Commissioned by: UN Environment, CTCN, Adaptation Fund

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

Implemented by: HUB & Practica

Country: Mozambique

Deliverable: 3.1 Flowchart design for the expected system including all the components for the selected farm.

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

Flowchart design for the expected system including all the components for the selected farm

PRACTICA HUB

January 2025

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With the support of the Ministry of Science and Technology and High Education

Implemented by PRACTICA & HUB

Commissioned by UN Environment, CTCN, Adaptation Fund

Disclaimer

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 includes aquaculture, biodigester, bio composting, and hydraulic management systems (including water storage and solar pumping integrated systems for drip irrigation).

This deliverable aims to provide the methodology and technical specificities for designing the complete system flowchart that includes the four components: solar pumping systems and irrigation, aquaculture, bio-composting and biogas production.

2. Methodology

To successfully design a Water-Food-Energy (WEF) System, it is essential to understand the limiting factors hindering the system's expansion. The limiting factor concept is explained with Liebig's law of the minimum[1], which states that the rate of growth or success of a plant depends on the amount of the scarcest of its essential nutrients available to it. Figure 1 below exemplifies the law by showing different elements present in plant nutrition and how the limiting one hinders the production yield.

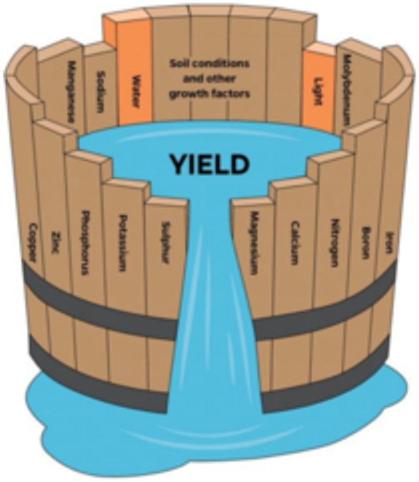

Figure 1. Exemplification of Liebig's minimum law.

Translating this principle to this technical assistance, the first step is determining the limiting factor to set up the basis for designing this system. Two significant constraints were identified: One is water, and the other is land available for agriculture. To make the system flexible and as adaptable to typical conditions in the Zambezi Valley, the area defined as the minimum basis for designing this system has been defined as 0.5 ha for agriculture.

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[1] https://www.oxfordreference.com/display/10.1093/oi/authority.20110803100104700

Once the agricultural production area is determined, the next step is calculating the water consumption to ensure enough water for irrigating the crops. This is followed by integrating the reservoirs for fish production (aquaculture), where the nutrient-rich water will later be used to irrigate the horticulture fields. Finally, the animal, biogas and biocomposting production units have been integrated into the smart farm system.

3. Flowchart of the Water-Energy-Food System

Figure 1 below shows an overview of the water-energy-food flowchart of the system that is being designed for the selected farm. The green arrows represent inputs into the system, and the red arrows showcase outputs, which are often a result after a particular process takes place. This diagram aims to show the interconectiveness between the technologies and to provide a common ground to begin the technical design and sizing of the technologies in the field.

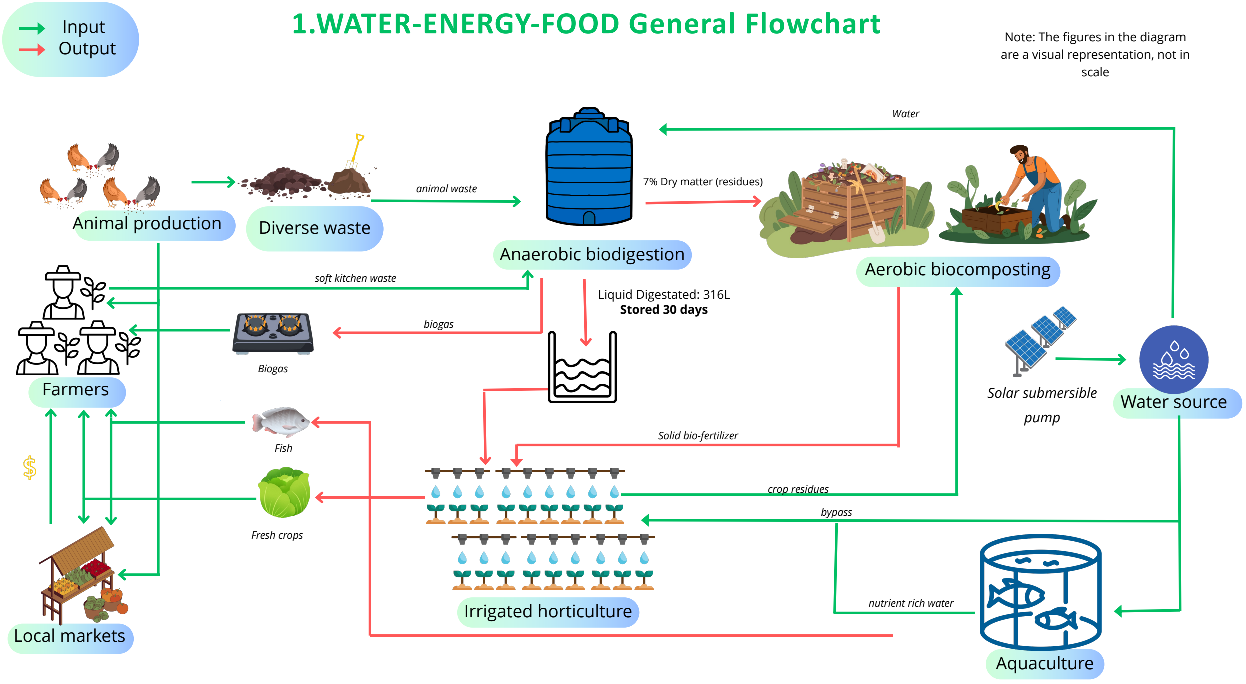


Figure 1. Flowchart of the Water-Energy-Food nexus technologies.

4. Distribution of the technologies in the farm

The information collected in deliverable 2.4 includes mapping the different land uses on the farm. The figure below provides an overview of the overall distribution of how the technologies can be distributed on the farm. The red square represents the biogas facilities, and the yellow square represents the facilities for chicken production. Green small squares are the facilities for bio-composting, next to the two aquaculture tanks represented in blue. The 12 yellow-green squares represent 0.5 irrigated area in total (see figure below).

Figure 2. Overview of the productive areas distributed in the selected farm.

5. Solar Pumping and Irrigation System

Once the links between the technologies have been identified and the areas have been assigned to each technology, this chapter presents the steps followed by each specialist for the technical design and integration of each technology into the overall WEF farm. This information can later be used to replicate this experience in a different setting under different conditions.

5.1 Methodology for selecting the water pump.

To make a successful design of an irrigation system, there are several steps to take to select a solar irrigation system adapted to the farm situation:

1. Identify the water source and determine the yield available during the driest season.
2. Determine how much water is needed to irrigate at the peak of the crop season and the availability of daily energy available from the sun.
3. Select the application and conveyance system and determine the required pump yield.
4. Calculate the friction losses and total head (Technical term that represents how much pressure the pump will need to provide).
5. Select the pump that fits the design needs and is available in the market.

6. Buy the correct pump and irrigation equipment.

5.2 Location, field size and slope of the selected farm

The minimum area for the design has been defined as 0.5 ha of agricultural land.

As expressed in the previous deliverable, the selected area for implementing the Technical Assistance farm of Mr Domingos Tomas, with the farmland linked to the city by a dust road. GPS coordinates are shown in the table below.

Table 1. GPS coordinates selected farm.

Latitude	19 01’29’’ South
Longitude	33 27’11’’ East
Altitude (m)	640

The farm is already producing only 2.5 hectares; see deliverable 2.4. However, as presented in the methodology, the design will be done for a module of 0.5 ha, which can then be replicated towards the expansion of the productive area. This aims to solve the main limiting factor to expanding agricultural activities, as stated by the farmer: the lack of available investment.

The farm terrain rises about nine meters from the lake to the center of the farm (see red arrow in the image below), after which the terrain flattens. The maximum slope in this trajectory is 5.4 %.

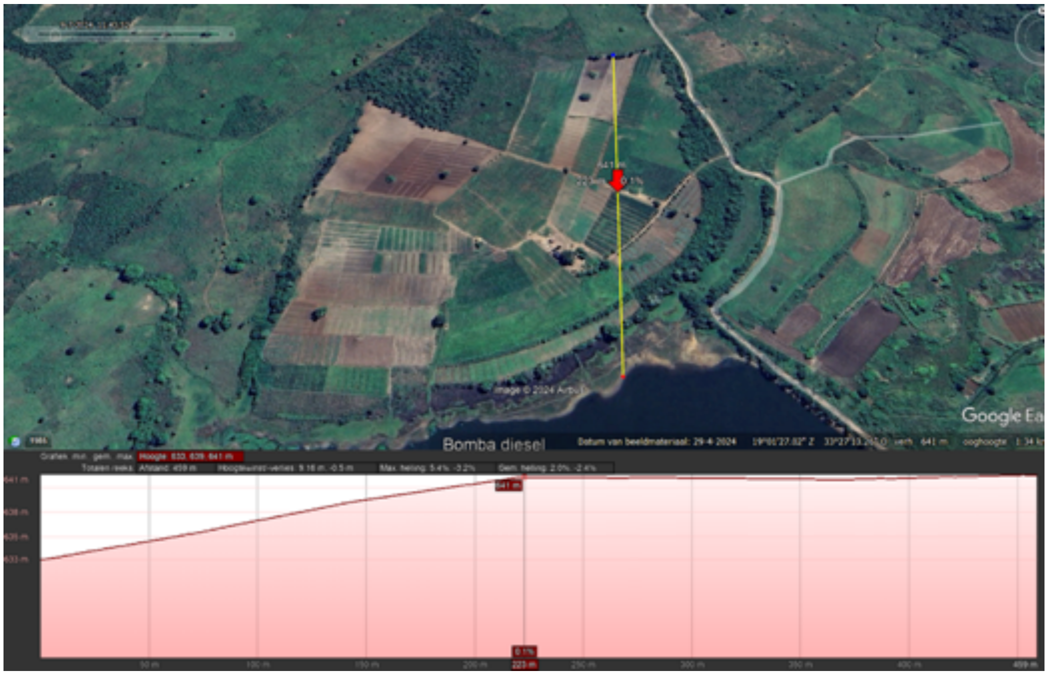


Figure 2. Slope analysis from the lake to the center of the farm.

Drawing a diagonal line from the lake to the upper left side of the farm (see image below) shows an elevation of nine meters towards the center of the farm (red arrow) and a total elevation difference of 15 meters (see figure below). The maximum slope in this direction is 7.8%, with an average slope of 3.6%. The collected slopes will mainly be used to design the aquaculture system and the solar pump's capacity.

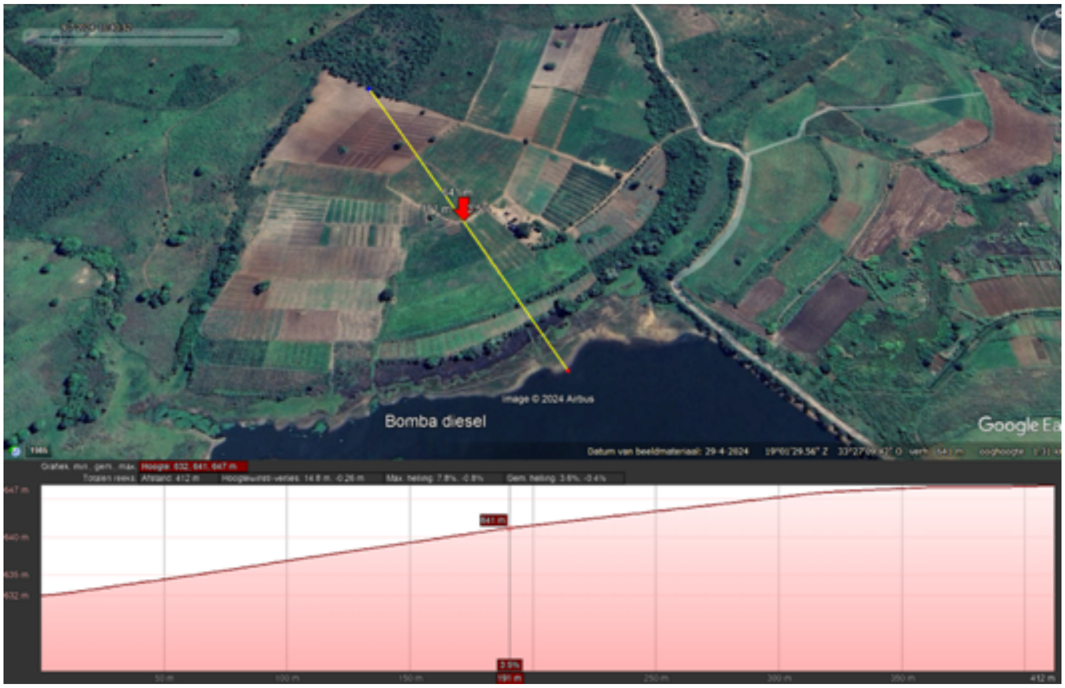


Figure 3. Slope analysis from the lake to the upper left side of the farm.

