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Presented by

Frank PROSPEROUS

Solar water pumping systems for rural water supply and small scale irrigation schemes in Africa

Defended on 02/09/2019 Before the Following Committee:

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DECLARATION

I, Frank PROSPEROUS, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here have been fully cited and referenced in accordance with the academic rules and ethics.

Signed: 29th August, 2019

……………………………………

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CERTIFICATION

This is to certify that the thesis entitled "**Solar pumping system for rural water supply and small scale irrigation schemes, A case study of regional HUBs of IsDB, Rabat, Morocco; Dakar, Senegal; Abuja, Nigeria**" that is being submitted by Frank PROSPEROUS, Masters student, Registration number PAUWES/2017/MEE17, in partial fulfillment for the award of Masters in Energy Engineering to the Pan African University Institute of Water and Energy Sciences (Including Climate Change) is a record of bonfide work carried out by him. This thesis has been submitted with our approval as the supervisors.

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……………………………	……………………………..
Signed: 29th August, 2019	Signed: 29th August, 2019

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DEDICATION

This thesis is dedicated to my loving Mother Ms. Margaret C. Lwakatare and in the bright memory of my beloved father Mr. Prosperous G. Msafiri who helped to shape who I am today.

ABSTRACT

Non-renewable energy sources usage for water pumping in African communities threatens the energy security of our continent and contribute to climate change through the use of environmental unfriendly energy sources. These indigenous energy sources may lead to loss of economic and environmental viability due to widely use of diesel motors. This research analyzed the technical, social and economic feasibility of solar water pumping system as an alternative clean energy source. Before conducting a thoroughly detailed designs and analysis of the cost, introductory information about the accessibility of identified sites and all necessary materials were acquired through site maps and local SWPs suppliers. Site conditions as well as all materials and methods to collect information were included but not limited to literature review, site visit and physical observation, interview, consultation, photograph, software and checklists. This study found that system oversizing and downsizing affects the technical and economic performance. 11 out of 17 surveyed projects in Tanzania have negative NPV i.e the value of cash flow is less than the investment cost of the project for the duration of 20years. Investment cost of the systems increases with an increase of array capacity however in same cases the same array capacity may be having different investment cost in different areas. According to IRENA the unit cost of PV system is Africa is averaged to USD 1.30 (IRENA, 2016), but the average cost per watt of surveyed installed systems goes to USD 5.6, and this may vary from one country to another due to different external factors such as transportation and labour cost.

Keywords: Photovoltaic, solar pumping system, Irrigation Schemes, Water Supply.

RÉSUMÉ

L'utilisation de sources d'énergie non renouvelables pour le pompage de l'eau dans les communautés africaines menace la sécurité énergétique de notre continent et contribue au changement climatique par l'utilisation de sources d'énergie non écologiques. Ces sources d'énergie indigènes peuvent entraîner une perte de viabilité économique et environnementale en raison de l'utilisation généralisée des moteurs diesel. Cette recherche a analysé la faisabilité technique, sociale et économique d'un système de pompage solaire de l'eau comme source alternative d'énergie propre. Avant de procéder à une conception et à une analyse détaillée des coûts, des informations préliminaires sur l'accessibilité des sites identifiés et tout le matériel nécessaire ont été obtenues par l'intermédiaire des plans du site et des fournisseurs locaux de SWPs. Les conditions du site ainsi que tout le matériel et toutes les méthodes de collecte d'information ont été inclus, sans toutefois s'y limiter, dans l'analyse documentaire, la visite du site et l'observation physique, les entrevues, les consultations, les photographies, les logiciels et les listes de vérification. Cette étude a révélé que le surdimensionnement et la réduction des effectifs du système ont une incidence sur le rendement technique et économique. 11 des 17 projets étudiés en Tanzanie ont une VAN négative, c'est-à-dire que la valeur du flux de trésorerie est inférieure au coût d'investissement du projet pour une durée de 20 ans. Le coût d'investissement des systèmes augmente avec l'augmentation de la capacité du réseau, mais dans les mêmes cas, la même capacité du réseau peut avoir des coûts d'investissement différents dans différents domaines. Selon l'IRENA, le coût unitaire d'un système photovoltaïque en Afrique est en moyenne de 1,30 USD (IRENA, 2016), mais le coût moyen par watt des systèmes installés étudiés est de 5,6 USD, ce qui peut varier d'un pays à l'autre en raison de différents facteurs externes tels que le transport et le coût de la main-d'œuvre.

Mots-clés : Photovoltaïque, système de pompage solaire, systèmes d'irrigation, approvisionnement en eau.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
AfDB	African Development Bank
AC	Alternating Current
ANTHC	Alaska Native Tribal Health Consortium
BCR	Benefit Cost Ratio
BOS	Balance of System
CBR	Cost Benefit Ratio
DC	Direct Current
DOL	Direct Online Starter
DWE	District Water Engineer
FAO	Food and Agriculture Organization of the United Nations
GIZ	Deutsche Gesellschaft fur Internationale Zusammenarbeit
GSES	Global Sustainable Energy Solutions
GSWI	Global Solar and Water Initiatives
ICRC	International Committee of the Red Cross
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
IsDB	Islamic Development Bank
LCCA	Life Cycle Cost Analysis
NPV	Net Present Value
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NE	National Engineers
PBP	Payback Period
PRO	Public Relation Officer
PV	Photovoltaic
SWP	Solar Water Pumping
TZS	Tanzanian Shillings
UENR	University of Energy and Natural Resources
USDA	United State Department of Agriculture
VFD	Variable Frequency Drive
WB	World Bank

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

In Africa irrigation is a key to safeguard harvest most of the year. Nevertheless, irrigation is way too expensive for many farmers (Mossali, 2014). However part of Africa is semi-arid in that faces water shortage and declining water quality. Different activities in different sectors in Africa are limited to the availability of water resources thus playing the biggest role to the African economy (Schyns, 2013). Groundwater resources have been proved to be the best water source that can be used to supply water in rural communities while facilitating the smooth running of social economic development of African countries (Malak, 2016; Schyns, 2013; Khan, Sarkar, & Islam, 2013). Nevertheless, different research papers in Solar water pumping in most part of Africa does not take into account the water quality and how it can affect the end users in terms of consumptions due to aquifer overexploitation, intrusion of nitrates, pesticides and other untreated water discharges.

Today Africa is blessed with a massive amount of solar radiation but in most cases different farmers still use diesel generators or electricity to run small scale farm's irrigation systems, this is due to lack of knowledge on the best green and economical choice of technology to be used to perform the same function. A technical report written by Freischlad indicates that Agriculture shows an important role in Senegal as in most Sub-Saharan economies. Despite of having a wide range of agricultural productivity technologies still the implementation becomes more unreliable due to lack of energy supply (Freischald, 2017), on other hand Daysi indicates that solar-powered water pumps has been used most in Malawi, Mali, Ghana, Senegal, Gambia, Cameroon, Uganda, Zambia, Nigeria and Zimbabwe (Suaquita, 2016). A favorable alternative is to harness the solar energy which available in our continent for irrigation and water supply.

Solar powered pumping systems are capable of delivering water from rivers and wells in a large volume depending on the type of pump required. In this system the PV generator is supposed to be mounted facing the solar radiation for optimum energy extraction, this PV generator is then connected to a controller together with the PV protect, PV Combiner (If available), and PV disconnect. Other components are Submersible pump which acts as an appliance which utilizes solar energy, stilling tube for pump casing, well probe, cable splice kit, grounding rod, surge protector which can be installed at each controller sensor, Safety rope, water meter, pressure sensor float switch and water storage tank.

It should be noted that PV modules produce electricity only when there is sun that is during the day, so if there is a need to use energy during night to supply water or to irrigate then the battery system or elevated water storage tank should be included. Energy can be stored as water by pumping water into a tank while the sun is shining and distributing it by gravity when needed during night (Eker, 2017).

Recently studies in the area of solar water pumping have been highlighting few major aspects and components in separate ways, these studies focused on the design procedures, components required, economic feasibility and few on environmental aspects in different countries in Africa and Asia but did not put together all the critical criteria.   A study conducted by Saidou and his fellow researchers in Niger highlighted the design procedures of solar water pumping through showing how PV generator can be coupled directly to the pup with AC/DC converter, they highlighted the importance of storing water in the tank to cut the cost of using batteries in the system but did not put clear all the economic and financial aspects (Saïdou, Mohamadou, & Gregoire, 2013). A study conducted in Onipe community in Nigeria during 2014 by Nwobi et. al shows that to pump water using a generator contribute 3,204kg/year of CO2 for a system of 0.75Kw to pump 15,000 Liters of water in a daily basis while Solar powered system is Carbon dioxide emission free, even though the author managed to come up with the financial and economic viability he did not manage to put clear how solar PV system is CO2 emission free (Nwobi, Ajide, & Abu, 2014).

A research conducted in Dangila Area of Ethiopia in 2014 shows that solar water pumping is more attractive for small scale irrigation systems compared to large ones in remote areas. Zegeye et al. miscarried measures to improve the system efficiency to ensure the system technical sustainability apart from finding the optimum tilt angle of the panels (Zegeye, Tadiwos, & Aman, 2014). Kokate et al in 2015 Mumbai India highlighted in their report that the efficiency of PV system is much higher over conventional energy system and managed to show how the MPPT controllers can be used to obtain the best efficiency of PV system (Korpale, Kokate, & Deshmukh, 2015). Abu-Aligah suggest that in order to eliminate the cost of the system to about 1/3 it is important to remove the batteries in solar water pumping (M.Abu-Aligah, 2011). Lastly in a study conducted in Bangladesh found out that the cost of Solar PV system is half of the diesel engine for the 25 years of Life Cycle of the system, and on the other end the author agrees with Abu-

Aligah on the sense that the combination of battery storage and storage tank of water is still an economic viable to sole the challenge during dry season (Biswas & Iqbal, 2018).

In this framework this research will deliver sole opportunity for financiers and other clients through looking deeper into the combination of all Nature and purpose of such projects; Cost of project and means of finance; Technical viability; and Economic and Financial Viability of the system.

1.2 OBJECTIVES

1.2.1 Main objective

To examine the most effective and efficient solutions and propose a cost-effective solar water pumping system for rural water supply and small-scale irrigation in Africa.

