' work by developing simple applications, adapting to different agricultural methodologies and allowing simple product storage (Mitter et al., 2021).

3.3.2 Different processes for producing biofertilizer

3.3.2.1 Process based only on organic waste

The process of producing biofertilizer based only on organic waste consists of fermenting manure existing on the farm, with or without adding other organic waste (ash), nutrients (sugar and milk), and water.

In Mozambique, biofertilizers based on organic waste are not widely used due to insufficient skills and know-how. There is little information and research on the effect of biofertilizers on the main crops produced in the country. Work carried out at the Faculty of Agricultural Sciences of the Zambezi University (Candido and Chipiringo, 2014, unpublished data) in the municipality of Ulónguè with biofertilizers based on organic waste in lettuce cultivation shows that the biofertilizers had similar results to chemical fertilizers.

Figure 11. Biofertilizer production. A: Anaerobic fermentation and B. Aerobic fermentation.

3.3.2.2 Production of microorganism-based biofertilizer

The production process of microorganism-based biofertilizers is economical and simpler than chemical fertilizers (Vessey, 2003). Bioinoculants based on microorganisms are developed for application to the surface of plants, seeds or mixed into the soil with eventual colonization of the rhizosphere or endosphere of plants (Mataranyika et al., 2022). Zambrano-Mendoza et al. (2021) showed a 30% increase in productivity and a 21% reduction in production cost per kilogram due to biofertilizers. Farmers can reduce the application of synthetic fertilizers and sustainably increase crop yields through this technology. However, one potential approach may involve the integration of precision agriculture principles, allowing the identification of specific areas within a given field that may be best suited for a particular formulation tailored to the unique characteristics of the soil and crop (Mitter et al., 2021).

In Mozambique, microorganism-based biofertilizers (rhizobium and bradyrhizobium) are mainly used for soybean and common bean cultivation. Key factors, which include microbial strains, type of formulation, carrier materials and field applications, must be considered during the production of biofertilizers (Malusà et al., 2012). In this context, six fundamental steps must be considered before standardizing the commercial production process of biofertilizers.

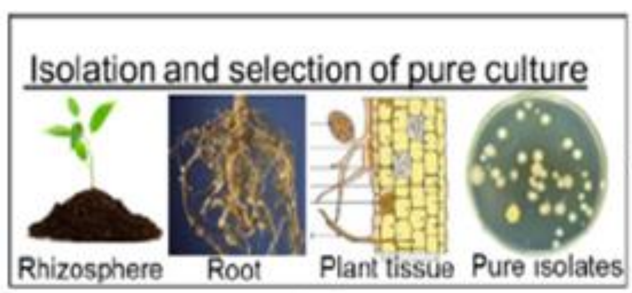

Figure 12.Standardization process for commercial biofertilizer production (Raimi et al., 2010)

1. The isolation, identification and functional characterization of potentially active and non-toxic microbes that can promote plant growth. Functional characterization of microbial strains is performed using general laboratory techniques (Thomas & Singh, 2019).
2. The selection of a pure culture of the target strain(s) based on the desirable functions of the biofertilizers in the field. This step

also involves analyzing the mechanisms and pathways by which strains promote growth. Molecular techniques, including genomics, metabolomics, proteomics and transcriptomics, together with culture-based methods, have enabled comparative analysis of the plant growth promoting capacity of inoculant strains (Krishnamoorthy et al., 2020).

3. The selection of suitable formulation materials is essential in determining the form of the product, whether liquid or vehicle-based, such as granulate, powder or paste (Abd El-Fattah et al., 2013).
4. The choice of a viable propagation method for cultivation and multiplication of the selected strain(s) in the laboratory under optimal conditions to preserve the inherent properties of the microbial strains for effective performance when used in the field (Suthar, et al., 2017)5.
5. The prototyping and testing of the products in the field to assess the results (Bhattacharjee & Dey, 2014).
6. The testing of products in the field on a large scale to ultimately determine the actual efficiency and limitations of the products under various regions and ecological conditions before formalizing a standardized process for commercial production (Bhattacharjee & Dey, 2014).