5.3 Identification of water sources and their availability

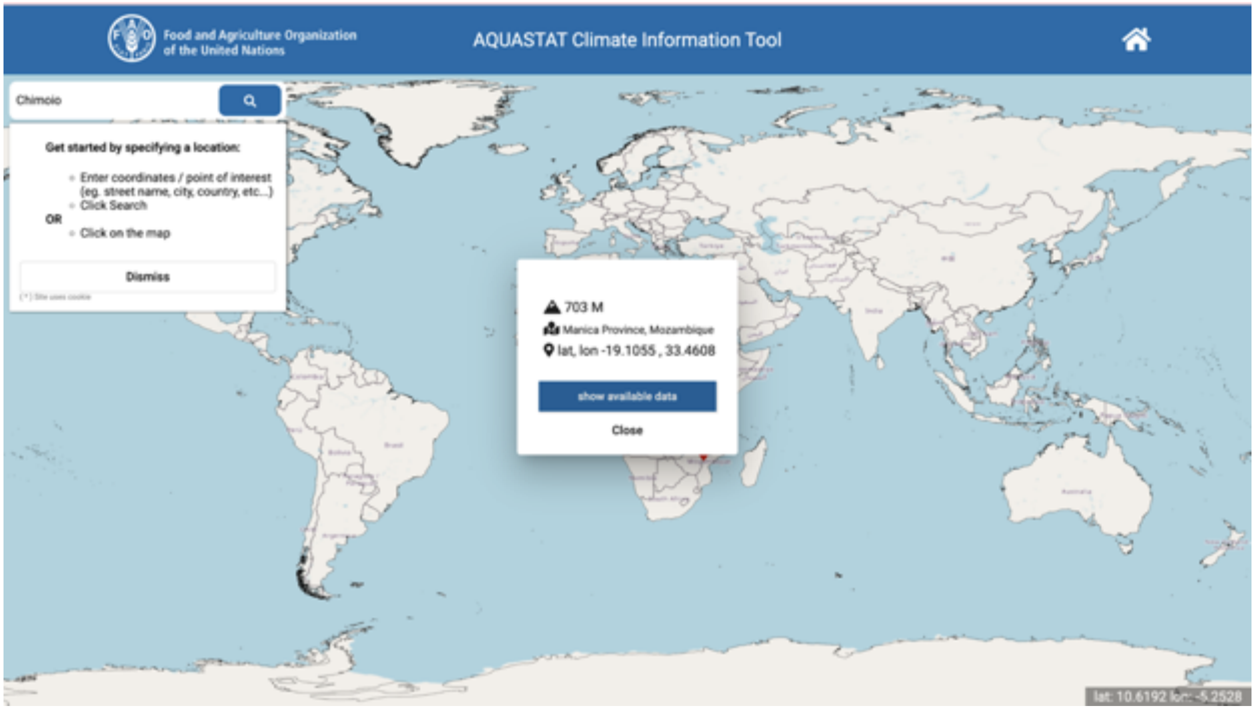
Irrigation water can be sourced from groundwater reserves or rivers and stored surface water. The demand for irrigation water is characterized by its volume, location, timing, and quality. Irrigation typically requires a substantial amount of water, which may not always be of the highest quality. Regarding timing, the need for irrigation water can extend throughout the growing season and, where sufficient resources exist, continue into the dry season to support multiple crop cycles. Peak demand for irrigation water often doesn't align with the highest flows of surface water. This situation necessitates the use of storage capacity, which can be provided by natural water sources like lakes, wetlands, and aquifers or through the construction of purpose-built dams (FAO, 2014).

The specific location of the selected farm puts it in a privileged position, as it is located in the dam's catchment area. Following the suggestions found in literature (FAO, 2014), a sustainable water flow rate for surface water can be fixed as 30 m^3/h; this value will be used further in the design process.

As the consortium recognizes having a reliable surface water source is not common in the Zambezi Valley, the design trajectory will also include drilling a borehole to provide access to water. By doing this, we ensure the design can be replicated in different settings.

5.4. Weather Data

The selected farm is located in Chimoio city, Manica province, Mozambique. The web application AQUASTAT, designed by FAO, was used to gather the climatic data from the closest climatic station to the project area.



Chimoio

Get started by specifying a location:

- Enter coordinates / point of interest (eg. street name, city, country, etc...)
- Click Search

OR

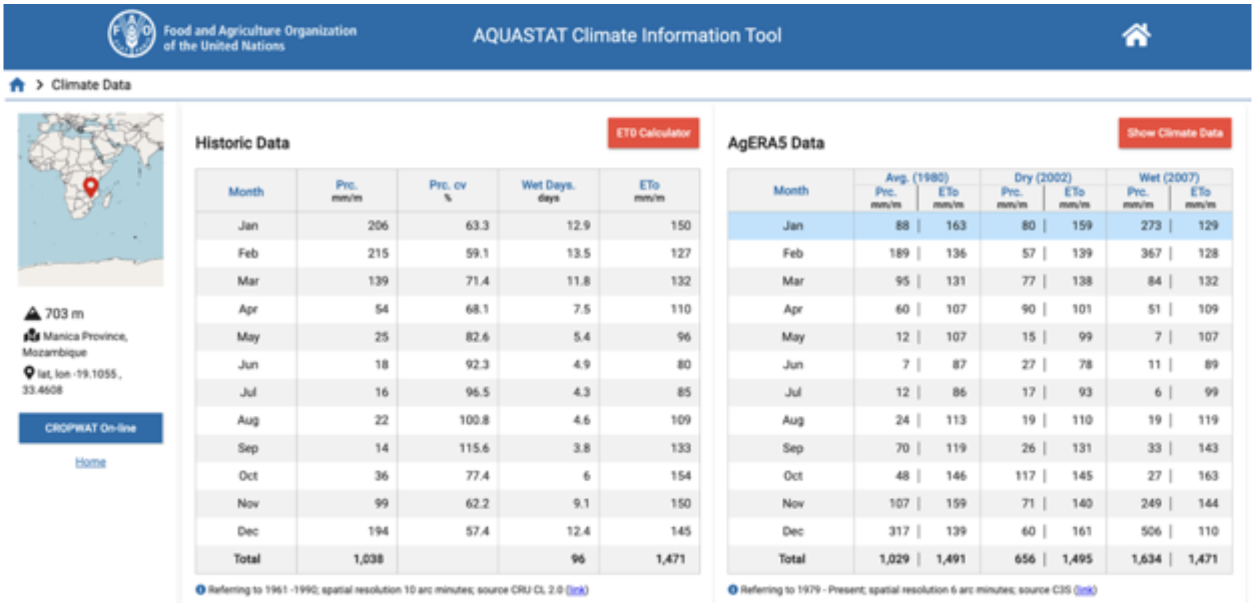
- Click on the map

703 M
Manica Province, Mozambique
lat, lon -19.1055 , 33.4608

lat: 10.6192 lon: -5.2528

Figure 2. Manica province meteorological station was selected to gather weather data.

Once it has been selected, obtaining the climatic data is simple. The user must click on the red bottom on the right top of the screen to show climate data in more detail. After selecting the chosen year, the data will be displayed automatically.



Historic Data

Month	Prc. mm/m	Prc. cv %	Wet Days. days	ETo mm/m
Jan	206	63.3	12.9	150
Feb	215	59.1	13.5	127
Mar	139	71.4	11.8	132
Apr	54	68.1	7.5	110
May	25	82.6	5.4	96
Jun	18	92.3	4.9	80
Jul	16	96.5	4.3	85
Aug	22	100.8	4.6	109
Sep	14	115.6	3.8	133
Oct	36	77.4	6	154
Nov	99	62.2	9.1	150
Dec	194	57.4	12.4	145
Total	1,038		96	1,471

Referring to 1961 -1990; spatial resolution 10 arc minutes; source CRU CL 2.0 (link)

AgERA5 Data

Month	Avg. (1980)		Dry (2002)		Wet (2007)	
	Prc. mm/m	ETo mm/m	Prc. mm/m	ETo mm/m	Prc. mm/m	ETo mm/m
Jan	88	163	80	159	273	129
Feb	189	136	57	139	367	128
Mar	95	131	77	138	84	132
Apr	60	107	90	101	51	109
May	12	107	15	99	7	107
Jun	7	87	27	78	11	89
Jul	12	86	17	93	6	99
Aug	24	113	19	110	19	119
Sep	70	119	26	131	33	143
Oct	48	146	117	145	27	163
Nov	107	159	71	140	249	144
Dec	317	139	60	161	506	110
Total	1,029	1,491	656	1,495	1,634	1,471

Referring to 1979 - Present; spatial resolution 6 arc minutes; source C3S (link)

Figure 3. Historical data for the Manica province climatic station in AQUASTAT.

The climatic data will then be used to calculate the water requirements in the field. The process is described in chapter 3.4

Table 2. Manica climatic conditions, obtained from AQUASTAT.

	Prc.	**Tmp. min.**	**Tmp. max.**	**Tmp. Mean**	**Rel. Hum.**	**Sunshine**	**Wind (2m)**
Month	**mm/m**	**°C**	**°C**	**°C**	**%**	**KJ m^{-2} day^{-1}**	**m/s**
Jan	206	20.7	29.7	25.2	77.80	20052	3.1
Feb	215	20.5	29.0	24.7	79.7	23053	2.8
Mar	139	19.7	28.7	24.2	78.9	18535	3.0
Apr	54	17.9	27.4	22.6	77.2	15808	2.7
May	25	14.9	25.9	20.4	73.9	16211	2.3
Jun	18	12.7	24.0	18.4	71.7	12418	3.5
Jul	16	12.4	23.9	18.1	70.3	14994	2.1
Aug	22	13.7	25.6	19.6	67.6	18339	2.9
Sep	14	15.7	28.0	21.9	65.4	22073	2.7
Oct	36	17.8	29.4	23.6	67.2	24932	2.7

Nov	99	19.2	29.7	24.4	70.6	20265	2.5
Dec	194	20.2	29.5	24.8	75.7	23615	2.4
Total	1038						

5.5.Determination of water needs for irrigation

The agronomic design is a fundamental component in any irrigation project, and solar irrigation is no exception. This is the part in which mistakes can pose serious consequences. Hydraulic calculations are of no use if these are built over the wrong base. A bad agronomic design can lead to soil salinization due to a lack of soil washing or insufficient water volume during the dry season, decreasing crop yields.

Different methods exist to estimate crop water requirements. This is because procedures for directly measuring water used by crops are complex, laborious, and expensive. The choice of method for estimating water needs will be determined essentially by the type of information available in the area where the irrigation project will be established. For this particular technical assistance, we will use the FAO web application to calculate the Reference Evapotranspiration (Eto), which uses the Penman-Monteith model developed in 1948[2].

Once the climatic data is preloaded, see above. The next step is to select the crop and the planting/sowing date. For this case, as the community will be growing different kinds of vegetables, we choose the option 'vegetables', and the sowing date, according to the farmer and corroborated by the agricultural extension worker from ADVZ,, can be safely determined as the 1st of April, see figure below.