1.2.2 Specific objectives

- To assess and identify the social, technical, and economic sustainability of solar water pumping (SWP). [**SPO1**]
- To propose an integrated optimization design criteria that can be used to enhance the performance of SWP. [**SPO2**]
- To bridge the knowledge gap in current practices that do not take into consideration the O&M and capacity building framework for SWP in Africa. [**SPO3**]

1.3 PROBLEM STATEMENT AND MOTIVATION OF THE STUDY

In this modern era agriculture has become one of the reasonable economic sector in Africa, being the source of income through cash crops and food crops cultivation this sector faces difficulties due to lack of water mostly in rural areas as well as lack of environmental and economical friendly technologies of pumping water from the surface or underground water source to the farms for irrigation, in some cases small farms are most vulnerable due to the rise of diesel prices to run the generator for irrigation (Lahmidi, 2013), this mainly occur in areas where there is a growing use of butane gas for irrigation purposes, for example in case of Morocco the growing use if butane gas leads to the increasing deficit in the subsidizing fund (Khan, Sarkar, & Islam, 2013). Apart from agriculture the access of clean and reliable water supply for rural areas in Africa is still a major problem (Malak, 2016; Missaoui, 2016; Schyns, 2013; Sakairi, 2006), to ensure the achievement of sustainable development goals in water supply I propose the fully utilization of ground water in rural areas where the water sources are inadequacy but the ground water source are obtainable, this goes together with the use of sustainable energy i.e solar water pumping to supply water to the community without forgetting the prior treatment before consumption.

1.4 RESEARCH QUESTIONS

- Is the use solar water pumping (SWP) system sustainable (technical, social, and economic) and affordable compared to the use of non-renewable energy sources? [**Q1**]
- How the design criteria do affect the system performance in Africa? [**Q2**]
- Does the current SWP system installed in Africa incorporate appropriate O&M practices as well as Capacity Building after installation? [**Q3**]

1.5 SCOPE OF THE STUDY

The high diesel costs affects water pumping requirements for water supplies and small scale irrigation system, this can be solved by using solar water pumping system as an alternative to diesel generators. This study covers the system optimization and assessment of Economic, technical and environmental feasibility of solar water pumping. It also provides the general decisions and recommendations for the system application and deployment in terms of Operation and Maintenance Practices as well as Capacity building in Africa. This thesis will be centered only to the development of theoretical models which can be implemented practically in Africa for a duration of four to five months. The figure below shows the relationship between the specific objectives, Research questions and scope of this study.

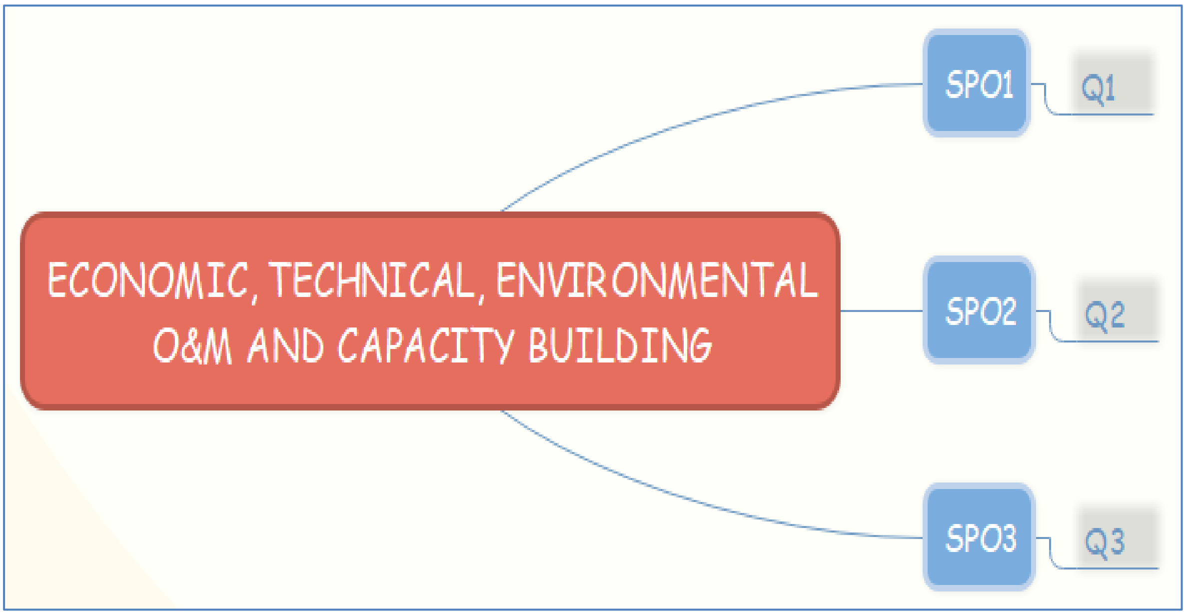


Figure 1. 1 Relationship between Scope, Specific Objectives and Research Questions

1.6 SIGNIFICANCE OF THE STUDY

The following are the benefits intended to be achieved by this research;

- It will open the door to the access of sustainable agriculture and water supply,
- It will facilitate the way forward to Energy, water and food security through the Water-Energy-Food Nexus approach,
- It will improve the livelihood through economic (at governmental and individual level) and environmental improvement.

1.7 CONCEPTUAL FRAMEWORK OF THE STUDY

This explains the visual illustration of the key concepts and relationships among them starting from the problem statement towards the output of this research work as shown in the figure 1.2 below.

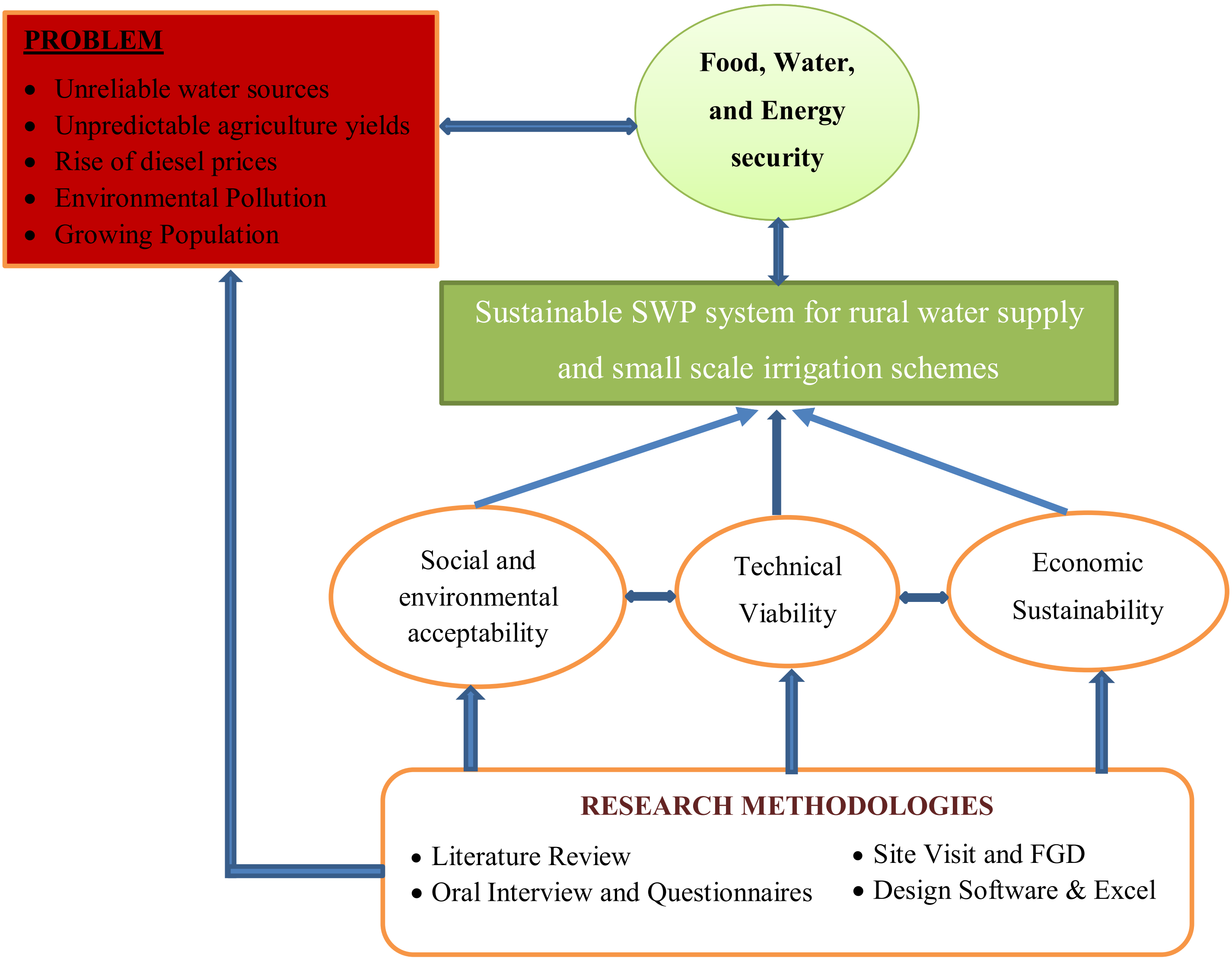


Figure 1. 2 Conceptual Framework of the research (Source: Author)

CHAPTER TWO

OVERVIEW OF SOLAR WATER PUMPING SYSTEM

2.1 SOLAR-PV PUMPING SYSTEM

Solar PV pumping system is the framework with the set of scientific principles that utilizes solar radiation as the source of energy to pump water, this energy is converted into electrical energy by the solar panels and used to drive electric motors which are connected to the pump end. World Bank group described that this system is simple and sophisticated, it involves the perfect energy transformation process, from sunlight, to electrical energy, to mechanical energy, to stored energy (World Bank, 2018). Other's perspective differs from WB, they believes that these systems are somewhat complex systems and their design involves not only a "fit-for-purpose" PV pump system but similarly an assessment of water requirements to demand side, skills and understanding of the end user on the system (Amevi Acakpovi, 2012; Hartung & Pluschke, 2018). To pump water by using solar pumping system depends on the three main variables i.e pressure, flow of water, and power to the pump (S.S. Chandel, 2015). SWP tends to have high initial costs but still most studies shows that they are attractive to off grid areas where irrigation and water supply is still a main problem (Wijetunge & Chandrarathna, 2006). This part will describe the components of Solar Water Pumping (SWP), design parameters, design procedures, configuration and applications of SWP.

2.2 COMPONENTS OF SOLAR WATER PUMP

There are two major components of SWP which are Power supply components which includes Solar array, Electronics components (controls) and energy storage (batteries) and the second component is Solar pumps which are designed to be operated by solar energy, these pumps has electric motors which can be either AC or DC connected to a pump end (Norman, 2015). However Jeff and Bill described the three main parts of SWP which are; the PV array, Motor and pump subsystem and the storage and distribution system that takes water to the point of use (Kenna & Gillett, 1984). Figure 2.1 categorizes the components of SWP into three including Water storage and distribution system.