In this context, Raimi and collaborators conclude that through adequate training, effective extension programs, and public-private partnerships, biofertilizer adoption and application can be improved. Collaborations should be made between government agencies, and private sector companies.

3.3.2.3 Production of vermicomposting

Figure 13. Vermicompost bed production.

Vermicompost production is defined as the production of biocompost using worms. This is a low-cost technological system that most farmers have adopted in Mozambique. Different types of substrates can be used for the vermicomposting process. Different types of earthworms, such as E. foetida, E. andrei, L. terrestris, P. excavatus and E. eugeniae have been used for vermicomposting different types of organic and industrial waste. In commercial vermicompost production, beds can be prepared 15 meters long, 1.5 meters wide and 0.6 meters high. The organic material, manure and agricultural residues must reach a height of 0.6 to 1 meter. Earthworms must be placed at 1kg/m3. Keep the beds at 40 – 50% humidity by sprinkling water on the beds at a temperature of 21 - 30oC. There must be a gap to protect the beds.

The three different processes to produce biofertilizers that have been presented have advantages and disadvantages that are presented in the table below:

Table 4. Advantages and disadvantages of biofertilizing production.

Process	Advantages	Disadvantages
Biofertilizer with organic waste	• Low-cost production, • There is no need for high-tech infrastructure, • There is no requirement for highly skilled personnel.	• When produced for the first time, there is a need to analyze macro and micronutrients present in the biofertilizer, • Difficult to reach consistency in the quality of the result. • Requires agricultural inputs from the farm.
Biofertilizer with microorganisms	• Boosts beneficial microbial activity in the soil • Improves nutrient uptake efficiency of plants • Can reduce the need for chemical fertilizers	• Requires careful handling and storage to maintain microbial viability • Quality can be inconsistent if microbial cultures are not well-maintained • Sensitive to environmental conditions such as temperature and humidity • May need supplementation with organic matter or nutrients
Vermicompost	• Converts organic waste into a valuable soil amendment • Improves soil structure, water retention, and fertility • Reduces greenhouse gas emissions from organic waste • Can be produced using a variety of organic materials	• Requires time and space for proper composting • Potential for inconsistent nutrient content • May attract pests if not properly managed • Needs regular turning and monitoring during the composting process

3.3.3 Challenges and Risks associated with Biofertilizer production

According to Raimi et al. (2020), Africa's main challenges include a lack of production facilities, inadequate production equipment, a lack of qualified personnel, insufficient financing, and a lack of awareness about biofertilizers. Government intervention can mitigate these challenges through the deliberate financing of institutions involved in developing and producing biofertilizers. Encouraging public-private partnerships can stimulate large investments in biofertilizers and cause an increase in demand and supply of the product.

The International Institute of Tropical Agriculture, Mozambique, refers to the lack of production facilities, lack of a well-developed distribution network, no regulatory framework, and lack of agro-dealers in rural areas as challenges in Mozambique for upscaling the use of biofertilizing.

3.3.4 Design aspects to be considered for Biocomposting systems

The key factors that need to be considered for the production of biocomposting are described below:

1. Waste Types and Sources

    a. Organic material: determine the types of organic waste available (agricultural residues, manure, kitchen scraps).

    b. Waste composition: balance carbon-rich (browns) and nitrogen-rich (greens) materials to achieve an optimal carbon-to-nitrogen ratio.

2. System Size and Capacity

    a. Volume of Waste: Assess the volume of organic waste available at the production site to determine the appropriate size and capacity of the composting system.

    b. Scalability: consider the potential for scaling the system up or down based on future waste generation projections.

3. Location and Space

    a. Site selection: choose a location that is easily accessible, has good drainage, and is away from residential areas to minimize odours.

    b. Space requirements: Ensure enough space for the composting piles or bins and space for turning and processing the compost.