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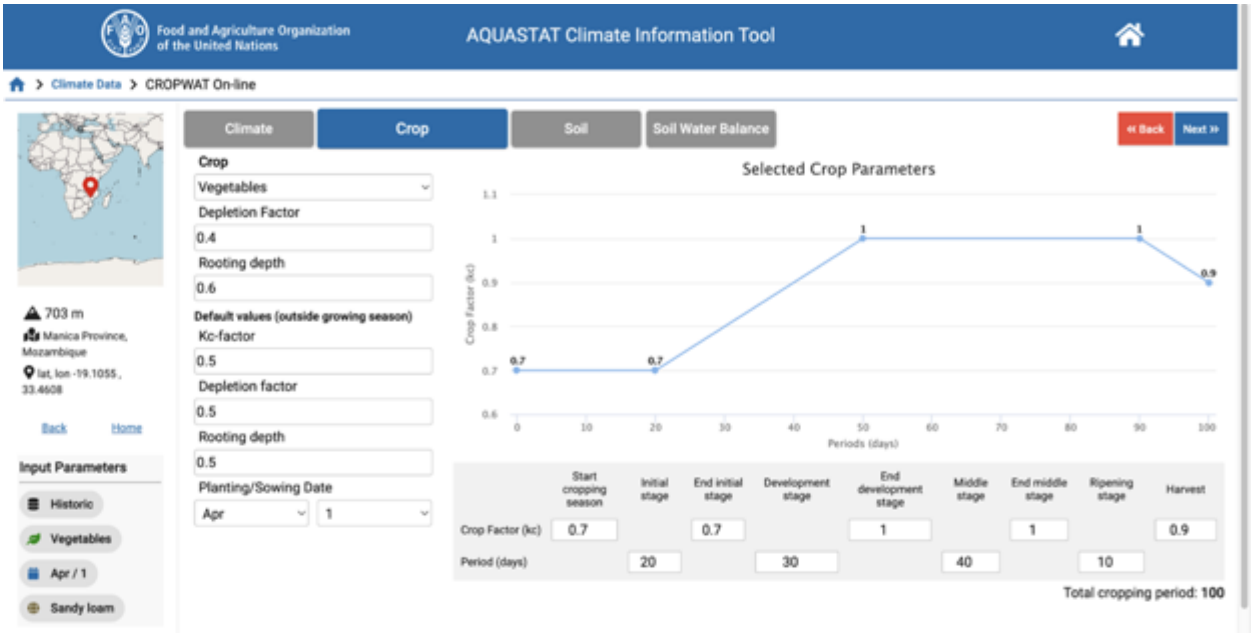
[2] For more detail on the Penman-Monteith equation visit https://www.fao.org/3/X0490E/x0490e06.htm



Crop: Vegetables

Depletion Factor: 0.4

Rooting depth: 0.6

Default values (outside growing season)

Kc-factor: 0.5

Depletion factor: 0.5

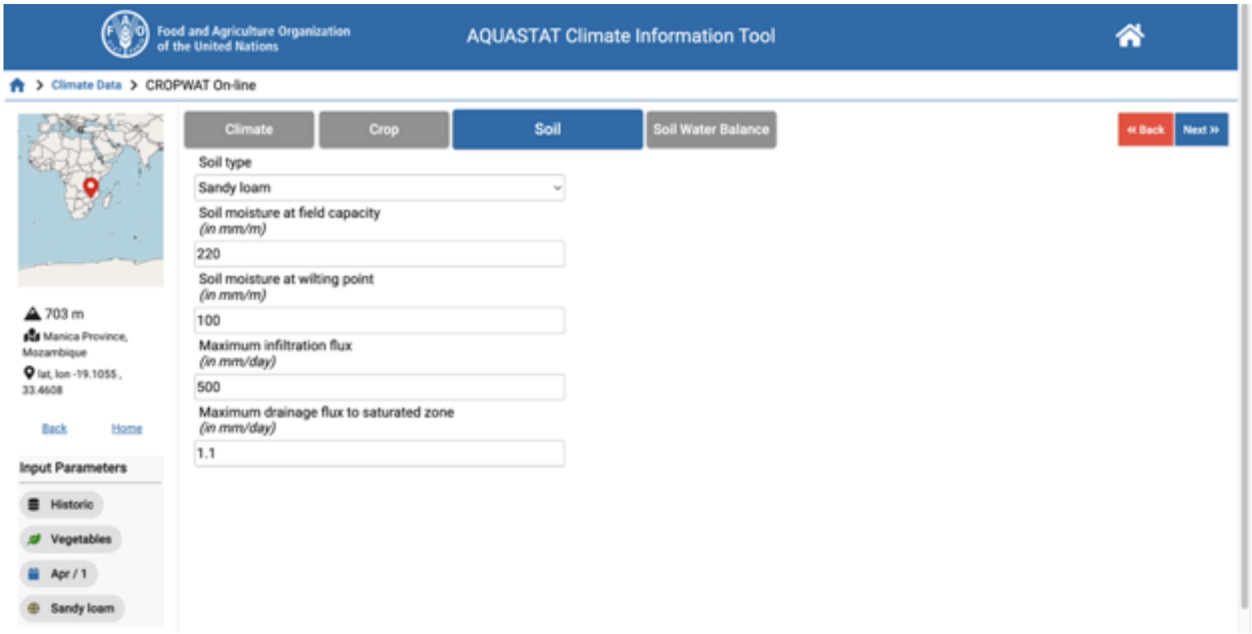
Rooting depth: 0.5

Planting/Sowing Date: Apr 1

	Start cropping season	Initial stage	End initial stage	Development stage	End development stage	Middle stage	End middle stage	Ripening stage	Harvest
Crop Factor (kc)	0.7		0.7		1		1		0.9
Period (days)		20		30		40		10	

Total cropping period: **100**

The second step is to select the type of soil found in the farming area. For this case, sandy loam is set; see below.



Soil type: Sandy loam

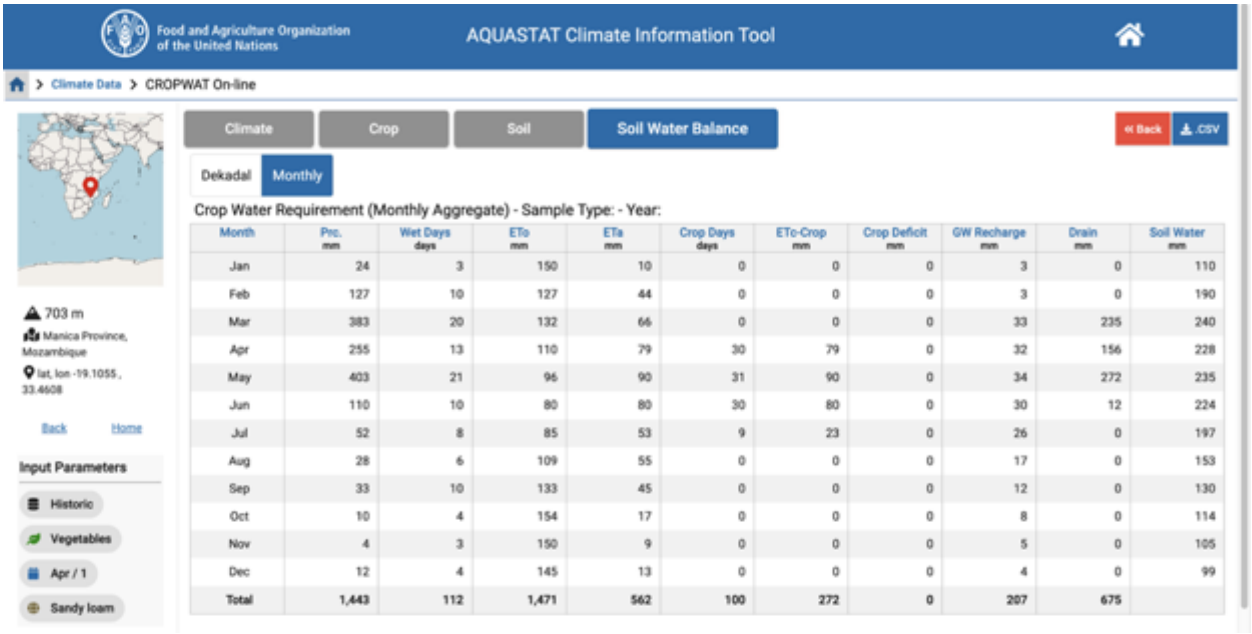
Soil moisture at field capacity *(in mm/m)*: 220

Soil moisture at wilting point *(in mm/m)*: 100

Maximum infiltration flux *(in mm/day)*: 500

Maximum drainage flux to saturated zone *(in mm/day)*: 1.1

Finally, the application calculates the crop water requirements (ETcrop) (including supplementary and obligatory irrigation) and displays the monthly values by clicking the soil water balance button.



703 m

Manica Province, Mozambique

lat, lon -19.1055 , 33.4608

Input Parameters

- Historic
- Vegetables
- Apr / 1
- Sandy loam

Crop Water Requirement (Monthly Aggregate) - Sample Type: - Year:

Month	Prc. mm	Wet Days days	ETo mm	ETa mm	Crop Days days	ETc-Crop mm	Crop Deficit mm	GW Recharge mm	Drain mm	Soil Water mm
Jan	24	3	150	10	0	0	0	3	0	110
Feb	127	10	127	44	0	0	0	3	0	190
Mar	383	20	132	66	0	0	0	33	235	240
Apr	255	13	110	79	30	79	0	32	156	228
May	403	21	96	90	31	90	0	34	272	235
Jun	110	10	80	80	30	80	0	30	12	224
Jul	52	8	85	53	9	23	0	26	0	197
Aug	28	6	109	55	0	0	0	17	0	153
Sep	33	10	133	45	0	0	0	12	0	130
Oct	10	4	154	17	0	0	0	8	0	114
Nov	4	3	150	9	0	0	0	5	0	105
Dec	12	4	145	13	0	0	0	4	0	99
Total	**1,443**	**112**	**1,471**	**562**	**100**	**272**	**0**	**207**	**675**	

Table 3. Evapotranspiration values for the Manica province.

	ETo	**ETc**
Month	**(mm)**	**(mm)**
Jan	150	0
Feb	127	0
Mar	132	0
Apr	110	79
May	96	90
Jun	80	80
Jul	85	0
Aug	109	79
Sep	133	125
Oct	**154**	**154**
Nov	150	37
Dec	145	0
Total	1471	

It is crucial to consider the complete irrigation season during the calculations of the ETc. In the case of Mozambique, it runs from April until the beginning of October each year. For this case, the maximum value is found in October with a monthly ETc of 154 mm/month. Divided into 31 average monthly days, it gives a value of daily ETc= 4.96=5 mm/day. This value will be used to design the irrigation system in further steps in this technical assistance.

As we have determined the ETc, the next step is determining the water volume required to irrigate (in m^3/day). The reference area is usually one hectare. This step is vital to select the right pump size. If the pump is too small, there will not be enough water to irrigate all the land.

First, we calculate the water requirements per ha:

$$Water\ requirement\ \left(\frac{m^3}{day}\right) = \ ETc\ \left(\frac{m}{day}\right) * Area\ (m^2)$$

$$Water\ requirement\ \left(\frac{m^3}{day}\right) = \ 0.005\ \left(\frac{m}{day}\right) * 10{,}000\ (m^2) = 50.0 = 50\ \frac{m^3}{day}/ha$$

5.6.Determination of sunshine hours availability

The first thing that needs to be understood is how the sun works. Using the sun as a power source will let the system 'behave' in a certain way. Understanding this behavior leads to the choice of the (number of) solar panels and the pump, the diameter of the distribution pipes, the selection of the well or water source, and the selection of the application systems.

5.6.1 Irradiation

When the sunlight enters the earth's atmosphere, some is absorbed, some is scattered, and some is reflected by clouds. The rest of the sunbeams pass through unaffectedly in the atmosphere. The absorbed part does not reach the surface but raises the temperature of particles in the air. The scattered part turns into diffuse radiation, and the part which passes unaffectedly is called direct beam radiation.

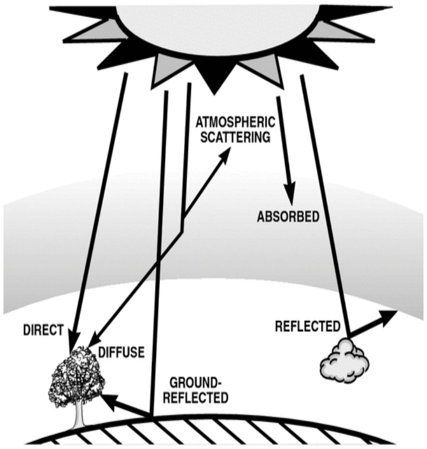


Figure 4. Different types of radiation.

Irradiance measures the power density of sunlight at a particular moment. In other words, it is the power of the sunlight measured in Watt per m^2. When entering the atmosphere, the irradiance level is around 1350 W/m^2. After passing the atmosphere at sea level, the irradiance is approximately 1000 W/m^2, or 1 $KW/m^{2,}$ at noon at the equator. This represents a combination of direct beam and diffuse radiation.

Irradiation is the total amount of energy received on the earth's surface during a specific period on one square meter of horizontal surface. Usually, the time frame for measurement is one day. It is usually expressed in KWh/m^2. The following map shows the daily average horizontal irradiation[3].

Figure 5. Daily average horizontal irradiation (kWh/m2) (JCR Photovoltaic Geographical Information System,2024).

It is essential to know that the data is the average horizontal irradiation. However, the irradiation will change during the day. A second effect that needs to be considered is the influence of seasons.

5.6.2 The critical month

The solar irrigation system should ideally produce sufficient water to meet the crop demands throughout the year. For dimensioning the system, the crux is to find the month having the most unfavourable combination of water demand and sunshine conditions.

As described above, average irradiation varies between the different months of the year. With the lowest irradiation, the system should still produce sufficient energy to meet the power

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[3] Solar GIS (www.solargis.com)

demand in the month. Figure 6 presents the irradiation on a horizontal surface for Chimoio, Mozambique.

These irradiation figures have been obtained from the photovoltaic geographical information system, website: https://re.jrc.ec.europa.eu/pvg_tools/en/.