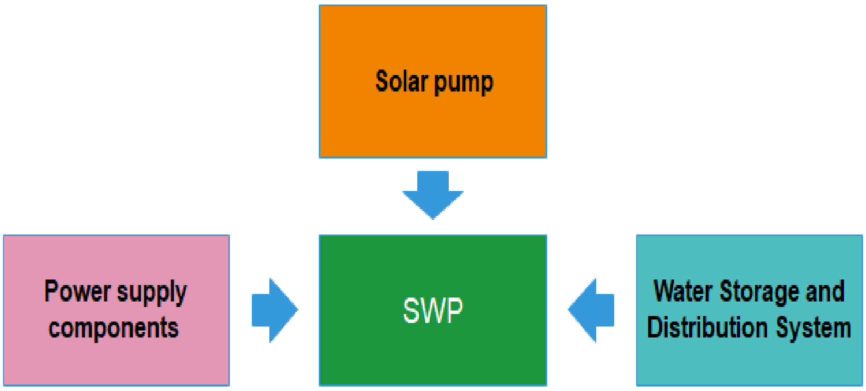


Figure 2. 1 SWP Main Components

2.2.1 Power Supply Components

This is the elementary unit of solar water pumping system built from the solar modules, to get the required voltage and current required by the solar pump, these modules should connected in either parallel or series connection. These modules are rated in different peak watt and tested at 1000W/m^2 radiation level and 25°C temperature (Roy Barlow, 1993). Solar modules are made up of smallest elements known as solar cells, the special layered semiconductors materials in solar cell when exposed to light produce direct current (DC) electricity (M.Abu-Aligah, 2011).

The energy storage in SWP systems is very important when there is a need to pump water during night and where there is a low level of solar radiation. There are many types of batteries but the most commonly used type is Deep Cycle Lead acid. This energy can be delivered to the load (pump) either in DC or AC (with the help of an inverter). They are constructed by the group of cells (or elements) with each cell delivering 2Volts, thus 6 lead-acid cells connected in series creates 12V battery. Good batteries always worth the investment but are too expensive, in SWP water storage tank can be offered into the system to avoid incorporating the battery into the system to reduce the cost (Davis & Shirtliff, 2017).

Charger controller is part of power supply component and the primary objective of charger controller is to protect the battery from overcharge or over-discharge. The basic characteristics of charger controllers are (Davis & Shirtliff, 2017);

- Rated nominal voltage (12, 24, 48V)
- The can handle maximum current (to avoid overcharge)
- Lights or alarms are the communication or indicators
- Low voltage disconnection (to avoid over discharge)
- Basic voltage regulation using a charge or discharge controller

2.2.2 Solar Pumps

A typical solar pump draws water from the well or surface water source to storage tanks or users directly (CONERGY, 2017). Solar pump choice is determined by the site condition, flow required and nature or type of water resource (surface or underground). Thus there are two major types of solar pumps depending on the location of water source; Submersible pump and Surface pump (Shehadeh, 2015).

2.2.2.1 Submersible pumps

The most commonly used ***submersible pumps*** are *centrifugal pumps* and *positive displacement* pumps (Giessen, Roek, Bom, Abric, & Vuik, 2015; Shehadeh, 2015; NSW Farmers & GSES, 2015; Saïdou, Mohamadou, & Gregoire, 2013).

a) Centrifugal Pumps:

The principal operation of centrifugal pumps is the rotation of blades known as impellers which are arranged in stages at high speed, water is thrown radially by centrifugal force (Giessen, Roek, Bom, Abric, & Vuik, 2015), and the pressure of water can be changed by the speed of rotating blades either in a clockwise or anticlockwise direction, this changes the flow of water (NSW Farmers & GSES, 2015). It is suitable and most regularly applicable for low flow (6 to 20m^3/day) and low water head (0 to 80m) (Shehadeh, 2015). Centrifugal pumps are more efficient but its efficiency decreases with the decrease in speeds, thus at low insolation the pump works at low efficiency (Chandel, Naik, & Chandel, 2015).

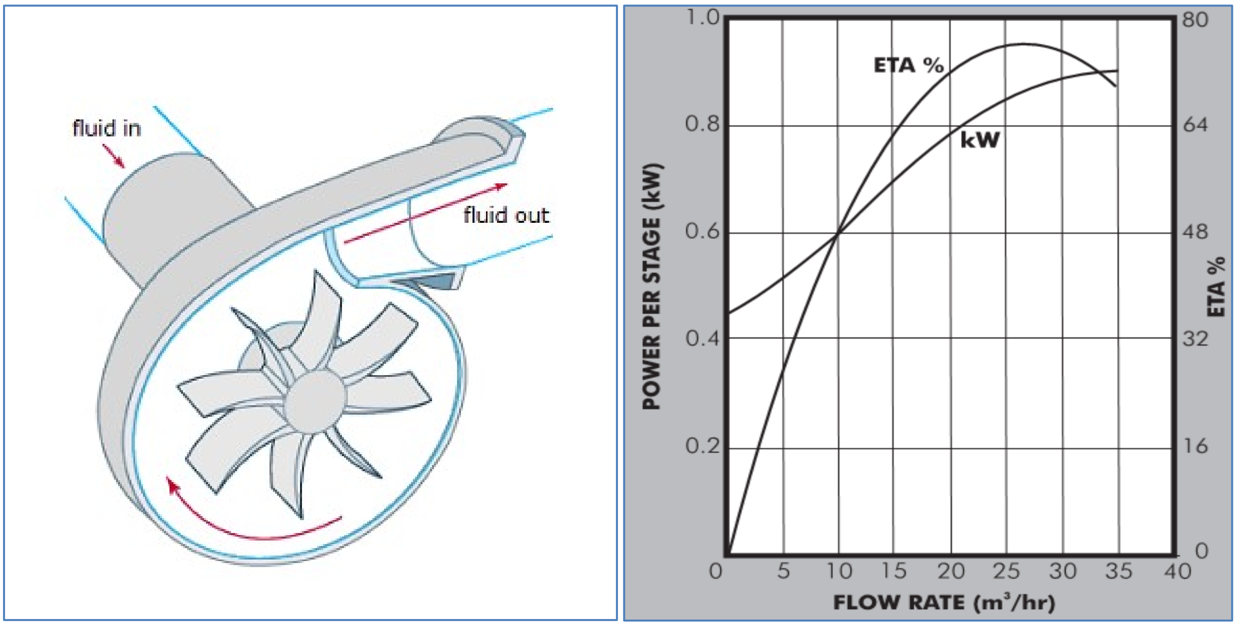


Figure 2. 2 schematic diagram centrifugal pump and power consumption graph

It should be noted that centrifugal pumps allows the pressure increase by increasing the number of stages, each stage of a centrifugal pump has the power it consumes during operation (Figure 2.2 shows the graph on the right side of power per stage/Efficiency ratio versus flow rate), additional flow the affect the power consumption, this means that the increase in number of stages in centrifugal pump will increase the number of solar panels in the system.

b) Positive Displacement Pumps:

Positive displacement pumps are more efficient where there is large heads and low flow requirements (Dursun & Saygin, 2005; Kishta, 2002). Connecting positive displacement pumps directly to the PV panels is unsuitable, instead a power conditioning and MPPT system has to be incorporated between the pump and PV panels. The water output is always related to the speed of the pump in direct proportionality but independent of the head (Chandel, Naik, & Chandel, 2015). The figure 2.3 below shows the three operating principles of positive displacement pumps as explained by Argaw, Foster and Ellis in 2003.

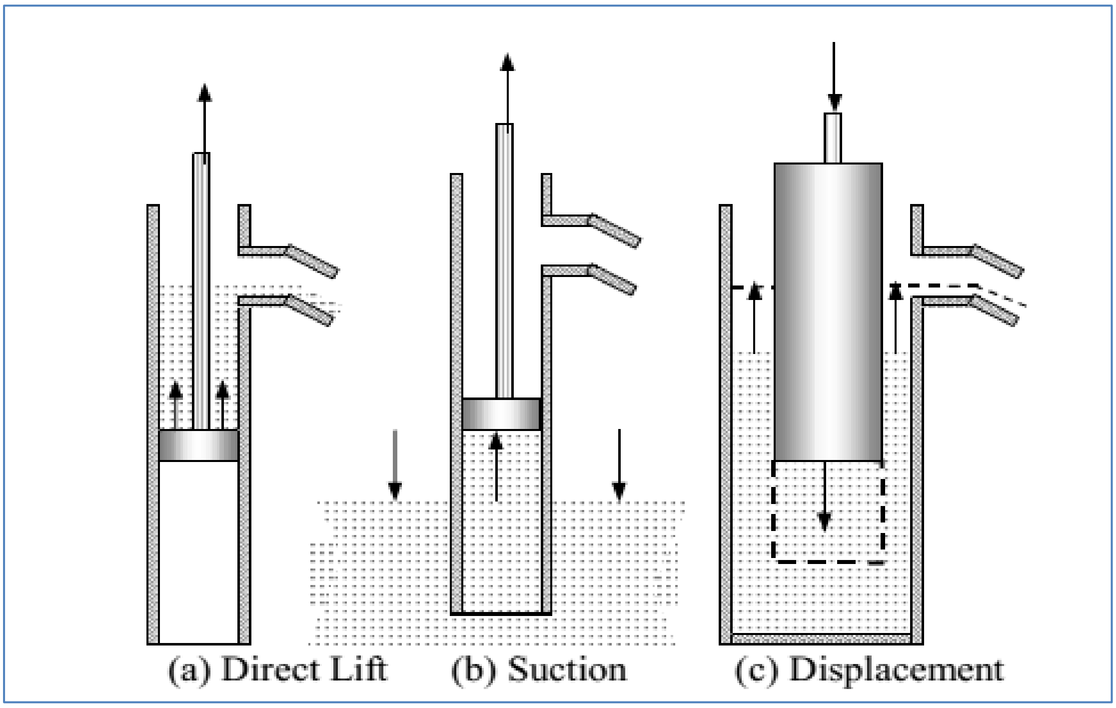


Figure 2. 3 Operating principles of positive displacement pumps

Source: (Argaw, Foster, & Ellis, 2003)

2.2.2.2 Surface Pumps

Surface pumps are commonly applicable in surface water sources such as ponds, shallow wells, and streams, the water to be pumped should not be more than 7 meters below ground level or pump inlet as suction lift. This suction lift needs to be maintained to a minimum limit so as to ensure the system reliability and pump efficiency (Global Solar and Water Initiatives, 2017; Shehadeh, 2015).