4. Climate and Environmental conditions

    a. Temperature: Ensure the system can maintain optimal composting temperature (typically between 55-60 Celsius degrees)

    b. Moisture control: Maintain proper moisture levels (550-60%) to facilitate microbial activity and prevent the compost from getting dry.

    c. Turning Frequency: Consider the schedule for regular compost turning to introduce oxygen and prevent anaerobic conditions.

d. Aeration Systems: Consider using passive or active aeration systems to enhance airflow within the composting material.

4. Permits and Regulations:

a. Permits: Ensure the composting system complies with local regulations and obtain necessary permits.

b. Environmental Impact: Identify potential environmental threats and mitigate potential negative effects.

5. En-Product Utilization

a. Quality Control: Implement quality control measures to ensure the compost meets agricultural standards

b. Application methods: Develop guidelines for the proper application of the compost to the crops and the soil

3.4 Solar Powered Irrigation Systems

3.4.1 Introduction

Solar irrigation uses solar energy from the sun to pump water from a source to bring it to the plants (to irrigate). Solar panels power the pump and conveyance lines to bring water to an agricultural plot, and application tubes, drips, or sprayers are used to apply water directly into the plant's root zones. The total set-up is called a solar-powered irrigation system.

Solar pumps are an alternative to manual and fuel pumps. There are important differences to consider from a technical perspective:

- Energy from the sun is free. So, running costs are much lower than for fuel pumps. However, solar pumps are often more expensive to buy.
- Submersible solar pumps allow access to water deeper than 7-8 m; therefore, they can be used in conditions where it is not possible to use manual or normal fuel pumps.
- Solar pumps can be more complex in their maintenance than manual or fuel pumps due to the fact that they are more difficult to source. Expertise from an electrician/solar technician is required for more complex repairs.
- Solar pumps provide a relatively low flow over the course of the day. This flow varies depending on the intensity of the sun. The more sun, the higher the flow. In comparison, fuel-powered pumps provide a high and stable flow in a short amount of time.

Solar Powered Irrigation Systems (SPIS) are commonly stand-alone systems, meaning that the energy generated is directly used to pump water, not taken from an electricity grid.

Sizes of SPIS vary. Stand-alone systems are often small-scale or medium size systems. To indicate the size of an SPIS, the following parameters are often used:

a) Photo Voltaic (PV) capacity of the system in kilo Watt (kW);
b) Number of acres of hectares being irrigated by the system.

Systems with a capacity of up to 4kW and irrigating less than 2 ha are often considered small-scale. Those with a capacity of up to 40kW and irrigated between 2 to 10 ha are considered medium-sized. Large-scale systems are those that irrigate more than 10 ha.

3.4.2 Different components of Solar Pumping Systems

Submersible pumps are typically used where water is available at a greater depth, and open wells are unavailable. The hermetically sealed motor-pump assembly is completely immersed in the water. Solar submersible pumping system operates directly off the solar panels as power source.

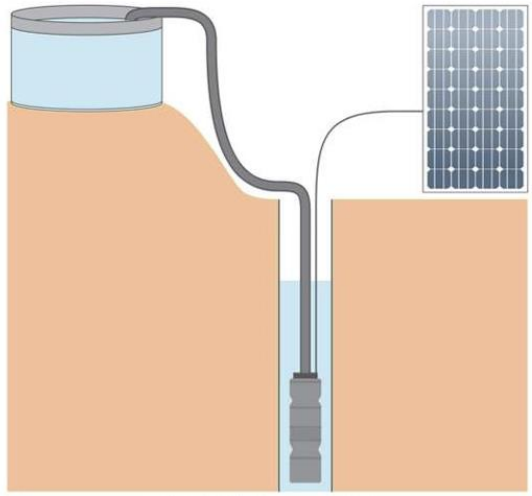

Figure 14. Submersible pump system (Water mission, 2019).