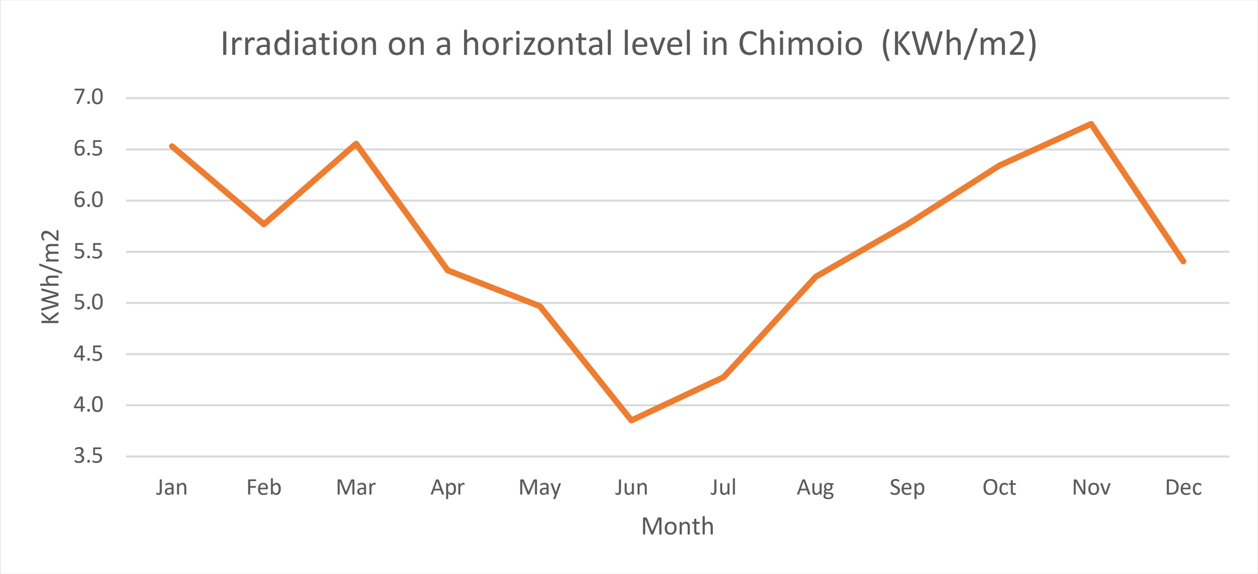

Figure 6. Average daily irradiation in Chimoio, Mozambique (Own elaboration with www.solargis.com data).

From Figure 6, it can be concluded that the month with the last favorable sunshine conditions in Chimoio is June, when the average irradiation per day drops to 3.64 =3.6 kWh per m^2, and during the water peak month (November), it rises to 5 kWh average. In Mozambique, the irrigation season is during 'winter' when days are shorter. So, the most critical period in terms of water needed by the plant and thus irrigation is from August until October (see figure below), when the days are longer. The average during this period is slightly above 5 h/day.

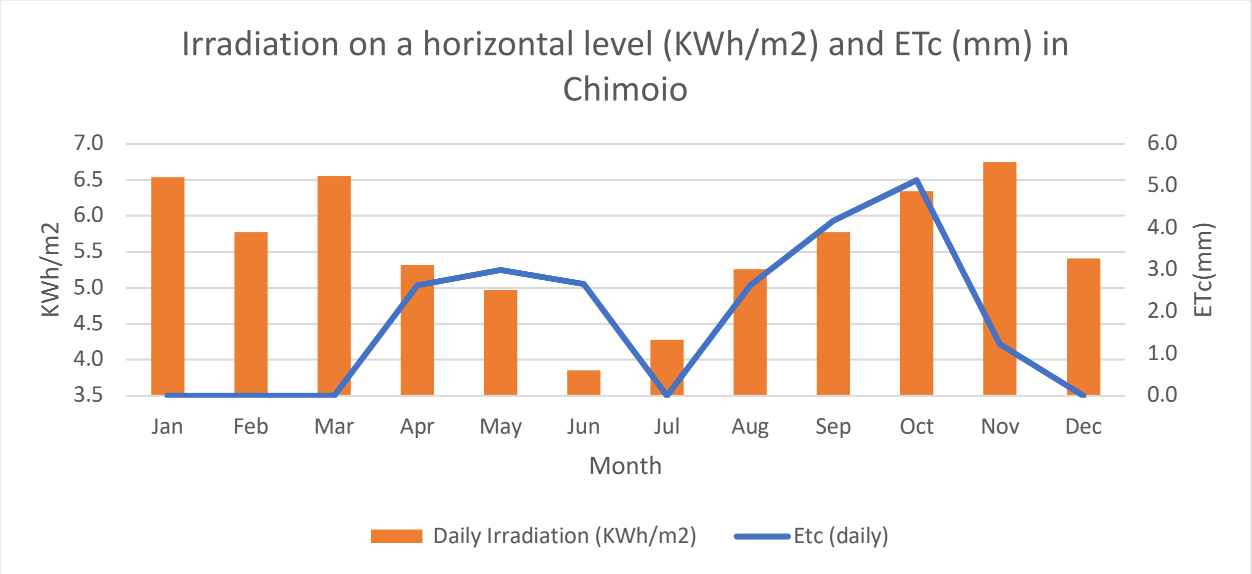

Figure 7. Average Daily Irradiation on a horizontal level (KWh/m2), ETc (mm) in Chimoio (Own elaboration with the POWER project data[4]).

Table 4 presents an overview of the information collected so far, which will be used in the following steps to determine how much area can be irrigated simultaneously and the type of pump that needs to be selected.

Table 4. Summary of information for the SPIS design.

Available area in the farm (ha)	19.4
Currently cultivated area (ha)	2.5
Expected area to be irrigated with SPIS (ha)	0.5
Water source	Surface water (Dam)
Water source flow rate (m^3/h)	30
Critical Evapotranspiration (ETc) (mm/day)	5
Daily water requirement per ha (m^3/ha)	50
Average daily Irradiation on a horizontal level (kWh/m2), during critical month	5
Daily Average available hours for critical month (hours)	5

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[4] https://power.larc.nasa.gov/data-access-viewer

5.7 Determine the water needs to irrigate the defined area

As the area of the irrigated module has been defined as 0.5 ha, we can estimate the water needs to irrigate the crops once established. The following formula is used:

$$Water\ requirement\ (m^3/day) = Daily\ water\ requirement\ \left(\frac{m^3}{ha}\right) * Irrigated\ area\ (ha)$$

$$Water\ requirement\ (m^3/day) = 50\ \left(\frac{m^3}{ha}\right) * 0.5\ ha = 25\ m^3$$

The water requirement per day to irrigate 0.5 ha is 25 m^3.

5.8 Determine the water conveyance, application method and pump yield

When the pump extracts water from the source, it must be transported to the field. And from that point, it needs to be transported to the roots. The first part, from pump to field, is called the **conveyance method.** Often, this is done by using a pipe or hose. The second part, within the field, is called the **application method.** The most common water application practices are furrows, sprinklers, drip, buckets, hoses, or spray cans.

Determining the conveyance and application methods is important because different methods have different water efficiencies. As a matter of clarification, when a method is water efficient, it means very little water is lost. No matter the application system, there will be losses in the system, and these will be expressed in percentages. According to the University of Nebraska,[5] table 2 shows the indicative values of application efficiency methods.

Table 2. Irrigation methods and their efficiencies.

Irrigation method	Efficiency (%)
Surface irrigation (furrows, basins, etc.)	60-70
Overhead irrigation (sprinklers, spray tubes, misters, etc.)	70-85
Drip irrigation	85-95

The next step is to calculate the pump yield required to cover the water needs. The following formula is used:

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[5] https://passel2-stage.unl.edu/view/lesson/bda727eb8a5a/8

$$Pump\ yield\ \left(\frac{m^3}{h}\right) = \frac{Water\ needs\ \left(\frac{m^3}{ha}\right) *\ irrigated\ area\ (ha)}{Number\ of\ hours\ of\ sunshine\ in\ a\ day\ (h)}) *\ Efficiency\ (\%)$$

$$Pump\ yield\ \left(\frac{m^3}{h}\right) = \frac{50\ \left(\frac{m^3}{ha}\right) * 0.5\ (ha)}{5\ (h)} *\ 0.95 = 4.75 \approx 5\ m^3/h$$

5.9 Proposed geometry of the irrigation system

The proposed geometry of the solar-powered irrigation system covers the plot assigned for irrigated horticulture with an area of 0.5 ha[6]. The figure below shows the location of the pump, solar panel installation, main pipe, drip system, and irrigated areas.

Figure 1. The geometry of the proposed irrigation system for Mr Domingos Tomas's farm

The specifications of the irrigation equipment that will be used are presented in the table below.

Table 3. Drip irrigation equipment specifications.

Spacing between emitter (m)	0.3
Dripper line length (m)	25

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[6] The online map can be accessed: https://www.google.com/maps/d/u/2/viewer?mid=1BVHos1E9ZB3v5Jd2_nWslQg7BOvKka4&ll=-19.024103170259878%2C33.452756100000016&z=17

Total drip line length (m)	16,667
Total length of supply ramp (m)	200
Main pipe length (m)	220

Once the geometry of the irrigation system is clear. It is crucial to define how the irrigation system should be managed. Aspects such as crops, production practices and plot characteristics. For Mr. Domingos Tomas, the management includes cycles of 28 minutes, where 390 m^2 will be irrigated at once. See the table below for more details.

Table 4. Irrigation management.

Number of lines used per irrigation cycle	52
Duration of an irrigation cycle (min)	0h 28 min
Irrigated area of one irrigation cycle[7] (m^2)	390

5.10 Calculating the head of the system and friction losses

Total head is a technical term for calculating the pressure the pump needs to provide to let the system function as designed. It is expressed in meters. So, if the total head is calculated to be 10 meters, it means the pump needs to work as if it must pump the water 10 meters high. This step is highly relevant when selecting the right pump. Some pumps can provide a high flow and little pressure (head). Some pumps provide a very low flow but very high pressure (head). Knowing the head and the required flow allows the technician to select the right pump. Not calculating the right head might result in a situation where no water will reach the field.

To calculate the head, the following data needs to be collected:

1. The dynamic water level at the water source
2. The height difference at the highest point in the path from the water source to the field (in meters)
3. The required pressure of the application method (in meters)
4. The friction losses of the pipes in the conveyance system (in meters).

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[7] The irrigated area considers 0.3 m extra from the left and right form the last drip line installed in the field. Therefore, the total irrigated area is calculated as: (16 m width+ 0.3 m*2) x (50 m length)=830 m^2

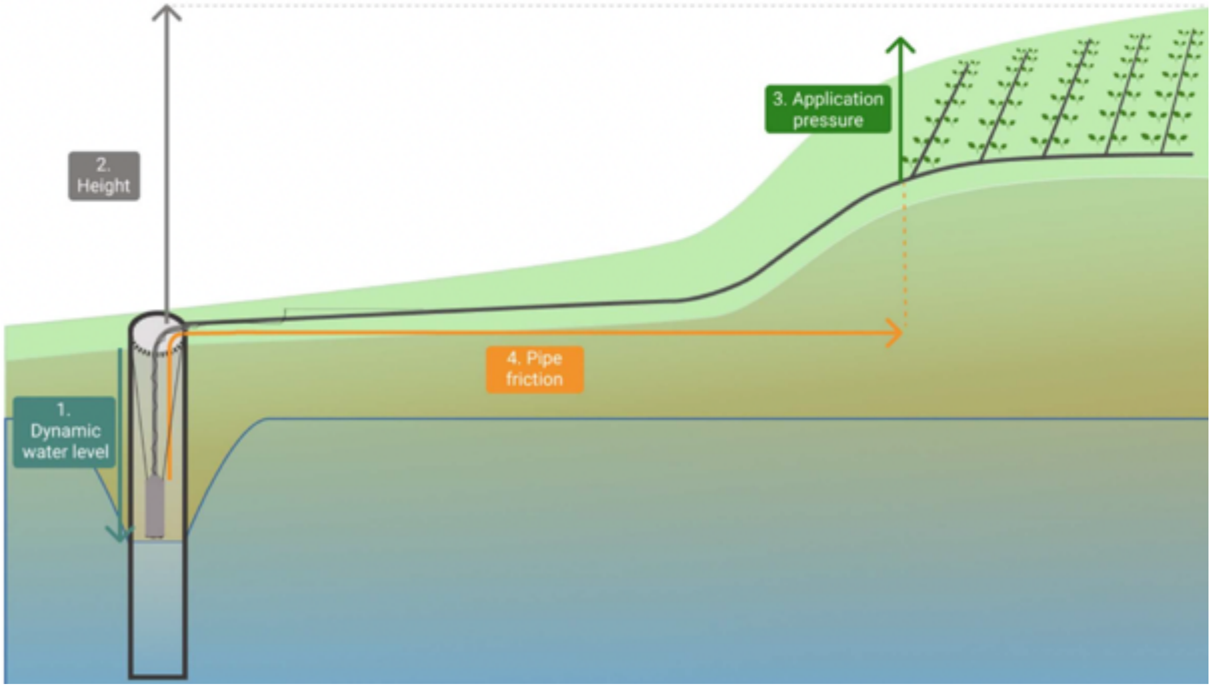

Figure 2. Schematic representation of total head (Practica 2022).