2.2.3 Electric Motor

Solar pumps are integrated with electric motors which can be either AC or DC motors, the two types are explained below:

2.2.3.1 DC Motors

DC motors operates under Direct Current source, thus makes the motor more applicable where the direct coupling with PV panels is required. When opting DC motors it's necessary that you consider high efficient motor. Permanent magnet that exist in brush less DC motor communicates with the stator electronically to lessen the requirement for brushes (Shrestha, Jha, & Karki, 2014). When the motor opted is DC motor type the there is no need to convert the DC from panels to AC by using DC/AC Converter (Saïdou, Mohamadou, & Gregoire, 2013). DC motors are extensively applied in small applications with capacity below 3 kW (Jenkins, 2014). Samatha et al (Shirahatti, Sonasale, Wahile, & Suryawanshi, 2016) concluded that DC motors are very expensive since they require regular maintenance of the brushes.

2.2.3.2 AC Motors

These Motors uses Alternating Current to operate, they are widely used and commercially available at different ranges. According to Shrestha and others, Induction Motor and asynchronous motors are the basic two types of motors available (Shrestha, Jha, & Karki, 2014). El Shaikh et al. described that AC motors can be further be divided into single phase motors (up to 3hp) and three phase motors which goes beyond 3hp (El Shaikh, Teaima, & Abdellatif, 2018). 1kW or less motors are not suitable for PV powered systems due to their tendencies of having low efficiencies. Additionally, to deliver the high starting current power conditioning circuitry needs to be added (Shrestha, Jha, & Karki, 2014). There are about five starting methods of AC motors which are: DOL, Star –Delta, Auto Transformer, Soft Starter, and VFD. Connecting a DC motor directly from PV system is considered as a least expensive method of pumping water by using solar energy (El Shaikh, Teaima, & Abdellatif, 2018), but as mentioned above by Jenkins this should be more applicable to a system with less than 3kW. Based on 2014 prices, AC motor was economic compared to DC motors for PV pumps where: $(\text{Flow rate } \times \text{Water head}) > 600\text{m}^4/day$ (Shrestha, Jha, & Karki, 2014). Apart from the other comparisons AC motors are reliable and cheaper compared to DC motors, thus to choose either to use AC or DC motors can be a complicated exercise. Girma identified five criteria that should be used for choosing a motor pump for a PV system, these criteria are; price, efficiency, reliability, availability, and the wattage (Girma Z. , 2015). Figure 2.4 below shows then typical motor parts.

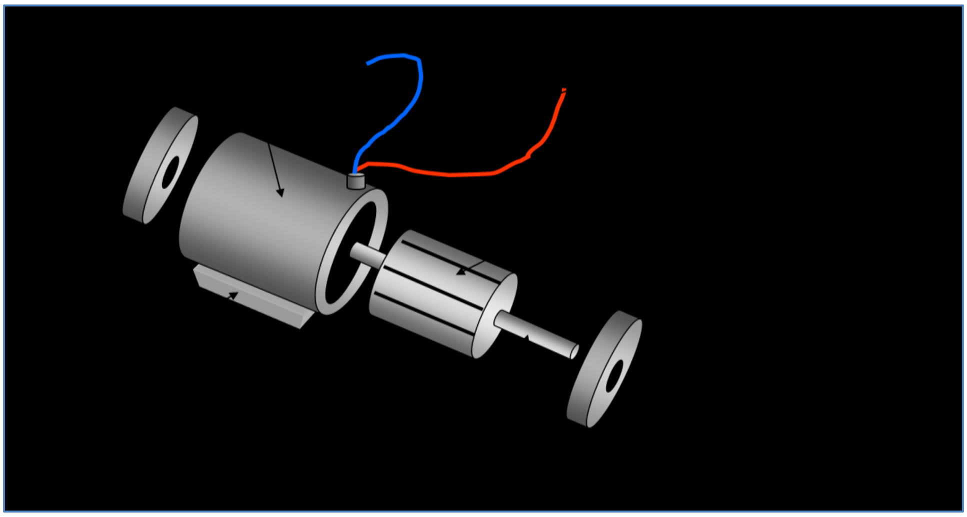


Figure 2. 4 Parts of surface electric motor (Source: Davis & Shirtliff Training Manual)

2.2.4 Pump Controllers and Protectors

According to Girma the two primarily functions of pump controller are; to monitor and modify the characteristics of the electricity produced by the photovoltaic solar panels that is Voltage and Current so that to ensure safe pump operation, and the Second function is to control or decide when the pump goes on and off electronically or non-electronically (Girma Z. , 2015). The basic components to be controlled and monitored are electricity from the PV panels, water level in the well, and the water level in the tank/storage (Ratterman, Cohen, & Garwood, 2007). Controllers described in this part will include; electronic controller, pressure tanks, float switches, pressure switches, and variable speed drive.

2.2.4.1 Electronic Controller

One of the electronic pump sensor is a Flow sensor. This sensor starts the pump when flow is detected and stops when flow stops. The other sensor is *dry run protection*, under this sensor the pump stop time should be adjusted to a range of running let's say between 10 to 180 secs. System is un-pressurized in no flow condition so rejecting pump cycling when there is no water. Motor maximum power determines the design of these electronics controllers (Davis & Shirtliff, 2017). Figure 2.5 shows different pump controllers available in the market in Tanzania.

Figure 2. 5 Electronic pump controllers

To protect the pump from dry running special sensors (dry running protection) that detects the water level in a borehole or surface water source has to be incorporated. If the pump purchased is embedded with dry-running protection, therefore it should be well-known that the water level detectors in boreholes should not be installed (Ismail, Soh, Cronin, M. Lisewski, & Vagani, 2012). Overflowing is prevented by installing sensors in the water storage tank, these sensors sense the different water levels in the storage tank and communicates with the pump on when to start and when to stop pumping.

2.2.4.2 Pressure tank

Pressure tank is mainly used when the pump or water source cannot meet the demand at that particular time, it works together with pressure switch. According to Davis & Shirtliff the pressure tank operates as a cushion pressure surges when a pump starts and stops as well as providing a drainage supply into the system to regulate pump cycling (Davis & Shirtliff, 2017). Wellcare defined the roles a pressure tank plays in water systems as to safeguard and extend the pump life by avoiding fast cycling of the pump motor; to provide water under pressure for delivery between pump cycles; and to provide extra water storage under pressure to support the pump in meeting the total demands of a system if the pump or well is incapable of supplying the required capacity (Wellcare, 2014). Consider the figure 2.6 below;

Figure 2. 6 outside and inside parts of a Pressure Tank

2.2.4.3 Float Switch

Float switch can be used to detect the water level in a borehole, water tank or water source that doesn’t have stable water level, it encompasses of a float raising a rod that activates a micro switch when the water level shifts to required or unrequired level. Figure 2.7 shows the pump down and pump up demonstration of installed float switch in a system as well as the appearance of pressure switch on the left.

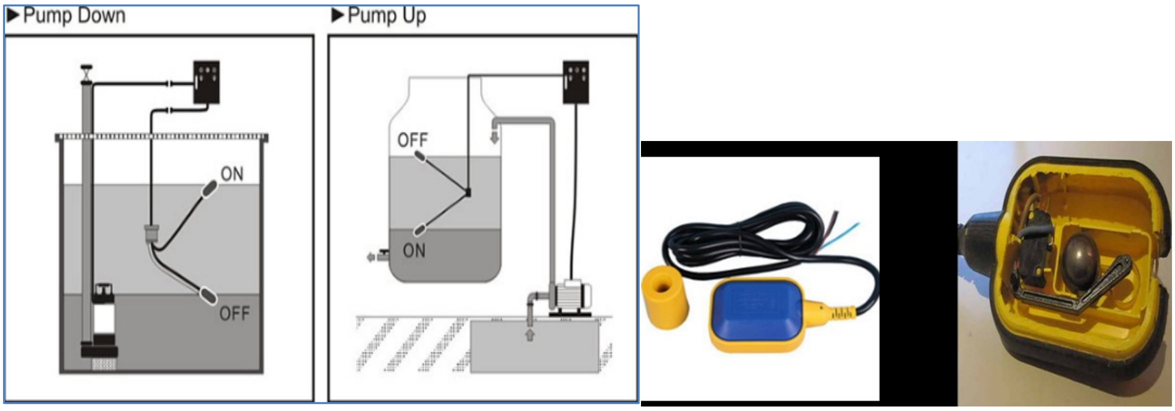


Figure 2. 7 Float switch set up and its appearance on left side

2.2.4.4 Pressure Switch

The main function of a pressure switch is to sense pressure in a water line and sends the information to the pump to either start or stop according to the requirement, this communication is only done when the pressure is outside the range of set pressure (maximum pressure and minimum pressure set). Booster pumps and submersible pumps are mostly installed with this kind of switches (US Department of Health, 2008). When the pressure rise or drop the switch makes the contact, and they are designed to operate at 16Amp current (Davis & Shirtliff, 2017). Consider the figure 2.8 below which shows the pressure switch and its part.