For open source/surface water sources, surface water pumps are installed at ground level to lift water from shallow water sources such as shallow wells, ponds, streams, and storage tanks. These surface water pumps are also suitable for lifting and pumping water from a maximum depth of 7 meters.

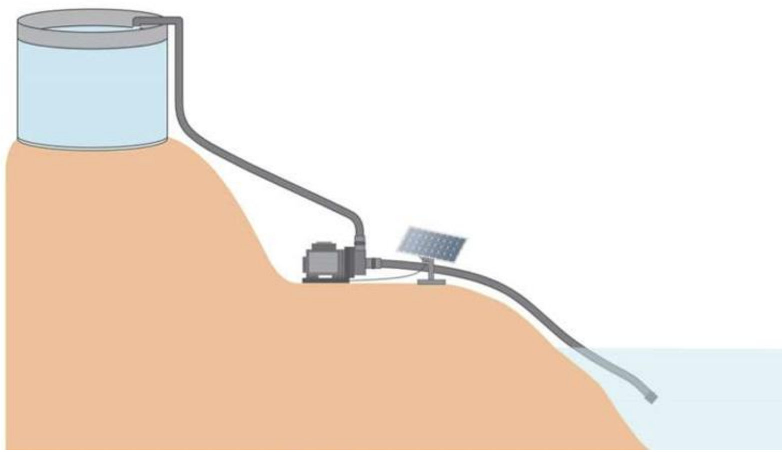

Figure 15. Solar surface pump system (Water mission, 2019).

Table 5 presents a comparison matrix between suction and submersible solar pumps (based on literature review and the consortium experience).

Table 5.Comparison between surface and submersible solar pump devices.

Aspects	**Solar suction pump**	**Solar submersible pump**
Location of the installation	Installed above the ground, usually next to the water source they are pumping.	Installed below the water level, submerged in the fluid they are pumping.

Functionality	Draw water from the source and then pump it to the desired location. Suitable for shallow wells and surface water.	Operate by pushing the fluid to the surface. They are more efficient for deeper wells and can usually provide higher pressure.
Maximum water depth	7m **maximum**	Depending on pump, pump is installed below the static water level.
Size and Design	Usually take more space as they are designed to sit above the ground. They usually have a more visible and accessible design.	Typically, it is smaller in size and designed to be submerged. They are more compact and often quieter compared to surface pumps.
Cost	Usually, it is more affordable in terms of upfront costs, but operational costs may be higher.	Generally, they are more expensive to purchase and install, but their efficiency can lead to long-term cost savings.
Theft	More visible and accessible, making them potentially more susceptible to theft or vandalism. Security measures, such as fencing or locking mechanisms, may be necessary to prevent unauthorized access.	Generally, they are less vulnerable to theft due to their submerged nature. They are out of sight and more challenging to access without proper equipment and knowledge.
Usually applied to	River, stream, pond, hand dug well, borehole (water at less than 7m)	Hand dug well, borehole
Resistance to silt/sand in water	Usually more resistant	Usually more sensitive to clog when exposed to salty water.
Type of installation	Generally portable	Generally fixed

3.4.3 Challenges and risks of using SPIS

There are different challenges and risks related to solar-powered irrigation systems in rural Mozambique. The main difficulty is not the actual use but rather the accessibility of the technology. Despite the decreasing prices of solar PV panels, the prices of solar-powered pumping systems are still much higher than fuel-powered pumps, especially when comparing pumps of similar capacity (flow and pressure). While the running costs of solar pumps are lower since no fuel is needed, the upfront investment is higher, which forms a barrier for most small-scale farmers. Women and youth who are more resource-constraint than men are disproportionately affected by this high investment cost. Therefore, introducing SPIS requires specific finance solutions to enable inclusive access to this technology.