5.10.1 Dynamic water level at the water source and height difference at the highest point in the field.

After analysing the difference in height between the location of the pump and the location of the highest point that the water will need to reach, the height difference was determined to be 10 m.

5.10.2 Required pressure of the application method

Mr Domingos Tomas is already working with the Rivulis drip irrigation line (see figure 3) with the following characteristics. 16 mm 6mil 1 lph 30cm, 1 bar of pressure. This means the flow is 1 liter per hour and works. under a pressure of 1 bar=10 meters, a diameter of 16 mm, and a wall thickness of 8 mm, ensuring a life expectancy of 2 to 3 years (if taken correctly).

Figure 3. Rivulis drip line already existing in the farm.

The required pressure of the application method to design the pumping system can be thus defined at **10 meters=1 bar**.

5.10.3 Friction loss and residual pressure

Friction losses are energy losses in the pipeline due to the friction of the water when it moves through the pipe. One meter loss means that the pump must provide a pressure of one meter extra to pump the water through the pipes to overcome the friction losses. There will always be friction and, therefore, head losses, but it is important to limit them. High friction results in the need for bigger pumps, more solar panels, hence higher investments.

A complex equation usually used to calculate the friction loss in a pipeline is the formula Hazen-Williams:

$$\Delta H_L = \frac{(10.69 * Q^{1,85} * L)}{c^{1,85} * D^{4,87}}$$

<u>In which:</u>
ΔH_L= the head loss in meters due to friction
Q=the water flow in m^3/s
L= the length of the pipeline in m
C= the Hazen-Williams coefficient for the roughness of the pipe (around 150 for PVC and PE pipes, depending on type/age). It has no units.
D= diameter of the pipeline in m.

If one analyses the equation in more detail, one can see:

- If you double the length of a pipe, the head loss doubles.
- The head loss will increase if you pump more water through a pipe. It increases non-linear. This means that if you double the flow through a pipe, the head loss increases more than double.
- The rougher the surface of a pipe, the higher the head loss. This is influenced by the material of the pipe and its age. For example, a brand-new GI pipe will have a smoother surface than an old, rusted pipe. Therefore, the head loss of a new GI pipe will be less than that of an old GI pipe[8].
- The diameter of a pipe. It is the most crucial factor in the formula. Doubling the diameter of the pipeline results in a reduction factor.

A first pre-calculation needs to be done before selecting the commercial diameter. This is done by following the formula below:

$$Estimation\ of\ pipe\ diameter = \sqrt{Q(\frac{m3}{S})}$$

$$Estimation\ of\ pipe\ diameter = \sqrt{0.0025(\frac{m3}{S})} = 0.050m = 50\ mm$$

The following data will be used for the specific design of the irrigation system.

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[8] https://www.engineersedge.0.2com/flui0.4d_flow/hazenwilliams_coefficients_table_13220.htm

Q= 5m^3/h= 0.00138 m^3/s
C=150
L=215 m
D= 50mm=0.50m

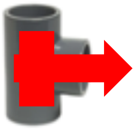
This results in the following calculation:

$$H_L = \frac{(10.69 * (0.00138)^{1,85} * (215))}{(150)^{1,85} * (0.050)^{4,87}} = 2.4012 \approx 2.4\ m$$

This value represents the friction losses in meters that the pump needs to cover for the friction losses only in the main pipe.

It is essential to realize that elbows, valves, T-pieces, etc., will increase the friction of the piping. This can be calculated per piece of hardware. Or, as an alternative, use a faction of the total head loss of the pipe to cover the head loss of the elbows, valves, etc. Table 5 shows an overview of head losses per item. Note that the numbers are the equivalent length of straight pipe added to the total length of the distribution network. They are not the head losses expressed in meters.

Table 5. Equivalent length of straight pipe in meters.

Equivalent length of straight pipe in meters									
Pipe size (inch)		1/4	3/8	1/2	3/4	1	1 ¼	1 ½	2
Elbow 90 degree		0.7	0.9	1.1	1.3	1.6	2	2.3	2.6
Elbow 45 degree		0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
T-piece (straight flow)		0.2	0.4	0.5	0.7	1	1.4	1.7	2.3
T piece (branched flow)		0.7	1.1	1.3	1.6	2	2.7	3	3.7

One-way valve (swing type)		2.2	2.2	2.4	2.7	3.4	4	4.6	5.8

One can see that if one adds 10% to a total length of distribution pipe of 1000 meters of 1 inch (to account for head losses in fitting work), one will account for (100/1.6= nearly 60 elbows. Therefore, for the residual pressure, one can take a fixed percentage of the total length of the pipe, 10 % is a widely accepted value. For this case, the 10% of 5 meters is 0.5 meter. Therefore, the total friction losses for the main pipe (including accessories) are 5.5 m.

The following calculation is to estimate the friction losses in the supply ramp.
For this case, the following data will be used:
$Q= 5m^3/h= 0.00138\ m^3/s$
$C=150$
$L=200\ m$
D= 50mm=0.050m; commercial diameter

This results in:

$$H_L = \frac{(10.69 * (0.00138)^{1,85} * (200)}{(150)^{1,85} * (0.050)^{4,87}} = 2.234 \approx\ 2.2\ m$$

Adding the 10% for accessories loss results in 2.4 meters of head pressure in the supply ramp.

Table 6 presents a clear overview of the total head the system will need to overcome to provide the required amount of water to the roots of the crops.

Table 6. Total Head to account for the pump selection.

Geometric height (m)	10
Dynamic level (m)	2
Friction Losses in the main pipe, including accessories (m)	2.4
Friction losses in the supply ramp, including accessories (m)	2.4
Friction losses due to filtration/water meter (m)	2
Operating pressure of the drip irrigation system (m)	10
Total Head (m)	**28.8 ≈29 m**

5.11 Pump selection

We can now select the pump by knowing the total head and the maximum daily water production required. The first selection is to determine the type of pump that is needed. Pumps fall into two main categories:

1. Suction pump: this means the pump sucks the water up first and then pushes it up. To suck the water up, the vertical distance from the pump to the dynamic water level should not be more than 7 meters. If it is more than 7 meters, it does not work.
2. Submersible pump: as the name suggests, the pump is submerged in water. That means the pump is in the water. Therefore, it does not need to suck the water up first. It just needs to push the water up. This means it can pump water even from great depths.

Table 7. Comparison between suction and submersible pumps.

	Suction pump	**Submersible pump**
Placement	Next to the water source	Inside the source, below the water
Maximum water depth	7m maximum	Depending on pump- well below the water
Usually applied to	River, stream, pond, hand dug well, borehole (water at less than 7 m)	Hand dug well, borehole
Resistance to silt/salts in water	Usually more resistant	Usually more sensitive (But some suppliers offer warranty)
Type of installation	Generally portable	Generally fixed
Fuel	All fuel pumps are suction pumps	Submersibles run on electricity, including from solar panels.

Whether a submersible or suction pump is chosen, finding a pump with the right characteristics for the given situation is vital. These characteristics depend on 2 main factors.

1. The required pump discharge.
2. The total head of the system.

Different pumps provide different amounts of water at different heads. This relation is shown in a pump curve. Each pump on the market has its own graph. Figure 7 shows 3 curves:

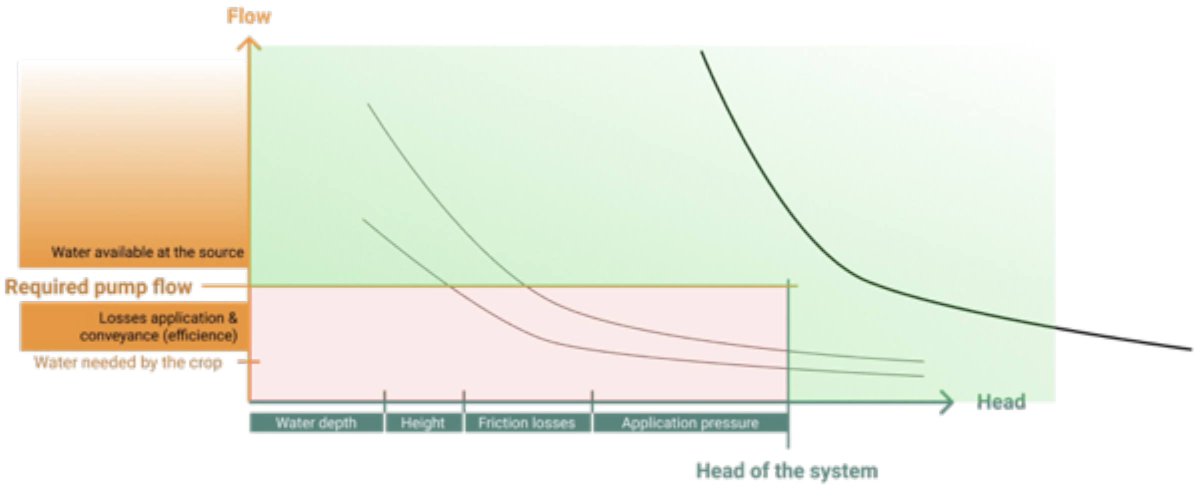


Figure 7. Flow vs Head of the system to select a pump.

The vertical axis shows the amount of water the pump will provide (the pump discharge), depending on the total head (horizontal axis).

- What can be seen is that **the higher the head, the less water the pump will provide** (each curve is going down as we go towards the right of the graph, so towards higher heads). **This is true for all pumps.**
- This graph also shows that **the pump can no longer provide any water at more than a specific head.**
- For the pump to work in the field, the curve must be in the green part of the graph. Here, on the left, the pumps corresponding to each of the two curves are unsuitable because they do not provide enough water at the head of the system considered.

As explained above, the pump selection can be multifactorial (budget, brand representation, operation, and maintenance knowledge close to the installation site, etc.). Therefore, if the technical conditions (H&Q), the consortium recommends that during the installation the pump is selected from one of the sector's two most renowned submersible pump brands, a good represented in the Mozambican market. These are Lorentz and Grundfos. Each brand has its own design software.

The example will be followed using the Grundfos product selection tool (https://product-selection.grundfos.com/). By introducing the Q (5 m^3/h) and the H (29 m), previously calculated. The software displays the pump SP 5A-8, which is within the required operational ranges, see figure 8.

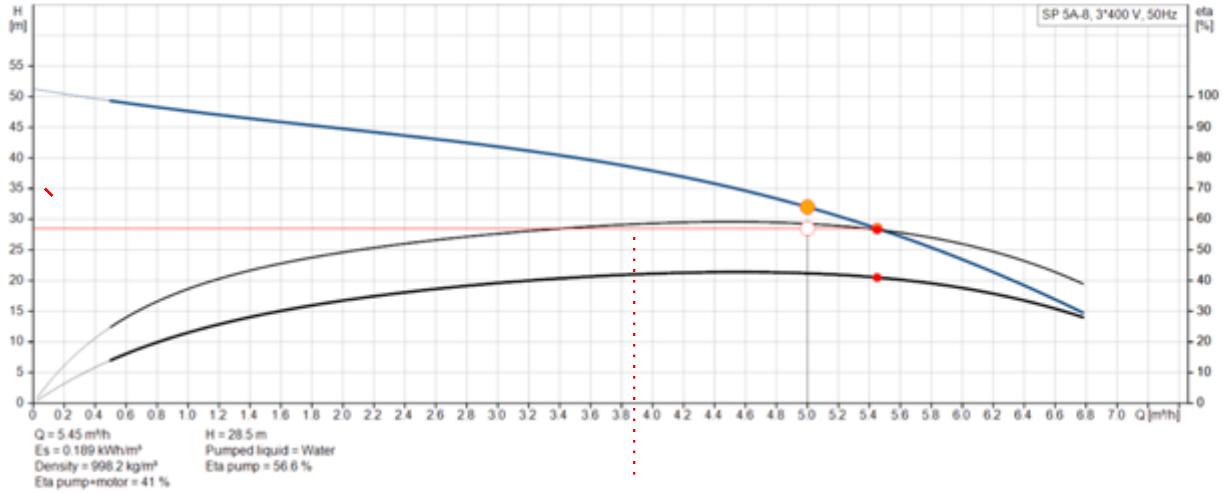


Figure 8. Pump curve of SP[9] 5A-8 submersible groundwater pump from Grundfos.

5.12 Calculating the power requirements of the solar array.

Calculating the power requirement of the solar array can be done using the following steps.

1) Calculate the hydraulic output power demand of the system.
2) Factor in the pumping efficiency.
3) Factor in the electric efficiency of the system.