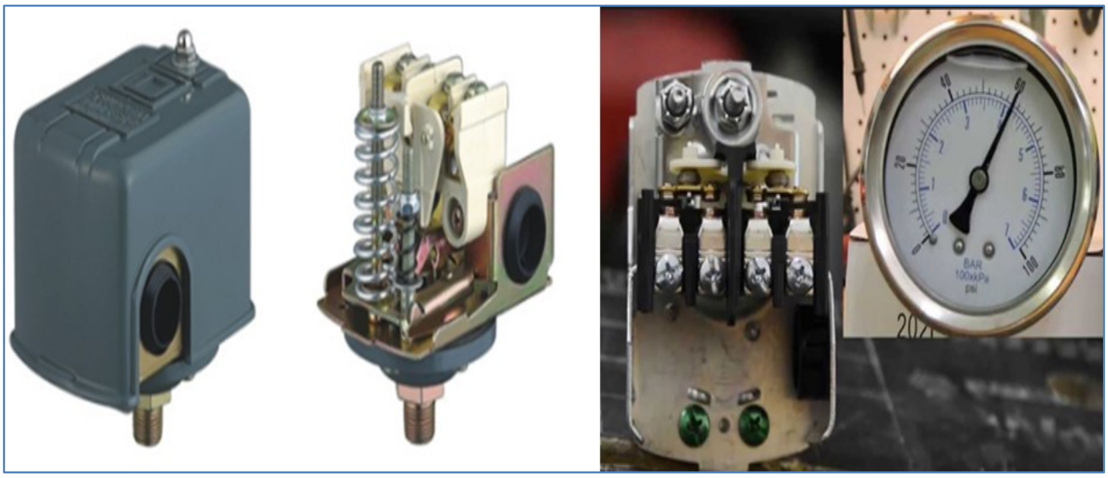


Figure 2. 8 Pressure switch (Source: Davis and Shirtliff (T) LTD)

2.2.4.5 Variable Speed/Frequency drive Controller

A variable speed drive (VSD) is the motor controller that regulates the output of motor by varying frequency and voltage, it consists of three parts; AC to DC converter, DC to AC converter and DC bus (GSES, 2015). Variable Frequency Drive (VFD) is designed to drive a standard 3 phase industrial motors by efficiently converting DC power from Solar PV into 3 phase AC Power, 230V and 380V and are available from 1kW to 50kW and above. VFDs was not designed for solar pumps but recently they are running of 3 phase solar motors due to their price becoming affordable. High efficiency during power conversion from DC to AC is one of the advantages of VFDs but this should be combined with MPPT to reduce electrical losses. And the limitation is the variation of motor speed which is contributed by the variation of solar radiation in a direct proportionality (Gläser, 2016).

2.2.5 Water Storage and Distribution System

To ensure economic viability of solar water pumping system, a storage tank needs to be added to the system to store water during the maximum production which can be used in times of cloudy or low supply duration (Morales, Busch, & Yasumiishi, 2010). Storage tank can store energy (potential energy) through storing water losses or unnecessary water flow during operation. In addition for in house connection pumping water from borehole to the elevated tank is considered as an efficient method of SWP (Shehadeh, 2015; Schnetzer & Pluschke, 2017).

In case where construction of water storage tank seems to be uneconomical the percentage should be allowed to account for cloudy days but this will add up to the number of solar panels than initial, Joynal et al went far and disagreed on the use of water storage tank because it’s expensive but yet the designed the system which has no batteries for energy storage, thus they allowed a 30% days as cloudy days on monthly basis (Joynal, Raka, Mithu, & Iqbal, 2017).

2.3 DESIGN OF SOLAR WATER PUMPING SYSTEM

The design and performance of solar water pumping depends mainly on the site parameters such as solar irradiance, flow rate, number of sunshine hours with the ambient temperatures, Hydraulic energy, Total Dynamic Head, and total quantity of water requirement (Shouman, El Shenawy, & Badr, 2016; Chandel, Naik, & Chandel, 2015; Callahan, 2013). The following steps are necessary during the SWP system design;

2.3.1 Site Assessment

The site assessment takes into the consideration which will make the solar panels to be located in a place where there is sufficient solar radiation (Malak, 2016). To ensure the maximum utilization of solar radiation on site the PV array should be oriented toward true south for the Northern hemisphere sites and true north for the southern hemisphere sites. Based on the location and changes with time the local declination is supposed to be taken into account (Priyanka, Raghavendra, Palled, & Veerangouda, 2018). Most of the site location have water that cannot be extracted with a hand pump, in such cases the wells must be able to provide sufficient water for the community (DACAAR, 2015). Based on New York State Energy Research and Development Authority, the following relevant issues were identified as the key aspects for the suitability of the site for Solar water Pumping (Sinton, Butler, & Winnett, 2015);

- Appropriate facing location without shading
- Suitable location for the installation of SWP components
- Closeness between Solar arrays and Pump to minimize wire size and cost
- If batteries are available they should be installed in a well ventilated, dry and temperature controlled place.

2.3.2 Determine the water source

The type of water source and its location influence the configuration of solar water pumping system, these water sources can either be surface or subsurface source. To determine the water source to be used the following aspects in Table 2.1 should be considered in both types (Sinton, Butler, & Winnett, 2015);

Table 2. 1 Important information on water source determination

	WATER SOURCES	
	Subsurface Sources	***Surface Sources***
INFORMATION	Static Water Level	Seasonal Variations
	Seasonal Depth Variations	Water Quality
	Water Quality	
	Recovery Rate	

2.3.3 Calculate the required water demand

Water demand can be calculated in terms of water supply for normal uses and water for irrigation, under irrigation case the several factors that will affect water demand are climate condition, soil type, characteristic of a crop, and variation in seasons, the following equation is designed to calculate the water demand for irrigation purpose only (Narale, Rathore, & Kothari, 2013);

$$W_d = \frac{C_a \times P_c \times K_c \times W_a \times PE}{E_u} \tag{1}$$

Where; W_d = Peak water demand (Liters/day/plant)

C_a = Crop area (Row to row spacing (m) x crop to crop spacing (m))

P_c = Pan Coefficient (from 0.7 to 0.8)

K_c = Crop Coefficient which depends on the growth stage and type of crop

W_a = Wetted area (%)

PE = Pan Evaporation rate (mm/day)

E_u = Emission uniformity of drip system, (taken as 0.90)

Water demand for normal consumption apart from irrigation takes into consideration per capital water demand, nature of activities i.e school, churches, mosques and market places. Standards are available based on the site condition. Water losses during transportation is also taken into account (Wu, et al., 2013).

2.3.4 Calculate the required total Head

Level differences in a system gives out the head, the total head of the pump is the results of several contribution such as static head, dynamic head, friction losses and head due to outlets (Raghuwanshi & Khare, 2018; Mermoud, 2006). The expression below shows the calculation of the Total Head in the system

$$H_{Total} = H_{Outlet} + H_s + H_D + H_f \tag{2}$$

Where:

H_{Outlet} = height of the outlet pipe above the ground level.

H_S = static head due to the depth of the water level in absence of any pumping.

H_D = dynamic head: It is the summation of a vertical distance from the water surface level to the water supply end (H_s) and total friction losses (H_f)

H_f = friction losses in the piping system, this depends on the flowrate.

2.3.5 Pump selection

The design of solar pump depends on the water flow (m^3/hr) and pumping total head (Hadidi, Berbaou, & Saba, 2016). After determining the total head and flow from water demand can be used to select the pump from manufacture's provided graphs, from selected pump you can easily identify the power needed by the pump (Davis & Shirtliff, 2017). Another method is to use the head and flow to calculate the amount of energy by the following formula (Moran, 2016);

$$P = \frac{Q \times \rho \times g \times H_{Total}}{3.6 \times 10^6 \eta} \tag{3}$$

Where; P = Pump Power in kW
Q = Flow rate in m^3/hr
H = Total Head in m
g = Gravitation force ($9.8m/s^2$)
η = Motor efficiency of the pump (usually taken as 0.7)
ρ = Density of water ($1000kg/m^3$)

2.3.6 Solar Array Selection and tilt orientation

Sreewirote et al. describe another design method which can be used to size our solar panels in which PV Panel Nominal peak Power (P_{pv}) is calculated by taking into consideration the peak sun hours (PSH), load of the system (E_{Load}), and the efficiency (η_{system})of equipment as shown in the equation below (Sreewirote & Leelajindakrairerk, 2017);

$$P_{pv} = \frac{E_{Load}}{PSH \times \eta_{System}} \tag{4}$$

According to Nshimyumuremyi, the array to be selected should be able to supply a minimum energy required by a pump, however an additional minimum peak power of energy (25% additional) should be added to account for losses and environmental factors (Nshimyumuremyi, 2015). A PV array contains PV modules which are separately framed, they are electrically connected to produce the required voltage and current to operate the load (Adeyemo, 2013).

To maximize the energy production PV panels should be installed by considering the angle and direction. The angle and direction for fixed panels should be the mean value of annual direction of the maximum solar irradiance as well as full sun exposure (Bengtsson & Nilsson, 2015).

2.4 BENEFITS OF SOLAR WATER PUMPING

Solar water pumping offers a number of benefits to users in Agriculture and Water supply, according to Lorentz in a case study in Morocco, the following are the highlighted benefits of solar water pumping (LORENTZ, 2013);

- No fuel cost is needed in solar water pumping system, thus reduces the energy bills and saves time by avoiding to refill fuel.
- Operation costs, fuel supply and transportation are not part of the problem since the sun is reliable and an endless source of energy.
- No many moving parts in solar water pumping system which reduces the maintenance and repair costs, hence gives the good return on investment compared to other types of energy.
- Solar energy is an environmental friendly energy source since the supply is done without the emission.

2.5 ECONOMIC ASPECTS

Under sizing or oversizing always affects the cost of PV modules because the cost always varies directly with power rating of the system, hence all components should be designed in efficiently to avoid the increase in the cost of the system (Roy Barlow, 1993). Economic evaluation of Solar water pumping system is done mainly to ensure that the system is viable or not. Life cycle cost analysis (LCCA), Net present Value (NPV) Internal rate of return (IRR), Benefit-cost ratio(BCR) and Payback period (PBP) are the five economic indicators that are mostly carried out (Narale P. D., 2012).

2.5.1 Life cycle cost Analysis (LCCA)

Life cycle assessment is the technique of assessing the cost of the system from cradle to grave, this method can be used to identify the most cost-effective system through comparison of two or more systems. The following equation is summarizing the LCCA of solar water pump (Narale, Rathore, & Kothari, 2013);

$$LCC = CC + MC + IC + RC + SC \tag{5}$$

Where; SC is the Salvage cost which is the net worth in the final year of the life-cycle period (Narale, Rathore, & Kothari, 2013). Capital costs (CC); this involves an initial investment cost of the project, installation and transport cost as well as the cost of physical elements (panels, pump, pipes, water storage tank, water meters, control boxes etc.) are involved in the Capital cost (Giessen, Roek, Bom, Abric, & Vuik, 2015). In 2012 IRENA describe the capital cost to be comprising cost of Modules and of the Balance of system (BOS), under which the BOS cost included items like structural cost, the electrical system costs and batteries or any other storage system (IRENA, Solar Photovoltaics, 2012). Capital costs is somewhat proportional to the system's rated power (Roy Barlow, 1993). Installation Costs (IC); is part of the capital cost, it can be included in the BOS while evaluating the cost of installing solar structures and electrical components. Operating and Maintenance costs (MC); there is no operating cost for solar water pumping sysstem but the only maintainance cost that can be taken into account involves activities like Wiping panels every month and Checking wires (Welsien & Hosier, 2015).