A second challenge is the lack of technical capacity to repair SPIS (Durga et al., 2024). Since it is a relatively new technology, farmers and local technicians have little experience. Therefore, farmers rely on technicians from the suppliers, who are often located in the capital or major towns. Besides the required technical skills and tools, spare parts are also not widely available and must be requested from the supplier. The long time it takes to fix a solar pump poses a significant risk to farmers, who may lose their harvest.

Finally, there are some technical challenges. This mainly depends on the farmer's previous experience. Solar pumps generally have a smaller output in terms of flow and/or pressure than fuel-powered pumps. In practice this means that irrigation may take longer, and that conventional irrigation techniques, such as furrows, are not always compatible. Introducing solar powered irrigation requires a shift in irrigated production practices, which requires time. Training and clear information provision by the supplier, as well as guidance offered to farmers by NGOs or the government, could support this development.

Another risk of using solar power is the risk of theft since most SPIS are not mobile. Protective measures against theft can increase the cost of solar powered irrigation systems.

Finally, another risk mentioned by many authors, including the World Bank (2024), is that SPIS may increase groundwater usage due to zero pumping costs. Especially in the densely populated South Asian region, this could cause major water security problems. However, groundwater abstraction could be greatly increased on average in nearly all Sub Saharan African countries, including Mozambique, even after stringent environmental provisions are made (World Bank, 2018). The challenge here is to use sustainable and replenishable water sources, such as shallow groundwater, and if surface water is used, assess to what extent the pumped volume can impact downstream users during the dry season. According to the World Bank (2024), investments in solar pumps should be coupled with efforts to measure and manage the risks associated with water depletion to ensure that the benefits of solar irrigation are maximized while mitigating potential drawbacks.

3.4.4 Design aspects to be considered for Solar Powered Irrigation Systems

The key aspects that play a crucial role during the design of a SPIS are the water source, selection of pumping system, internet of things (sensors and electronic components), and irrigation application systems. Each of them is described below:

Water source

The number one criterion for designing an irrigation system is the water source and availability during the dry season. The sustainable yield and water quality determine the project's feasibility and the irrigation system's maximum size. Next to this, the static and dynamic water level, the diameter of the well, and the horizontal and vertical distance to the field are key aspects to consider when designing the system and selecting the pump.

Pumping system

Solar-powered irrigation systems exist in a wide array of sizes and at various prices. According to Durga et al. (2024), larger pumps (3-5 HP) are more effective than small pumps (<2 HP) in cost and capacity to pump water from depth and to deliver at longer distances. Larger pumps had better utilization and demand than smaller individual pumps because of their improved economics and performance in the summer season. On the other hand, oversized systems increase the upfront investment cost and reduce the barrier to overpumping. Therefore, the exact pump model and panel capacity to be selected should result from a proper assessment of the required daily water volume and pressure head. While the pressure head results from the water depth, terrain, and selected application method, the water volume is mainly a function of the irrigated area in a given region. Apart from the choice between either fruit trees or vegetable production, the difference in water requirement between crops is minor and not critical for the design of an SPIS. In fact, most farmers change crops every season; hence, a certain margin for flexibility is recommended. Durga et al. (2024) confirm the need for flexibility, allowing farmers to modularly adapt and expand their irrigated area. In this sense, it is better to select a pump with some overcapacity rather than one that is fully optimized for a specific crop-season-combination.

The Internet of Things

Barman et al. (2019) describe how the Internet of Things (IoT) could substantially reduce the operational costs of India's solar-powered irrigation systems. It enables the automatization of irrigation systems through predefined field moisture levels and continuous monitoring through a range of sensors and microcontrollers, which will activate the pump when water is required. The measurements and operations are linked to a database and distant operation device using the IoT. While in the Indian context, the use of IoT in SPIS seems promising, Durga et al. (2024) came to a different conclusion in their review of SPIS in Sub-Saharan Africa (SSA). They report that while in theory the use of remote operation and the Internet of Things may improve the product design and adoption of SPIS, they found that in practice IoT adds to the high capital cost, which is already a critical barrier for the adoption of solar irrigation. Besides the cost, the researchers state that IoT and sensors require additional capacity for management and repairs, which is generally unavailable in rural areas of Sub-Saharan Africa. Therefore, using the Internet of Things may exacerbate the two main risks already hampering the scaling of SPIS in SSA, i.e. the price and the maintenance capacity (see 4.3).