5.12.1 Calculating the hydraulic energy demand of the system.

This calculation can be done in several ways. To understand the equations better, we first provide the general formula for potential energy. Every day, the daily water production requirement (in m^3) needs to be lifted over a certain height level H, from the water source to the application point. The general equation for potential energy is the following:

$$E_{pot} = m * g * H$$

In which:

M= the mass lifted (kg). Every m^3 of water has a mass of 1000kg.
g= the gravity force constant=9.81 (m/s^2)
H=the difference in height level = the hydraulic head (m)

This formula needs to be adjusted slightly to the situation. We calculate the energy per day. If Q is the daily water demand (m^3/day), then the mass of L is Q*1000 (kg/day). So, instead of m for mass, we write 1000*Q. We also fill in the value of the gravity force constant. The formula for the energy required per day becomes:

$$E_{day} = 1000Q * 9.81 * H = 9810\ Q * H$$

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[9] Grundfos SP are submersible borehole pumps, designed for pumping groundwater. Grundfos SP are all stainless-steel pumps, and they are available in 3 material grades. The pumps are suitable for boreholes in sizes ranging from 4” over 6” and 8” to 10”. The motor sizes for the pumps are available in 0.37-250 kW.

5.12.2 Calculating the hydraulic power output of the array.

This amount of energy per day needs to be produced in the number of peak sunshine hours (Psh) available per day during the critical month. So, we would need a power output per hour of:

$$P = \frac{9810 * Q * H}{Psh\left(\frac{J}{hr}\right)\, or\, (W * \frac{s}{hr})}$$

To calculate the required power per second, we divide this through 3600. As there are 3600 seconds in one hour. This equals to:

$$P = \frac{2.73 * Q * H}{Psh}$$

In which:

Q= water need in m^3/day
H= hydraulic height in m
Psh= number of peak sunshine hours per day in kW/m^2/day
Pout= the hydraulic output power. It does not yet consider the system's hydraulic efficiency nor the electric efficiency of the system.

5.12.3 Factoring the electric and hydraulic efficiencies of the system.

The total power demand P_{tot} of the system can be calculated with the following formula:

$$P_{tot} = \frac{Pout}{\eta * \varepsilon}$$

In which:

Pout= the hydraulic output power
η= the hydraulic efficiency of the pumping system. This is the proportion of the energy the pump receives from the pump motor effectively used for the water flow. The rest of the energy is converted into heat. Note that other hydraulic losses (friction losses) were considered while calculating the hydraulic head.
ε= the electric efficiency (considering losses in the motor, converter, losses through dust, losses through the ageing of panels, etc.)

Combining all equations, we come to the final equation:

$$P_{tot} = \frac{2.73 * Q * H}{P_{sh} * \eta * \varepsilon}$$

In which:

Q= water need in m^3/day
H= hydraulic height in m

Psh= number of peak sunshine hours per day in $kW/m^2/day$
η= the hydraulic efficiency of the pumping system.
ε= the electric efficiency

Therefore, the theoretical output can be calculated.

$$P_{theo} = \frac{2.73 * 25 * 29}{1000} = 1.98\ kW$$

To calculate the minimum pump required for the pump, we will assume a pump hydraulic efficiency (η)of 60%. Therefore, the minimum power required in the pump in kW is calculated as follows:

$$Min\ Pump\ power = \frac{P_{theo}}{\eta}$$

Using the data from this exercise, the calculation is as follows:

$$Min\ Pump\ power = \frac{1.95\ kW}{0.6} = 3.29kW$$

Once the minimum power in the pump is calculated, we need to factor in the capacity of the panels to convert the sun power into electricity. The efficiency of the solar panels (ε) is considered 50%. Therefore, the formula is as follows:

$$Min\ solar\ panels\ power = \frac{Min\ Pump\ power}{\varepsilon}$$

The calculation is as follows:

$$Min\ solar\ panels\ power = \frac{3.25\ kW}{0.5} = 6.6\ kW$$

5.12.4 Configuration of the PV Array

For the configuration of the PV array, we must first know the voltage used in the system, that is the voltage needed to operate the pump. This voltage must be produced by matching the voltage requirement with the number of solar panels in series, depending on the voltage output of one panel. The sizing of the cables and the configuration of the solar panels can be calculated manually. However, this is not easy. Suppliers usually do this with software packages to calculate it: they should be able to provide the correct configuration and cable sizes[10]. Table 8 summarises

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[10] A good resource to calculate it manually is the book: 'Solar Pumping for water supply. Harnessing solar power in humanitarian and developmental contexts.' Kiprono and Ilario,2020. It can be downloaded for free at Practical Action Publishing.

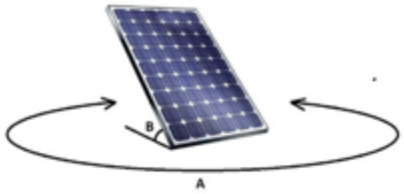
the power array calculations that should be matched and carefully reviewed against the supplier's proposal.

Table 8. Summary of the power requirements of the power array.

Pump group efficiency (%)	60
Power required in the pump theoretical (kW)	1.98
Minimum power required in the pump (kW)	3.29
Solar panel efficiency (%)	50
Minimal solar panel power (kW)	6.6

The sizing of the solar array is only correct if the panels are placed correctly. There are two main factors to be considered for this:

1. The orientation of the solar panels.
2. Shadow.



Orientation of the solar panels: The panels can be oriented in two different ways:

a. The direction it faces (A): North, west, east, or South.
b. The angle at which it is placed with the ground.

To get as much sun as possible on the panels, the following rules should be applied:
Panels should always face the equator. If panels are placed in the northern hemisphere, panels should face south. If panels are in the southern hemisphere, they should face north. For the Mozambique case, they should always face North.

Secondly, the latitude expresses how close or far the location is from the equator. They are expressed in degrees. The panels should be at an angle on the degree of the location. The angle should never be less than 15 degrees to ensure the panels stay as clean as possible.

For the location of the farm, the latitude is 19°01'33" South. Therefore, **the panels should be inclined towards the North at 19° degrees.**

Shadow: Shadow on the solar panels must be avoided at all costs. The effects of it are often underestimated and not well understood. Shadow, even the slightest bit, can disrupt the functionality of the entire panel and array. Just 10% shading of a solar array can lead to a considerable decline in efficiency and even, on occasion, total loss of water flow. Apart from the panels' placement, dust will influence the efficiency. Dust losses can be around 0-15%. Thus, panels should be cleaned regularly with clean water and only during the early morning/late afternoon when the panels are no longer hot.

Solar trackers: are devices that monitor the position of the sun and automatically or semi-automatically adjust the direction of the solar panels towards the sun so that productivity is increased. This can be done on two axes: the azimuth angle axe, which means following the sun from east to west during the day, and the zenith angle axe, which means following the sun's position from North to South. The ideal tracker adjusts both axes continuously to face the sun during the day and during the seasons. The main disadvantage of such trackers is the price, they require operation and maintenance and have the risk of breaking down. When installing trackers, taking the correct precautions against theft of the panels is more complex and costly. And with the current price levels, generally, it is cheaper, more convenient, and more reliable to install some more solar panels for the extra power than to install a solar tracking system of whatever kind. Therefore, **the design for Mr Domingos Tomas farm excludes the installation of solar tracking devices.**

5.13 Horticulture production

To boost horticultural production in the conditions of small producers, a production system has been devised to integrate other components to make production more accessible, improve quality and be highly sufficient to meet market demand. Horticultural production in an integrated system will allow the mineral nutrients needed by the crops to be combined and recycled through the connection with the biocomposting and the aquaculture

Nursery production will consider the quantity needed to cover an area of 0.5 hectares, distributed between the following crops: Lettuce, Cabbage, and Tomatoes. Seeds will be used according to the plot needs of each crop.

In the production system, it is recommended that the nursery be established in a greenhouse, allowing for greater protection of the seedlings in the initial phase and consequently reducing the mortality rate. A nursery must fulfil the following conditions: Dense and uniform, good drainage and aeration, high water retention capacity, no crusts or cracks, and weed and plant pathogen-free.

Table 1. Distribution of irrigated horticulture production.

		Dimension (m)			**Seed Spacing**		**Number of**		**Number of**	**Estimated yield (ton)/season of 4 months**
Crop	**Plot**	**Width (m)**	**Length (m)**	**Total area (m^2)**	**Width (m)**	**Length (m)**	**Lines**	**Plants in line**	**plants (lines*plants in line)**	
Lettuce	Plot 1	25	16	400	0.5	0.3	50	53	2667	0.4
	Plot 2	25	16	400	0.5	0.3	50	53	2667	0.4
	Plot 3	25	16	400	0.5	0.3	50	53	2667	0.4
Cabbage	Plot 1	25	16	400	0.5	0.5	50	32	1600	0.6
	Plot 2	25	16	400	0.5	0.5	50	32	1600	0.6
	Plot 3	25	16	400	0.5	0.5	50	32	1600	0.6
Tomato	Plot 1	25	16	400	1	0.3	25	53	1333	1.9
	Plot 2	25	16	400	1	0.3	25	53	1333	1.9

The irrigated areas (canteiros) will be proposed to be divided into plots measuring 25m x 16m, where the crops will be sown. A 1 meter gap will separate the plots to allow for crop growing and the use of machinery, if applicable. To ensure enough selected seedlings are available for the final field, 10 percent of the quantity obtained will be added to the density.

6. Aquaculture

Sustainable aquaculture is gaining dimension in a world where producing without depleting productive natural resources and without harming and damaging the environment becomes, politically and socially, the best option. Converting waste into new raw materials, efficiently using water and energy resources, ensuring animal welfare, and using scientific knowledge and technological development.

In this project, the combination of aquaculture with the other technologies (solar irrigation, biocomposting and biodigestion) will allow the nutrients from the fish farming tanks to be used for the fertilization of the crops.

The aquaculture component will consist of two tanks of 250 m^2 each, with a depth of 1 meter., totaling a water volume of 500 m^3. The following subchapters will describe the parameters for the construction of the tanks, the procedures for rearing the fish, and the integration with the other technologies.

6.1 Construction of the fish tanks

The key aspects to be considered for the construction of the tanks are installation area, topography, soil type and water availability.

6.1.1 Area and Topography

The area and topography of the site determine the shape, size, and number of tanks that can be built, as well as how much earth will need to be moved for the tanks to be constructed. As described in chapter 4, the aquaculture tanks are located near agricultural fields, where the slope is less than 2%, which makes them suitable places and may cause less soil movement for the construction of the tanks.

Figure 4. Location of the aquaculture fish tanks.

6.1.2 Soil Type

The soil type is important for defining the type of tanks that can be constructed, mainly due to the possibility of water infiltration if the soils are not of good quality. The most suitable soils for the construction of tanks are those with very clayey structure (more than 60% clay), or clayey, containing between 35-60% clay in their composition, see figure below.

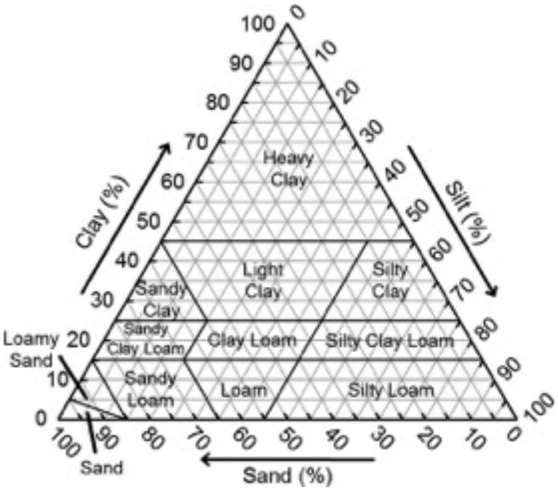


Figure 5. Atterberg soil texture scale.

The selected farm for this project has light clay soils, which, in principle, is suitable for the construction of the tanks[11]. However, to give the tanks greater impermeability properties, the

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[11] This can also be seen with the presence of an earth dam, which indicates the soil is impermeable enough to keep water from infiltrating.

bottom and walls of the tanks should be covered with high-density plastic (HDPE) with a thickness of 500 microns.

6.1.3 Water availability.

Water availability is a pivotal aspect to consider when implementing tanks. The design should consider that even in periods of prolonged drought, the amount of water is enough to meet the minimum requirements of the tanks, considering losses due to evaporation and infiltration. For this design, the water supply will come from the existing lagoon on the property and will be supplied by the solar pumps.

6.2 Structure of the tanks

The shape and distribution of the tanks have been selected according to the terrain to consider how the technology fits with other technologies such as irrigated agriculture, water circulation with the pump, etc.

The tanks will have a rectangular shape, with 25 m long and 10 m wide measurements, totaling an area of 250 m^2. The size of the tanks has advantages for its construction, which is usually done manually, and in its management, considering the water and fish population volume.