2.5.2 Net Present Value of the system (NPV)

The higher the NPV value for the project the more the favorable investment (McFaul & Rojas, 2012). The difference between the discounted total benefits and that of discounted total cost gives the NPV of the project. Calculated benefits of the project becomes much higher when the NPV is greater (Pan American Health Organization, 2017). NPV can be used to calculate the NPV;

$$NPV = \left[\sum_{t=0}^{n} \frac{B_t}{(1+d)^t}\right] - \left[\sum_{t=0}^{n} \frac{C_t}{(1+d)^t}\right] \tag{6}$$

Where B_t is the project benefits during year t, C_t is the project costs during year t, d is the discount rate, and n is the total number of years.

2.5.3 Benefit-Cost Ratio (BCR)

Cost Benefit Ratio should not be confused with BCR, BCR is the discounted ratio of the NPV of benefits to NPV of total cost. If you decide to use BCR make sure the value is greater than 1, this means the project is more likely to drive the positive benefits (Li, Chalvatzis, & Stephanides, 2018), if the BCR is less than 1 (cost is greater than benefits) then the project should not be taken, and if BCR is equal to 1 (Benefits is equal to cost) then it should proceed with viability (Pan American Health Organization, 2017). Consider the equation below;

$$Benefit\ Cost\ Ratio\ (BCR) = \frac{Discounted\ NPV\ of\ Benefits}{Discounted\ NPV\ of\ total\ Cost} \tag{7}$$

2.5.4 Internal Rate of Return (IRR)

Internal Rate of Return is the measure of profitability of the prospective investment. Is through this rate where by the NPV of all cash flow within a project is made zero (Li, Chalvatzis, & Stephanides, 2018). According to Sarasa et.al the IRR is higher with loan compared to the IRR when loan is not being provided, this is due to the fact that IRR is much more favoured by low interest rate (Sarasa-Maestro, Dufo-López, & Bernal-Agustín, 2019). The following formula can be used to crosscheck the value of IRR which makes NPV equal to Zero.

$$NPV = \sum_{t=1}^{n} \frac{F_t}{(1+IRR)^t} - I = 0 \tag{8}$$

Whereby: F_t is Cash flow during year t, I is Initial Investment of the project, n is the number of years of the investment. The purpose of IRR is to find the discount rate which makes the cash inflow and outflow equal, in the end the feasible project should be the one with IRR which does not exceed the required rate of return (Nábrádi & Szôllôsi, 2010).

2.5.5 Payback Period (PBP)

Payback period is the number of years required to recover the cost of project investment, it is obtained by dividing the total investment cost by the annual return of the same project (ANTHC, 2011). The project is considered to be profitable when the payback period is shorter (Li, Chalvatzis, & Stephanides, 2018). PBP is one of the utmost required method to measure the solar projects economic feasibility, it is a simple method and understandable. The following formula is used in calculating the PBP.

$$Payback\ period = \frac{Invetment\ Cost}{Annual\ Income - Expenditure} \tag{9}$$

However the method ignores several characteristics which can be critical in investment, these characteristics are the inflation, opportunity costs and risks (Hay, 2016).

CHAPTER THREE

RESEARCH METHODS

3.1 DESCRIPTION OF STUDY AREAS

Africa is the second largest continent and most populous in the world, it has an estimated population of 1.2 billion of people according to the 2016 statistics. The Nominal GDP of Africa is $ 2.33 trillion which makes it the fifth continent in the world, this is according to the 2018 economic statistics.

Figure 3. 1 Map of Africa

(Source: https://geology.com/world/africa-satellite-image.shtml)

Africa is the energy poor continent, most of people in Sub-Saharan countries lacks access to clean and reliable energy, this leaves South Africa country as an exceptional country together with the Northern African Countries where the energy access is quite much higher.

In this study learning sites were obtained from different parts of Africa through site visits and the review of appraisal reports, working papers, and articles. Among of the countries which were included are the United Republic of Tanzania, Kenya, Ghana, Cameroon, Senegal, Rwanda, Ethiopia, Egypt, Morocco and Zambia.

3.1.1 TANZANIA CASE STUDY

Tanzania is the largest country in East Africa, covering an area of $945,200km^2$ including $60,000km^2$ of Inland Water. Tanzania is found in the equatorial region in the East Africa between parallel 1^0S and 12^0S and meridians 30^0E and 40^0E. She is bounded by Kenya and Uganda in the northern side, Malawi and Mozambique in the southern part, Zambia in the South western part, Congo DRC in the western part, Rwanda and Burundi in the North Western part as well as Indian Ocean in the East part. Surveyed systems in Tanzania were located into three regions which are Kilimanjaro region in the North Eastern part, Dodoma region in central Tanzania, and Mtwara region in the South Western part. Figure 3.2 shows the map of Tanzania and the three visited regions.

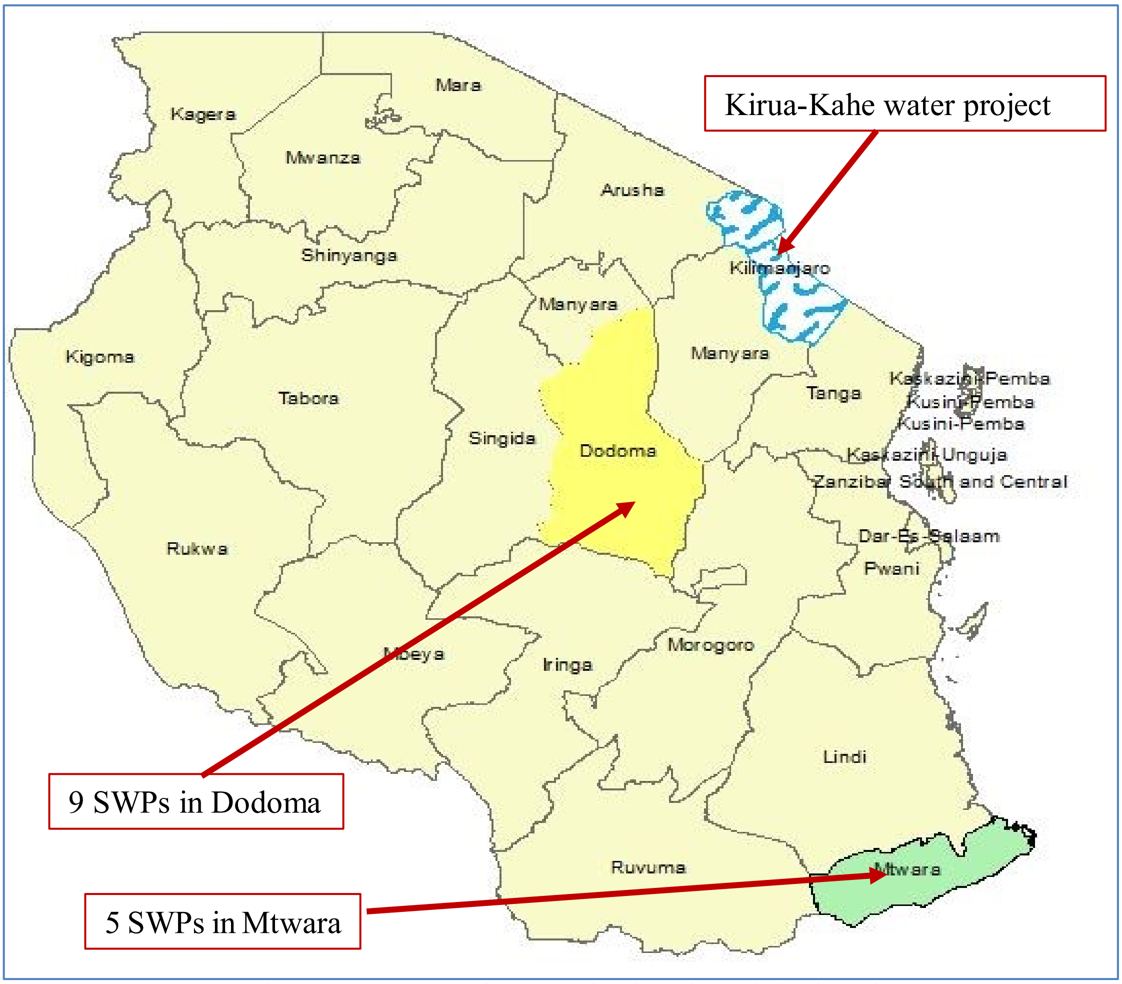


Figure 3. 2 Map of Tanzania showing visited regions

The United Republic of Tanzania has an estimated population of 56.9 million, growing at a rate of 2.7%, with an average growth of 6.7% per annum over the period 2007–2017, rate of urbanization annually is 5.36% while 31.6% of the population live in towns and the rest in village, more than 5million lives in Dar es salaam city, 1Million in Mwanza city, life expectancy is

62years, and the working group being 27.7%. Tanzania's annual solar resources exceed 5kWh/m^2 per day throughout the country; Insolation is generally higher and more consistent in the Lake Victoria basin and along the coast. However, in the elevated areas around Moshi and Arusha, and in Iringa and further south, insolation is considerably reduced (i.e. less than 4 kWh/m^2 per day) during the cloudy season (IRENA, 2017). Solar resources are especially good in the central region of the country (Including Dodoma), and it is being developed both for off-grid and grid-connected solutions.

A total number of 17 projects all under public ownership and private ownership were surveyed, 9 solar water pumping projects from Dodoma region, 3 from Kilimanjaro and 5 from Mtwara region.

3.2 METHODOLOGIES

Depending on the sources and nature of data which were necessary for this research the following methods which were used;

3.2.1 Site Selection

To facilitate the observational aspects of existing condition of solar water pumping for small scale irrigation and water supply schemes in Africa, different sites were picked from different countries based on the availability of published reports on solar water pumping in Africa. Apart from online survey in other African countries, Tanzania was assessed by physical observation and site visit method to obtain first-hand information.

3.2.2 Sample size

More than 25 published, one project from Mali, Feasibility study from Burkina Faso and reported projects from different countries were assessed analyzed in terms of technical and financial reliability, as well as 20 projects from Tanzania which were 5 from Mtwara, 9 from Dodoma, 3 from Dar es Salaam and 3 from Kilimanjaro were carefully assessed. 3 out of 20 projects are potential projects owned by Kirua-Kahe Water Supply Trust in Tanzania were used to assess the social, Technical and economic aspects. The Kirua-Kahe project designed to offer service to 20 villages serves a total number of 2000 household as beneficiaries. From the 20 villages 10% of households from two villages combined were picked up for questionnaire survey, which makes it 60 households, officers of Kirua Kahe and village water committees were targeted. The sampling method was random since all water beneficiaries from Kiruha-Kahe were treated the same due to nature of their economic activities and water service level. Table 3.1 below summarizes the number of respondents in each site for Tanzania.