Irrigation application system

While drip irrigation is often considered the most efficient and optimal water application system for SPIS, in reality, there is not one ideal application system for all situations. Besides water efficiency, the design of an irrigation application system involves factors such as crop choice, water quality, cost, availability and farmers' preference. Van de Zande et al. (2023) found that the preference for application methods for solar pumps differs amongst different types of farmers. Experiences by Practica in SSA found four main types of application systems adapted to small-scale SPIS: drip, spray tube, californian and sprinklers. The following table shows the main aspects to take into account when selecting the application system:

Table 6.Advantages and Disadvantages of each irrigation application system.

Application Systems	Advantages	Disadvantages
Drip	• High water efficiency, localized application	• High cost and fixed spacing of plants
Sprinkler	• Movable fixed options	• High cost, high pressure required, sensitive to wind, increased weeds
Spray tube	• Quick and easy to install and maintain	• Sensitive to wind, increased weeds, difficulties with high crops
Californian	• Low cost and easy to adapt by farmers	• More labour is required to irrigate

Once the application method is selected, an adapted calculation tool is recommended to determine the sizing and dimensions of the system. The IRRIS software developed by Practica could help to determine the field set-up, bill of quantities and installation aspects to consider for the chosen pump and application method. See the image below.

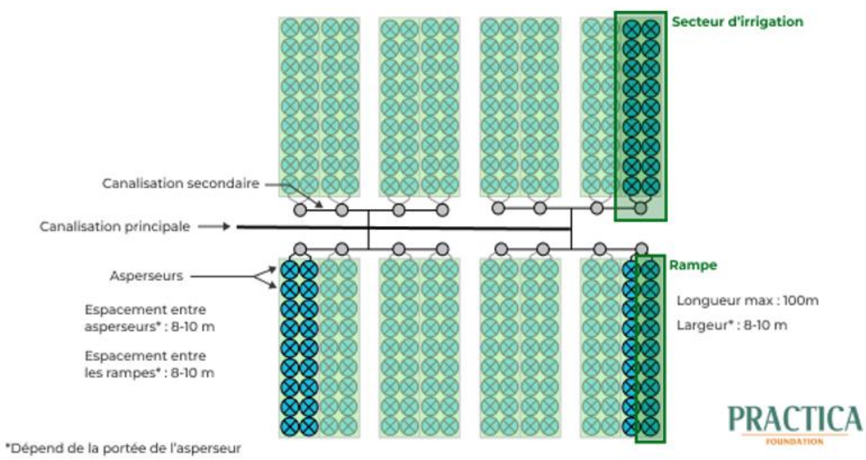

Figure 16. Irrigation application system representation (Practica, 2019).

4. Different Water-Energy-Food initiatives in the region

The consortium defines an innovative farm as one that includes the four mentioned technologies in this technical assistance into one functional and financially sustainable farm. To this date, only examples of pilots testing the technologies separately have been found in the context of Mozambique. Some initiatives aligned with the current technical assistance are presented below:

4.1 Water and Energy for Food initiative (WE4F) [7]

Water and Energy for Food (WE4F) is a joint international initiative of the German Federal Ministry for Economic Cooperation and Development (BMZ), the European Union (EU), the Ministry of Foreign Affairs of the Government of the Netherlands, the Norwegian Agency for Development Cooperation (Norad), Sweden through the Swedish International Development Cooperation Agency (Sida), and the U.S. Agency for International Development (USAID). WE4F, through its Regional Innovation Hubs, provides financial support, technical assistance, and investment facilitation to water-food, energy-food, and water-energy-food innovations. The supported innovations impact smallholder farmers, helping them unlock missing inputs, finance, technology, and markets. Farmers and food companies can use these innovations to enhance their climate resilience and reduce CO2 emissions.