Figure 6. Construction of fish tank for aquaculture in Sofala, Mozambique.

6.2.1 Ridge width

The ridge is the highest point of the dikes. Its width is defined according to the size of the tank, always bearing in mind the ease of carrying out routine activities such as the transport of inputs, fishing, and safe traffic of people, amongst others.

The width of the ridge is determined with the following equation:

$$W = 1.10 * (h)^{0.5} + 0.91$$

Where:

H=designed depth of the tank.

Applying the formula, and considering the depth of the tank in the central part will be 1.0 m, the height in the laterals should consider security factors and be 1.3m.

$$W = 1.10 * (1.3)^{0.5} + 0.91 = 2.2\ m$$

6.2.2 Slope

The lateral slope of the dike considers the type of soil in the area of installation of the tanks, as well as the interior slope (in contact with the water). Considering the soil type, the tank slopes will be built with an interior slope of 3:1 and exterior of 2:1.

Table 2. Recommended slope for tanks (Adapted from Proença and Bittencourt, 1994).

Soil texture	Interior pendant	Exterior pendant
Sandy loam	2:1-3:1	1,5:1-2:1
Agile-sandy	1,5:1	1,5:1
Stable clay	1:1	1:1

6.2.3 Freeboard or safety edge

The safety edge represents the distance between the maximum water level in the tank and the ridge. This aspect is key to preventing the tank from overflowing, which could compromise the structural stability of the tanks, especially in the rainy season.

Longest part of the dike (m)	Freeboard (m)
200	0.3
200 - 400	0.5
400 - 800	0.6

For the designed tank, the freeboard will be considered as 0.3 m

6.2.4 Soil Compaction

To ensure good soil compaction, the soil should be added in layers of a thickness not exceeding 20 cm. A tolerance of 20% for dike height loss during compaction can be considered acceptable.

hs=0.2 m

6.2.5 Wave Height

Due to the action of waves, the dike must be high enough to prevent water from overflowing. The height of the wave is established considering the direction and strength of the prevailing winds. The formula below calculated the height of the wave.

$$h_w = 0.014 * (F)^{0.5}$$

Where:

$h_w = Wave\ height$
F= fetch (length of the pond in the direction of the wind)

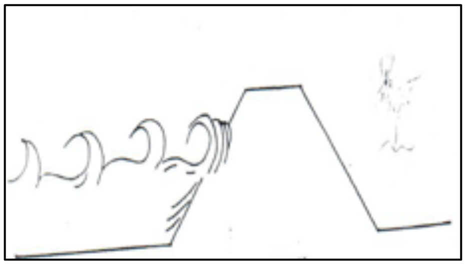

Figure 7. Wave height in an earth pond.

Applying the formula to the design, we obtain a wave height to:

$$h_w = 0.014 * (25\ m)^{0.5} = 0.07\ m$$

6.2.6 Height of the dike

The final height of the dike is estimated by taking into account the variables already calculated and applying the following formula:

$$H = h + h_w + h_f + h_s$$

Where:

H= Height of the dike in m
h=water depth in m
h_w=wave height in m
h_f=Freeboard in m
h_s= soil compactation in m

Applying the formula to the data already calculated

$$H = 1 + 0.07 + 0.3 + 0.2 = 1.6\ m$$

Therefore, the final height of the dike is 1.6 m

6.3 Estimation of soil volume

To estimate the soil volume that will need to be removed for the fish tanks' construction, the dike's cross-sectional area with the designed lateral slopes is considered, as shown in the figure below.

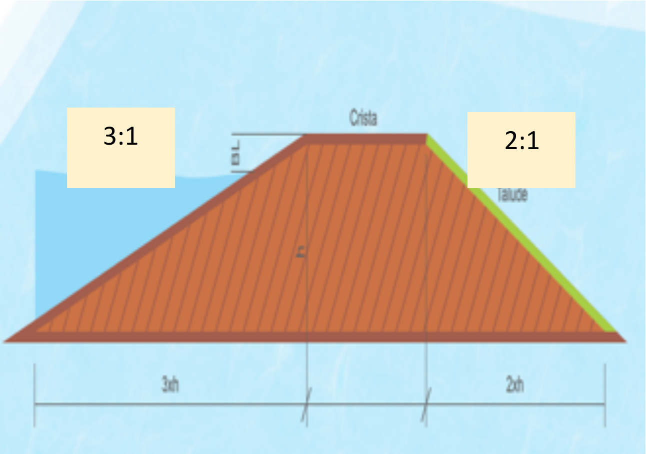

Figure 8. Cross-sectional area of the fish tank.

To calculate the cross-sectional area, the following formula is used

$$A = \frac{W + B}{2} * H$$

Where:

A= Cross-sectional area in m^2
W= Bridge width in m
B= Width of dike base in m
H= Height of the dike in m

The cross-sectional area for each tank is therefore calculated as follows:

$$A = \frac{2.2 + (3.2 + 2.2 + 4.8)}{2} * (1.6) = 8.16\,m^2$$

The volume of soil to be moved is estimated with the following form

$$V = (A * D * 2) + (A * d * 2)$$

Where:

A= Cross-sectional area

D= longest section of the dike in m

D= shortest section of the dike in m

$$V = (8.16m^2 * 50m * 2) + (8.16m^2 * 25m * 2)$$

$$V = 571\,m^3$$

This represents the total volume of soil to be moved

6.4 Summary of tank structure parameters

The table below summarizes the calculations of the parameters for estimating the elements of the aquaculture component.

Table 3. Elements for the design of aquaculture tanks.

Element	Value	Calculation formula
Width of dike crest	2.2 m	$W = 1,10(h)^{0,5} + 0,91$
Internal pendant	3:1	
External pendant	2:1	
Freeboard	0.3 m	
% of soil settlement	20%	
Wave height	0.07 m	$h_w = 0,014F^{0,5}$
Height of the dike	1.6 m	$H = h + h_w + h_f + h_s$
Cross-sectional area of dike	8.16 m2	$A = \frac{W+B}{2}H$
Total volume of soil	571 m3	$V = A * D$
Background pendant	1%	
No. of tanks	2	
Tank area	250 m2	

6.5 Water Supply system for the fish tanks

The water supply system will consider using the solar pump that will be installed for the irrigation system. The designed flow must guarantee the tank's water needs for the renovation and maintenance of suitable quality parameters such as pH and oxygen and to replace the volume lost due to infiltration and evaporation.

PVC pipes will carry out the water distribution. In the water collection area and in the discharge to the tanks, mechanical filters (1000 microns) will be installed to prevent the entry of organic waste (leaves, branches, etc). These filters should be cleaned periodically.

The water inlet into the tank will be at the opposite end of the drainage system to factor in water renewal. It should be at the height of approximately 0.50 m to favor oxygenation.

6.6 Drainage system

The drainage system will be built in the deepest part of each tank, with the aim of completely depleting it. The drainage will be installed with 110 mm PVC pipes, as shown in figure below.

An elbow will. Be attached to the drainage pipe of the tank, located at the base of the inner slope. Perpendicularly, a piece of pipe with a height equal to the maximum level of the tank will be placed. The regulation of the tank level will be done by rotating the pipe by the elbow at the desired angle. If it is necessary to drain completely, the pipe should be rotated 90 degrees from the vertical position.

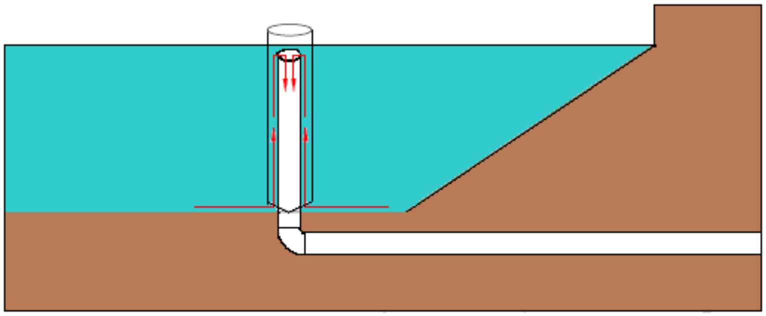

Figure 9. Drainage by elbow/pipe system.

6.7 Fish farming

6.7.1 Species

The farm's tanks will be populated with fish of the Nile Tilapia species. Tilapia is a native fish to the African continent and is currently the most farmed in Mozambique. *Oreochromis niloticus* (Nile Tilapia) and *O. mossambicus* (Mozambique Tilapia) are the two most commonly used species.

Figure 10. Tilapia O. niloticus.

O. mossambicus is an endemic species of Mozambique, but it is less used in national fish farms because it has a lower growth rate compared to *O. niloticus*.

The attributes that make Nile Tilapia suitable for fish farming are resistance against adverse conditions during cultivation, ease of reproduction, fast growth rate and high quality of the meat, which allows obtaining white fillets, with a mild flavour and without thorns. Other advantages are the high ability to take advantage of natural food (plankton), which allows good results to be obtained during breeding.

The tilapia fattening process can be carried out in earthen tanks, where the fingerlings are populated at densities dependent on the management conditions (level of food supplementation, means to maintain good water quality, technical capacity, among others).

6.7.2 Tank Settlement

The fingerlings for stocking the farm's tanks will be obtained from fingerling production hatcheries in Manica or neighbouring provinces (Sofala, Inhambane and Tete). Considering the conditions of the farm, namely the level of technification available and the conditions for crop management, the system to be used will be semi-intensive. This is an intermediate cultivation system between the extensive (low cultivation density, use of natural food) and the intensive (high density and high technification). Farmed fish should be fed balanced rations in the semi-intensive system, and tanks should be controlled, including monitoring fish growth and water quality.

6.7.3 Tank density

The stocking density has been defined as 5 fish/m$^{2 \text{ to ensure optimal growth rates}}$. Considering that each tank has an area of 250 m^2, the total number of fish is calculated by the following equation.

$$N = Area * density$$

Where:

N= Number of fish in each tank
A= Area of the tank in m^2
Density=stocking density in fish/m^2

Applying the formula, the estimated number of fish to populate each tank is:

$$N = 250\, m^2 * 5 \frac{fish}{m^2} = 1250\, fish\ per\ tank.$$

6.7.4 Production forecast

The forecasted growth rate in the tanks will depend on the conditions in which the tanks are managed daily. Especially on the correct feed supply in quantity and quality and on maintaining suitable water quality parameters.

The duration of the production cycle, from the stand to the harvest size (300 to 500g), is 6 to 8 months. Tilapia grows well at temperatures above 25°C, characteristic of the Chimoio region. With good management, a survival at the end of the production cycle of about 80% is expected, so the expected production in each tank is calculated as follows:

$$Forecast\ = N * \%\ survival\ rate * Average\ size\ (kg)$$

Where:

N= Initial number of fish used to populate the tank
%= Survival rate in percentage, usually 80%
Average size= Average fish size

Applying the formula to this desi,gn we obtain:

$$Forecast\ production\ (kg) = 1250 * 0.80 * 0.30\ kg$$

$$Forecast\ production\ (kg) = 300\ Kg/tank$$

The farm can produce 600 kg of fish per production cycle and 1.2 tons if they make two yearly production cycles.

6.7.5 Tank preparation

The preparation of the tanks includes:

- Total water drainage
- Cleaning to remove remains of organic matter at the bottom of the tank
- Repair all infrastructure (plastic lining of the bottom and slopes, inlet and drainage system, etc.)
- Organization of the material and equipment used during production.

The disinfection of the tanks aims to eliminate all microorganisms that may be at the bottom and walls of the tank. Disinfection is done by placing water at the bottom of the tank and diluting granular chlorine to obtain a residual chlorine concentration greater than 40 ppm[12] .

The following equation calculates the chlorine concentration for disinfection:

$$[Cl](g) = \frac{[Conc. ppm]x\ water\ volume\ (L)}{\%\ of\ Clx10}$$

Where:

- $[Cl](g)$= Amount of chlorine required to disinfect the tank (g)
- $[Conc. ppm]$ = Desired chlorine concentration (40 ppm)
- $Water\ volume\ (L)$ = Water volume in the tank (L)

Thus, if the tank to be disinfected contains a water level of 5 cm, the volume of water to be disinfected will be = 500m^{2}x 0.05m = 25m^{3}x1000 L/m^3 = 25,000L and using granular chlorine with 65% active chlorine, the amount of chlorine to use will be:

$$[Cl](g) = \frac{[40\ ppm]\times 25m^3)}{650} = 1.538g = 1.5\ kg$$

6.7.6 Fish Feed

The fish will be fed using balanced feed (containing the nutrients necessary for its development). The diets used in tilapia farming have between 28% and 55% crude protein, expecting a feed conversion (total ration/final biomass) of 1.4 to 1.8 under ideal temperature conditions (25 to 30°C). The amount of feed to be distributed will be estimated based on the estimated biomass in the tank (estimated total weight of the fish) and the nutrition rate (NR) suggested by the feed manufacturer or technician (historical data). The feed will be distributed at a frequency of 2 times a day at the beginning, reaching 3 or 4 times a day when the fish have an individual weight of more than 200g.