Table 3. 1 Number of respondents from each project visited

	Water Committee		***Households***		***Water Officials/designers***		***TOTAL***
	M	F	M	F	M	F	
Kirua-Kahe SWP	7	2	41	19	3	1	73
Mtwara Project	-	-	2	-	1	1	4
Dodoma Projects	-	-	6	3	2	1	12
Dar es Salaam	-	-	-	-	1	2	3
TOTAL	**7**	**2**	**49**	**22**	**7**	**5**	***92***

3.2.3 Data Collection and Analysis Methods

To study the social, technical and economic aspects questionnaires, Physical Observations, in-depth oral interview, Focused Group discussion, Literature review, and Consultations were used. Excel were used to analyze the statistical data and prepare graphs and charts for representation.

The following part describe in details the methods used for this study under field and desk studies data collection;

a) Site visit and physical observation

More than 13 sites were visited in Dar es Salaam, Dodoma, Kilimanjaro and Mtwara regions in Tanzania. Site condition were observed and the size of the systems were noted down as well as their technical components. To assess the environmental and social sustainability in line with the available site condition questionnaires were administered to the users while technical survey were done through confirming the information provided by the system owner through observing system components such as solar panels, inverter sizes and capacity of water storage tanks. Photographs were taken by cameras and videos were recorded to record the existing condition found onsite. Figure 3.3 below technical Manager describing the village borders being served by Kirua Kahe project.

Figure 3. 3 Site visit done at Kirua-Kahe

b) Oral Interview and Questionnaire

Oral interviews and questionnaires were administered to key stakeholders to facilitate the specific objectives of this research. Questions administered to water officials (Appendix IV), installers, TAREA, and individual system owners were categorized into four sections; General information which aimed at social status, ownership of the project, water consumption and security of the system; Technical information which aimed at providing technical information such as the size of the solar system, operation time, yield, and characteristics of water sources; Economic, Social and Financial Assessment as well as Operation, Maintenance and Capacity Building. TAREA as decision makers had their own questions (Appendix I) and questions were responded by the Managing Director. Figure 3.4 shows the oral interview conducted at Kirua-Kahe water supply trust with 4 officials including PRO, technicians, Accountant and Managing director.

Figure 3. 4 Oral Interview between my team and Water Supply trust

Primary information was obtained through questionnaires which were conducted to 60 households for Kirua-Kahe project, 10 questions (Appendix II) with 6 closed questions and 4 open questions were prepared for each questionnaire for Economic, Social and Financial assessment to allow flexibility. Questions were written in English but translated into Swahili language during administration to help respondents to be able to provide required information. Among of 60 respondents 32% were females and 68% were males. Figure 3.5 below shows how questionnaire was administered at household level in Kilototoni Njiapanda.

Figure 3. 5 Doing questionnaires at household level

c) Focus Group Discussion

Focused Group discussion were conducted only for Kirua-Kahe water project since it is the Community Based Water Management (CBWM), 10 representatives (Water committee led by the chairperson) from the community were called for the discussion which took 1 hour and 46 minutes. 14 open questions (Appendix III) were divided into 5 Aspects, i.e Social aspect; Economic; Legal, institutional and Organizational; skills and knowledge as well as Technological aspect. The information were Recorded by using mobile phones (audio and video) and books and later transcribed. Figure 3.6 shows the FGD with water committee team

Figure 3. 6 Focused Group Discussion with water committee

d) Consultation

During data collection different peoples in different organizations were consulted and provided information which helped to accomplish this work. Engineers, sales officers and Technicians from Companies like Simusloar, and Davis & Shirtliff (T) were communicated time to time to validate technical and financial information. TAREA played their roles to direct me towards different companies which installed SWP in rural areas with respects to their sites and offices. Finally Communication was established between supervisor and student during data collection and analysis regarding the type of information and reporting format needed to undertake this work.

e) Literature review (desk study)

Studies about previous work regarding solar pumping was done. A review of research papers and funded projects in Africa by IsDB, World Bank, and UN organizations was done in case studies. Excel form were prepared to record each project and their costs. Reported and published information from governmental bodies was surveyed. Table 3.2 gives the insight on where the information were obtained as well as the research methods to be used to accomplish specified objectives.

Table 3. 2 Research methods and their respective objectives

RESEARCH OBJECTIVES	RESEARCH QUESTION	RESEARCH METHOD	SOURCE OF INFORMATION
To assess and identify the social, technical, and economic sustainability of SWP. [**SPO1**]	Is the use solar water pumping system sustainable (technical, social, and economic) and cheap compared to the use of non-renewable energy sources? [**Q1**]	• Oral Interview • Questionnaire • Consultation • Simulation Software • Governmental Statistics • Site Visit and Photograph • Projects, Research papers, Appraisal Reports review	• NASA & Other meteorological data centers • IsDB, WB, AfDB, ADB reports and projects • Grundfos Product center and Excel • EIA reports • Own Observation
To propose an integrated optimization design criteria that can be used to enhance the performance of SWP. [**SPO2**]	How the design criteria do affect the system performance in Africa? [**Q2**]	• Oral Interview • Consultation • Simulation Software	• Installed Systems on sites by solar companies • Own Observation • Research Papers

To bridge the knowledge gap in current practices that do not take into consideration the O&M and capacity building framework for SWP in Africa. [**SPO3**]	Does the current SWP system installed in Africa incorporate appropriate O&M practices as well as Capacity Building after installation? [**Q3**]	• Literature review (papers) • Consultation	• Published Papers, business and economic reports • Own Observation • Supervisor

3.2.3 Conceptual Framework of Research Methods

Data collection on this study is divided into two categories, the first on is desk study where all the information will be obtained without going directly to the site and the second part is when some of the information will be taken directly from the field. Figure 3.7 shows the conceptual framework of research methods to be used and data collection.

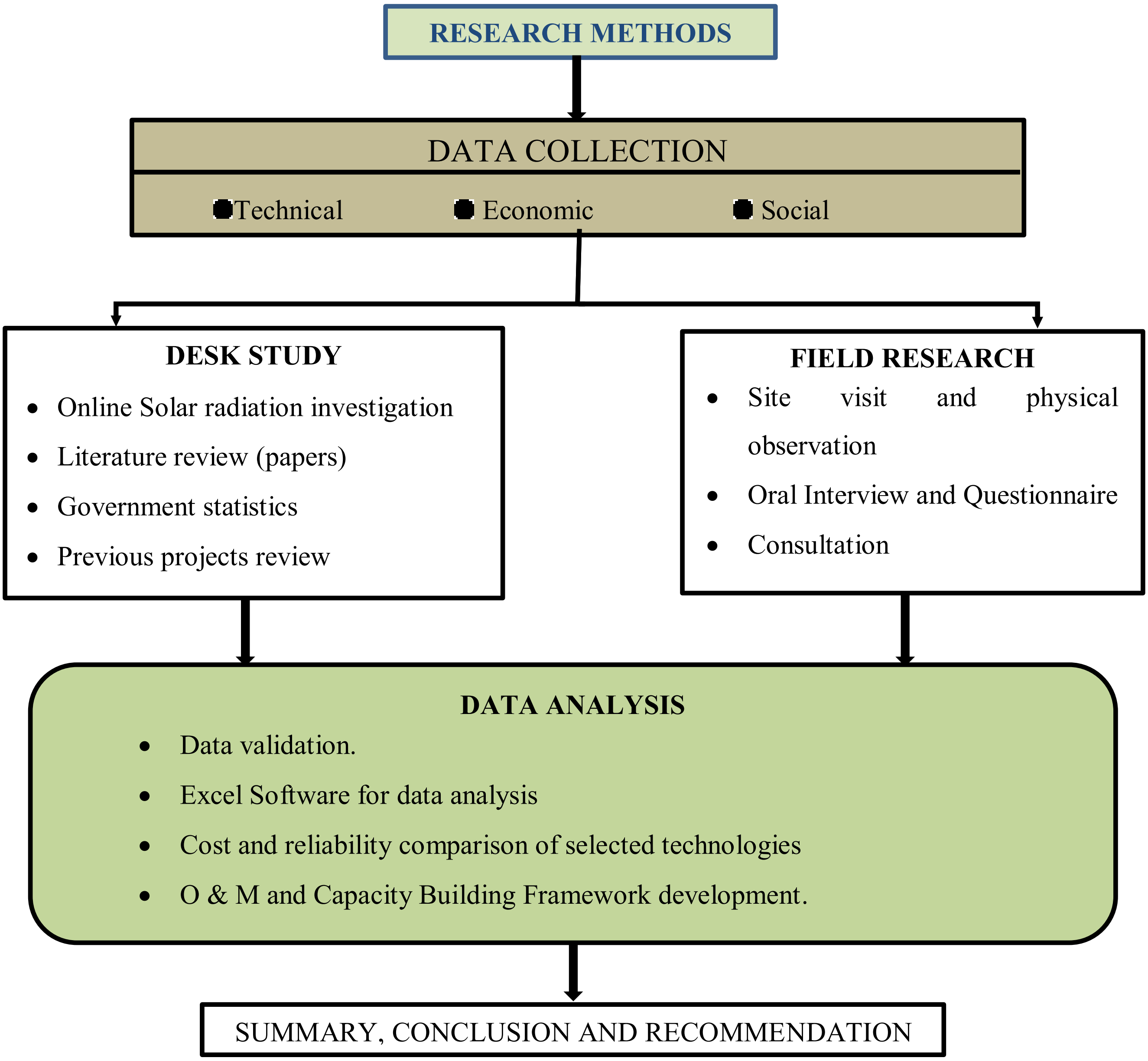


Figure 3. 7 Conceptual Framework of Research Methodologies

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 LESSON LEARNED FROM TANZANIA

This chapter dictates the research findings obtained from the case study areas to present the status of solar water pumping system in rural Tanzania. It describes the Technical feasibility, Economic, Social and Financial Status, Operation and Maintenance as well as Capacity building of selected projects.