4.2 Sofala province Water, Energy, and Food security project (SWEF)[8]

The project aims to improve the adaptive capacity of rural smallholder farmers to the impacts of climate change and to reduce poverty in an inclusive manner. The project includes innovative and inclusive solutions to tackle chronic and transient food and nutrition insecurity caused primarily by low agricultural production. It also introduces solutions to improve access to water, sanitation, and clean energy by exploiting the food, water and energy nexus. The project will promote well researched climate smart agricultural technologies to improve agricultural production and conserve the natural environment. The overall activities for this project included establishing demonstration pilots for testing different climate smart agriculture technologies and conducting knowledge sharing and capacity building activities to enhance adoption of selected practices. This project is anchored in Mozambique's National Agricultural Strategy (PEDSA 2011-2020), which aims to achieve broad based economic development through agricultural sector growth. The strategy aims to turn agriculture into a modern, commercially driven and inclusive sector to achieve national economic development. By diversifying the crop production base, and improving the production of nutritious food and high value cash crops through climate-smart agriculture (CSA), this project will directly contribute to the attainment of PEDSA's vision.

[7] https://we4f.org/

[8] https://www.entwicklung.at/en/projects/detail-en/sofala-province-water-energy-and-food-security-project-swef

4.3 Revenue diversification pathways in Africa through bio-based and circular agricultural innovations (DIVAGRI)[9]

The DIVAGRI project proposes a wide range of bio-based innovative solutions adapted to specific conditions in target countries. The focus is not only on the primary production sector but also on the food and bio-based industries, thus promoting partnerships between producers, processors, retailers, and consumers and opening new sustainable avenues for businesses, services, and value chains that support rural communities.

Through the project, different bio-based solutions are being codesigned with rural farming communities in the countries where implementation is being done. These solutions are later tested and further improved through a participatory approach towards improving their performance. Finally, the overall goal is to create new sources of income in the targeted farming communities through new bioproducts from residues such as biogas, slurry, biocompost, etc.

For this technical assistance, the know-how on the production of biocompost using the vermicompost method is relevant so as not to duplicate efforts and try to reinvent the wheel. The manual published by CITT in the past years provides a clear step-by-step approach towards setting the suitable bio composting production system.

4.4 African Biodigester Component (ABC)[10]

The African Biodigester Component (ABC) supports the growth and sustainability of the commercial biogas sector in Sub-Saharan Africa. It is a programme from the Netherlands Enterprise Agency (RVO), and focuses on Burkina Faso, Kenya, Mali, Niger and Uganda. The. The program aims to create sustainable biodigester markets in the countries mentioned above by creating awareness on the demand side with a strong focus on the biodigester business case, providing result-based evidence, and providing business development services to the local companies that enter the development trajectory.

Initiatives such as the ABC show the complex approach that needs to be taken to support the creation of a sustainable introduction of technologies in rural communities. In conclusion, they mention numerous financial, political, sociocultural, informational, institutional, and technical factors contributing to biodigesters' low adoption rates. This knowledge will be tapped in during this technical assistance to minimize risks of failure.

4.5 Feed the future Mozambique Climate Smart Agriculture-Beira Corridor (FTF-RESINA)[11]

The five-year USAID Feed the Future Climate Smart Agriculture Beira Corridor (FTF-RESINA) aims to increase local producers' agricultural productivity and profitability while increasing their

[9] https://divagri.org/
[10] https://english.rvo.nl/subsidies-financing/see-clean-cooking/abc
[11] https://www.acdivoca.org/projects/usaid-feed-the-future-ftf-resiliencia-integrada-na-nutricao-e-agricultura-resina-in-nampula-and-zambezia-provinces/

resilience to climate change by adopting resilient agricultural technologies and practices. The objectives are to improve household food security approaches, yields of nutritious commodities and profitability of agricultural enterprises. They promote this by integrating climate-smart agriculture practices and tools and good management of multi-use water systems. They have been promoting the adoption of drip and solar irrigation practices with the smallholder farmers' communities they work with.