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[12] World Organization for Animal Health

The biomass calculation considers the initial number of fish populated in the tank, the estimated survival, and the average weight at the ration's calculation date. Weekly samplings should be carried out to assess the average individual weight. The goal is to evaluate the growth and estimate the biomass to calculate the diet. Factors such as temperature and water quality influence the determination of the amount of feed.

The amount of feed to be administered daily is calculated using the equation:

$$Food\ ration\ (Kg) = Biomass \times Nutrition\ rate\ \ (\%)$$

Where:

- Biomass = *Initial No. of Fish (1250) x Estimated Survival x Average Fish Weight*
- Nutrition Rate = Value provided by the manufacturer for the size of the fish or estimated by the producer's experience.

For example, considering fish that have an average individual weight of 200g, survival at the time of assessment of 85% and a recommended nutrition rate (NR) of 2.5%, the amount of feed to be distributed will be:

$$Ração\ diária\ (Kg) = 1250\ fish \times 85\%\ survival\ rate.x\ 0.2Kg\ de\ peso\ ind.x\ 2.5\%\ de\ NR$$
$$Ração\ diária\ (Kg) = \mathbf{5.3\ Kg}$$

The tank should receive a daily amount of 5.3 kg of feed subdivided into 2 meals, resulting in 2.7 kg per meal.

6.8 Integration with the other technologies.

In fish farming, less than 70% of the feed supplied is converted into biomass in the cultivated organisms (see figure below), with the remaining 30% being lost to the water in the form of organic matter. The use of these by-products in agriculture fields, provides recycling, as water rich in nutrients, mainly nitrogen and phosphorus, could be used as fertilizer.

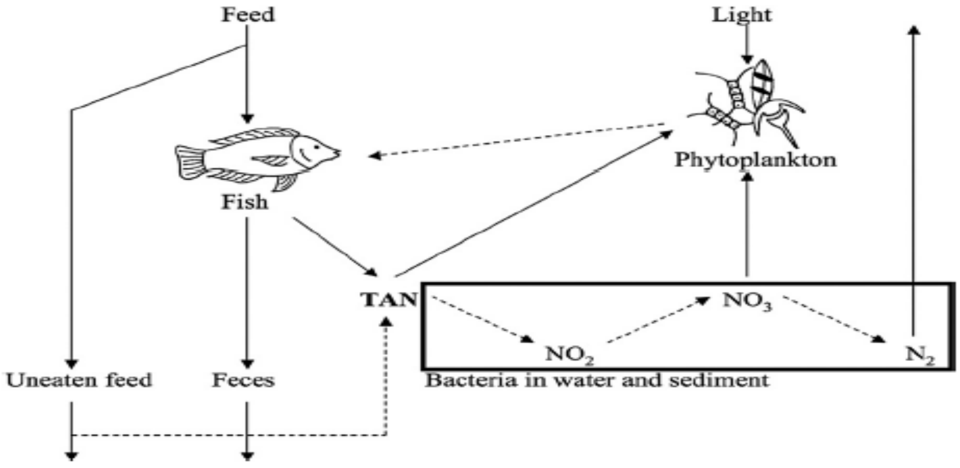

Figure 11. Waste recycling in fish tanks.

In the present project, the aquaculture compartment will consist of 2 ponds of 250 m^3 each, totaling a volume of 500 m^3. To maintain good water quality in the ponds, a minimum renewal of 5% of the total volume will be necessary, which accounts to 25 m^3 of wastewater to be drained to the 0.5 ha of integrated horticulture field. On the other hand, organic fertilizers from the composting compartment could be used for initial pond water preparation, promoting an algal bloom important for the pond environment.

7.Biogas

7.1 Biogas consumption requirements

The current firewood consumption has been estimated by the farmer to be 20 kg, every two to three days per week. Oven-dry firewood has an estimated energy content of 20 MJ per kilogram. To calculate the energy consumption in firewood, the following formula is used:

$$Energy\ requirements\ (\frac{MJ}{week}) = Kg\ of\ fuel * \ Power\ (Joules/Kg) * Frequency\ (days)$$

Applying the formula:

$$Energy\ requirements\ (\frac{MJ}{week}) = 20\ \frac{MJ}{Kg} * 2.5 \frac{(days)}{week} * 20\ kg = 1000 \frac{MJ}{week}$$

Biogas energy content is considered to be 35 MJ/m^3.

The following formula calculates the requirement of biogas production that equals the energy requirements.

$$Biogas\ consumption\ per\ week\ (m^3/week) = \frac{Energy\ requirements\ (\frac{MJ}{week})}{Energy\ producton\ per\ m3\ of\ gas\ (\frac{MJ}{m^3})}$$

Applying the formula:

$$Biogas\ consumption\ per\ week\ \left(\frac{m^3}{week}\right) = \frac{1000\left(\frac{MJ}{week}\right)}{35\ \left(\frac{MJ}{m^3}\right)} = 28.57\ m^3/week$$

This results in an estimated current biogas consumption of 4.1 m^3 of biogas per day.

The Swiss Federal Institute of Aquatic Science and Technology indicates that 150 - 300 L of biogas is used per person, per meal[13]. Four permanent workers and eight family members are present on the farm, so the household consists of 12 people. These people account for 1800 - 3600 L of biogas used for cooking. If we take the top of this range and assume a relatively high biogas use of 3600 L, there is an estimated biogas of 3600 L every day. So, for the following calculations, we consider 3600 L (or 3.6 m^3) of biogas is needed for the farm to cook its daily meals.

7.2 Feedstock amounts and properties for biodigestion

The biodigestion feedstock comprises both waste streams currently on the farm and waste streams that must be collected. The calculations on how much of each feedstock is currently present are shown below in Table below. New waste streams must be attracted, as the present waste streams are insufficient to achieve the biogas production goal of 3600 L/day. The total feedstock menu is shown in Table 2. Human feacal matter is excluded from Table 2 (shown in the table as 0 kg/week) because of expected social-cultural objections of farmers to use this waste stream for biodigestion.

Table 4. Calculation of currently available feedstocks for biogas production.

	Dry matter	Background information	Feedstock L/week	Feedstock kg/year	Feedstock kg/week	Biogas yield L/kg	Biogas yield L/day
Produced and bought chicken manure	50%	500 MT/1000 kg		2000	38	200	1,099
Kitchen + agricultural waste	15%	0,7 kg/L	179		126	120	1,292
human faecal waste	30%	1,8 kg/day			13	30	54
Total currently present feedstocks					**177**		**2,445**

Two feedstocks are the easiest to obtain to increase the biogas potential of the feedstocks on the farm (bought cow manure and used cooking oil; see in blue in Table 2). Firstly, cow manure can easily be purchased as a cattle farm is nearby. Using cow manure for biogas will decrease the amount of chemical fertilizer the farmer uses, thus making it economically favorable for the farmer. Additionally, cow manure is environmentally favorable because chemical fertilizers do not have to be made from fossil fuels and methane emissions from cow manure degradation at the cow farm are prevented.

Used cooking oil is generated at a rate of 1.27 kg/month per household[14]. Considering the 12 people on the farm, it is safe to assume the quantity of 3 regular households, coming down to 0.9 kg/week. Because the biogas yield from this feedstock is relatively high, it will be wise for the cook to realize that the used cooking oil should not be discarded as waste. Recycling used cooking

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[13] Direct Use of Biogas | SSWM - Find tools for sustainable sanitation and water management!)

[14] Households awareness and practices on used cooking oil recycling in Felda Lepar Hilir 1, Pahang (2022).

oil will also contribute to awareness for recycling other organic kitchen waste with the biodigester.

To create a digestate that flows freely inside the digester, the feedstocks must be diluted to a mixture of 10% dry matter in the digestate. For this dilution, water is used. Furthermore, the nitrogen (N) content of the digestate must not reach 4 g/kg. To ensure this, more water is added to the feedstock mixture. This results in a digestate with a dry matter of 6% (Table 2).

Table 5. Feedstock for biodigestion.

Feedstock	**Dry matter**	**Feedstock kg/week**	**Biogas yield L/kg**	**Biogas yield L/day**	**Days before digestion**	**Digestion after 60 days**	**kg/week dry matter**	**N g/kg**
Produced and bought chicken manure	50%	38	200	1,099	30	100%	19	27.0
Kitchen & agricultural waste	15%	126	120	1,292	70	60%	19	4.0
Human faecal waste	30%	0	30	0	30	100%	0	15.0
Bought cow manure	30%	346	30	1,484	30	100%	104	10.0
Used cooking oil	80%	0.9	900	113	15	100%	1	1.0
Subtotal	28%	511		3,988			143	9.8
Dilution of water/liquids	0%	1074	0	0	0	100%	0	0.0
Total with dilution	9%	1585		3,589				3.2
Digestate	6%	1268		0				3.9

7.3 Size, dimensions and location of biodigester

The size and dimensions of the digester are shown in Table 3. It may be noted that digester diameter and length may vary according to the available material as long as the tube-like shape is maintained for ease of flow and the volume of the digester stays the same.

Table 6. Size and dimensions of the biodigester.

Biogas production	3589	L per day
Retention time	60	days
Digester liquid volume	13.6	m3
Digester total volume	19.4	m3
Digester filling height	70%	
Digester diameter	1.5	m
Digester length	11.0	m

The southeastern trade winds define the dominant wind direction in the Chimoio region. Because the wind is coming from the south-east, the digester is located to the north-west of the house, just where the current latrine is located. The slope on which the farm is situated has no significant influence on the direction of the wind. Furthermore, the biodigester is situated uphill from the biocomposting so that the digestate can flow from one to another under the power of gravity.

7.4 Protection and pressure and temperature regulation

The biodigester is a vulnerable structure, so protection from vehicles, animals, and unauthorized people is desired. For this, it is envisioned to build two pole fences alongside the digester, ½ of the diameter of the digester high. Because the digester is built inside a trench of ½ of the digester diameter deep, the fences are just as high as the digester when the gas storage is full.

The temperature regime in Chimoio is seasonal, with the lowest month being July (avg 18.1 °C, min 12.4 °C, max 23.9 °C), and the highest in January (avg 25.2 °C, min 20.7 °C, max 29.7 °C). This means n fluctuations are relatively small but slightly below optimal 25-40 °C temperature. To create a greenhouse effect, the fences alongside the digester can be covered with transparent plastic foil. This will ensure a temperature of >25 °C. Additionally, it is strongly advised to insulate the buried part of the digester since heat loss, especially to wet ground, will be significant.

Whenever the gas reservoir in the top half of the biodigester is not entirely full, gas pressure will be below cooking use. To counter this, gas pressure is regulated by rods/poles on the gas roof, placed perpendicular to the length of the biodigester. These are, in turn, held in place by the fence poles.

8. Biocomposting

The biocomposting process that will be designed for this process will include vermicomposting as a sustainable alternative to chemical fertilizers. Vermicompost results from the transformation of organic material, such as crop residues and animal ma,nure among others by earthworms.

The vermicompost production process will be based on the system using bedding (5 x 1 x 0.4 meters in length, width and height, respectively). The beds for raising worms and producing vermicompost will depend on locally available materials, and in consultation with the working group and the farmer requirements (excavated, blocks and bamboo). The maximum time for harvesting the vermicompost will be 60 days. In storage, the humidity of the vermicompost should be between 35 and 40%, and can remain for six months. The application of vermicompost in the agricultural fields will be 1 kg /m^2.

Table 7. Materials required for the production of vermicompost

Materials	Quantity per Bed	Quantity/0.5ha
Vegetable waste	63%	5 tons
biogas production paste	7%	

Animal manure (cattle and chicken)	30%	
Eisenia fetida (Earthworms)	1kg	

8.1 Liquid biofertilizer

Liquid biofertilizer is an emerging technology in Mozambique. It has specific beneficial microorganisms capable of fixing, solubilizing or mobilizing plant nutrients through their biological activity. Biofertilizers can be derived from manures and plant extracts (Bhattacharjee et al., 2014).

In this project, the liquid biofertilizer will be filtered from the biogas production. The quantity depends on the capacity of the biodigester (see chapter 6 for biogas production). At the end of the biogas extraction, the biofertilizer will be collected, filtered and stored in drums for one month. The storage location should be cool, shaded and, if possible, dark. The dilution for application of the biofertilizer will follow a 1:1 ratio. Biofertilizer can be applied by spraying, direct application in the hole and drip irrigation.

Table 8. Materials required to prepare liquid biofertilizer in a 200L drum.

Materials	Quantity
Animal manure	60kg
Ashes	15kg
Molasses	15kg
Milk	15L
Water	180 L
0.5 inch hose	3m

9.Sources

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