4.6 Identified recurrent risk and mitigation measures

During the literature review, numerous initiatives aiming to improve the livelihood conditions of smallholder farmers in Africa and Mozambique popped up. Notably, most of the risks apply to the different technologies to some extent.

Table 7. Barriers and Mitigation Measures to scale up WEF technologies in global South rural contexts (adapted from WorldBank, 2019).

	Main barriers	Description	Mitigation measures
Technical	Poor technical expertise and inadequate training and follow-up	Lack of expertise in the construction, operation, and maintenance of the technologies, especially in rural regions. Lack of availability and/or access to technicians for repairs	Support the adoption of easy-to-use technologies, enhance the use of materials that can be sourced in local markets (not only the capital)
	Lack of inputs (water, feedstock, food, fertilizer)	Lack of access to good quality inputs E.g., manure is the most important feedstock for digesters: farmers with low numbers of cattle are less willing and/or able to adopt digesters. Furthermore, rearing cattle and other livestock in grazing systems makes dung collection for biogas unfeasible.	
	Lack of suitability and availability of spare parts used	Reliance on expensive imported construction materials and spare parts: unable to access shops to replace broken or stolen components.	
	Poor design and construction: unsuitable for	Local conditions are not fully considered: e.g., local demand, access to	

	local conditions and/or users	maintenance/knowledge, spare parts, etc. Land tenure: the majority of demonstration pilots are owned by the government, it is not feasible if the land is not owned by a farmer who will have agency on the project once it finishes.	
Economic	High investments, installation and maintenance costs	Depending on the technology, investment costs are high compared to the regular income of smallholder farmers.	Most smallholder farmers are very price sensitive. Therefore, a cost effective technology needs to be designed (e.g., using cheaper, locally produced materials). Target better-off farmers who have access to financial services. E.g., microfinance and credit. Studies show that smallholder farmers are more likely to adopt technologies if their income is medium or high (they have less to lose)
	Reduced supply of family labor	Reduced supply of household labor as a result of progress with education and in search for paid employment	
	Not seen as a productive investment	There is a lack of long-term vision to foresee these investments as an opportunity to increase the income fo the household in the medium-long term	Show solid business cases around the technologies that realistically consider the resources, knowledge, and socio-cultural aspects of the community for which the technology has been designed.
Socio cultural	Lack of interest/ motivation	Low interest in trying new technologies seems complicated	Provide clear and open information, training and capacity building to the smallholder farmers
	Lack of knowledge	Lack of awareness about the technology and its benefits and low literacy levels make adoption of any technology more difficult	Level of education/ awareness plays an important role
	Traditions	Preferences for production technologies can hinder or boost the uptake of different technologies	
	Gender	Women tend to perform part of the work and thus are involved in the use of the technologies. However, they	Consider gender issues within farming households

		barely have any say in decision-making regarding investing in specific technologies.	
Institutional	Absence of policies, regulatory frameworks and standards	Regulatory vacuum creates uncertainty among users of the technologies towards making investments in certain technologies	Use existing structures in the agricultural sector: target farmer's associations for information provision, awareness creation, training and capacity building Identify key institutional players, strengthen their capacities to effectively carry out their roles, and provide technical and management support to all key players.
	Absence of information	In most countries, up-to-date information, knowledge sharing, and research are lacking to close the gap between the users of the technologies and the private suppliers.	Support the government to standardize proven technologies or formulate minimum requirements to make a quality control templates and allow private companies to enter the market. Build platforms at national and regional levels for information exchange and promotion of regional cooperation.

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