4.1.1 Kiruha-Kahe SWP station for water supply

Kirua-Kahe Project is the project which is under community ownership managed by the board of Gravity water supply Trust in Kilimanjaro region, Tanzania. This projects serves 1130 houses with an estimated number of 6 people per household which makes 6780 peoples. Apart from households the Kirua-Kahe water supply serves 4 schools, 12 churches and 5 mosques

4.1.1.1 Socio-Economic Status of Kiuha-Kahe

58% of people served by Kiruha-Kahe water supply project involve themselves mostly in Agriculture and Business while 22% of respondent involves in businesses such as small retail and wholesale shops, 17% conduct agriculture for their living which involves cultivation and livestock keeping together while fishing accounts for 1% and 2% livestock only. On the other hand since agriculture involves both cultivation and livestock keeping, this means agriculture around the region accounts for 77%. Figure 4.1 shows the distribution of economic activities.

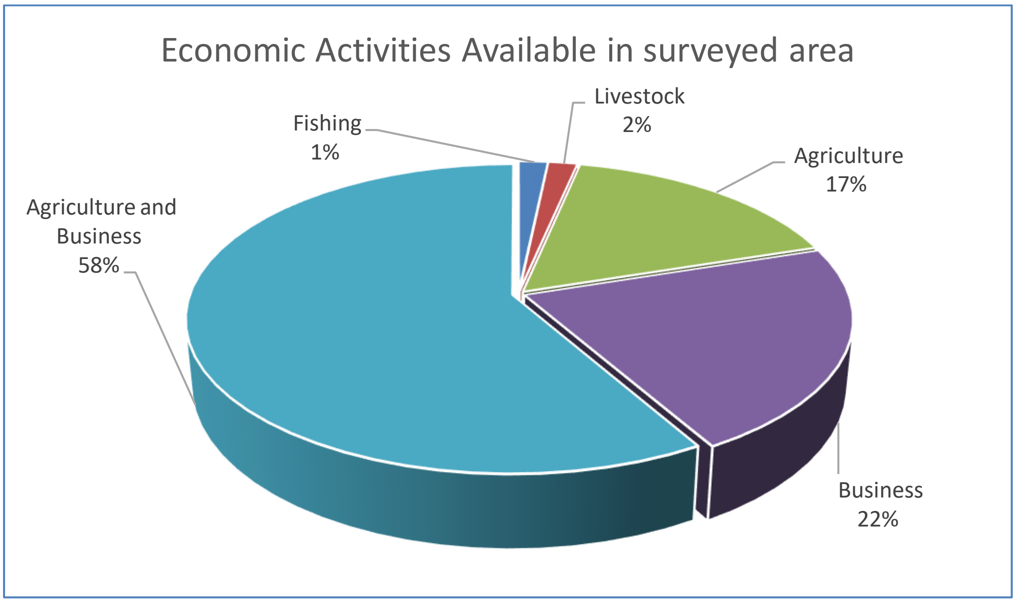


Figure 4. 1 Distribution of Economic Activities at Kiruha-Kahe

The social economic activities around Kiruha-Kahe contributes to the income generation of the community, from the survey conducted 50% respondents may generate an income of $300 to $500 per household each month; while 27% ranges from $100 to $300 monthly; while only 18% of households confirmed to earn more than $500 per month as shown in the table 4.1. This indicates that without external support i.e from donors or government almost 82% may not afford the Solar water pumping system at household level hence the lack of clean and reliable water supply.

Table 4. 1 Distribution of Monthly Household Income

Percentage	Income Class
5%	$2-$100
27%	$100-$300
50%	$300-$500
18%	More than $500

4.1.1.2 Management of Kirua-Kahe Solar Water pumping project

Kirua-Kahe top Water Management comprises of the Board, District water engineer, and Manager as described in the figure 4.2. The Board is formulated by the Manager, Village Chairmen and Vice Chairmen from the served villages while the Municipal council remains as the Board advisor. Chairman and Vice Chairman are elected after every 3 years by the committee members. Committee members are 10 including the chairman and Vice Chairman from each Village, the function of Water Committee is to ensure that the system is run sustainably and in secured form, they are also responsible in discussing and solving challenges that may arise and conducting annual meeting with the Public Relation Officer and Accountant to go through the annual income and expenditure. This offers cooperation between the service provider and customers.

District Water Engineer (DWE) works hand in hand with the Manager of Kirua-Kahe water supply trust. District water engineer is responsible for developing, managing and implementing engineering activities and programs such as but not limited to design of infrastructures and facilities which goes hand to hand with economic strategy and evaluation. The duties of Manager is to control three offices which are Technical team, Public relation officer who act as the link between customers and Manager. Technical team comprises of qualified technicians who are responsible in performing routine checks of water infrastructures including water intakes, power supply system and meter readings, they prepare annual report through recording operation and maintenance activities of the system and they review and implement indicated plans and changes provided by DWE and Manager as well as handling security matters. Public Relation Officer is responsible for maintaining relationship among Customers (Water users), water board and stakeholders. They prepare strategies and campaigns to create awareness to the community members through publications in local media, meetings with committee members, and speeches in churches and mosques about the proper ways of using water and maintaining public infrastructures. Accountant maintains the record of all financial transactions that are taking place in the project, providing annual financial statements as well as internal audit.

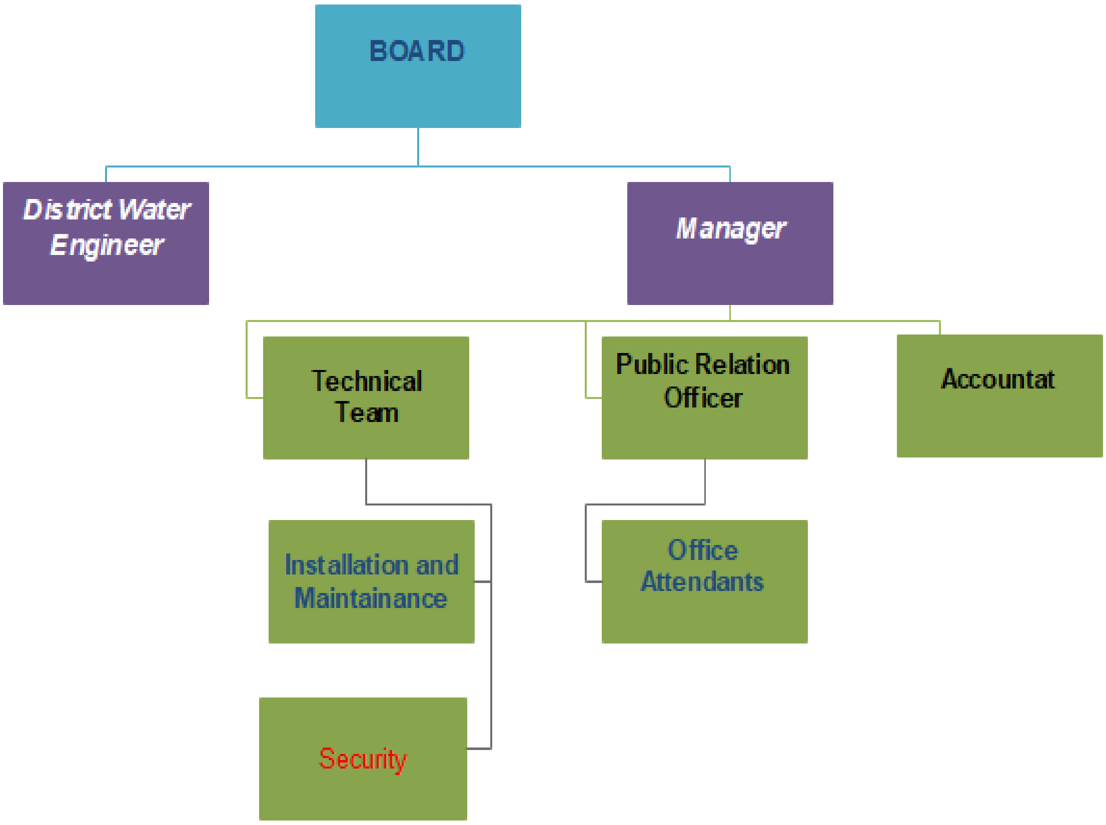


Figure 4. 2 Kirua-Kahe Organization Structure

4.1.1.3 Technical Assessment

Kiruha-Kahe solar water pumping system has three Boreholes two with 90 m depth each and one with 120 m depth, all these boreholes provides water by using submersible pumps with 3 phase and 5.5 kW each, these pumps are manufactured by Grundfos. Pumps are set at the depth of 96 for the boreholes with 120m depth and 60m for the 90m depth. Three PV stations were installed to run each pump on site, there is no batteries for storage. Table 4.2 below summarizes the technical information for all three solar water pumping power station at Kiruha-Kahe Water supply.

Table 4. 2 Technical Information for the three Boreholes stations

STATION	Pump Power (kW)	Pump Set (m)	Number of PV panels	Panel Capacity (W)	Total Array capacity (kW)
BH$_A$	5.5	60	100	92	9.20
BH$_B$	5.5	60	300	92	27.60
BH$_C$	5.5	96	32	260	8.32

Photovoltaic modules installed are expected to have the life expectancy of 20 years, while the pump capacity is 21.6 m^3/hour. Figure 4.3 below shows one of the solar array with 27.60 kW array installed at Kirua-Kahe.

Figure 4. 3 A 27.6 kW array installed at Kiruha-Kahe

The number of operation hours depends on the amount of solar radiation but mostly pump start operating on solar from 08:30AM to 04:00PM, the rest of hours in a day have a low or no solar radiation available to run the pump. The minimum and maximum voltage at which pumps operates are set at 384 V and 400 V respectively. The maximum total head is 90 m which is counted for Borehole B. Three inverters are installed and each one has the capacity of 5.5 kW which are RSI 5500 product from Grundfos as shown in the figure 4.4;

Figure 4. 4 Three installed inverters at the SWP station

a) Average solar radiation and sunshine hours

Solar irradiance information were taken from Lyamungo with the given average solar radiation on the monthly basis, located at -9 latitude, 37 degree longitude and 1250 m elevation above sea level. These solar radiations gives us the insight on the generation factor which is equivalent to the daily sunshine hours. At Standard condition (i.e 25^0C and 1.5 A.M) a solar panel is designed to generate 1000 W/m^2/day. Following the formula below the Generation factor will be obtained where L should be first taken as zero.

$$G.F = \frac{(1-L)R}{1000W/m^2/day} \qquad (10)$$

Whereby; L is the overall energy losses which takes into account all the losses until the energy before energy conversion, R is the minimum solar radiation. G.F is the generation factor.
Things to note, the sunshine hours does not take into consideration all the losses but these losses are taken during the design which depends on the environmental factors such as variation in temperature, radiation, soiling and dusts, ageing and variation in maximum energy. Figure 4.5 indicates the average solar radiation and sunshine hours which can be used to cross-check the design.

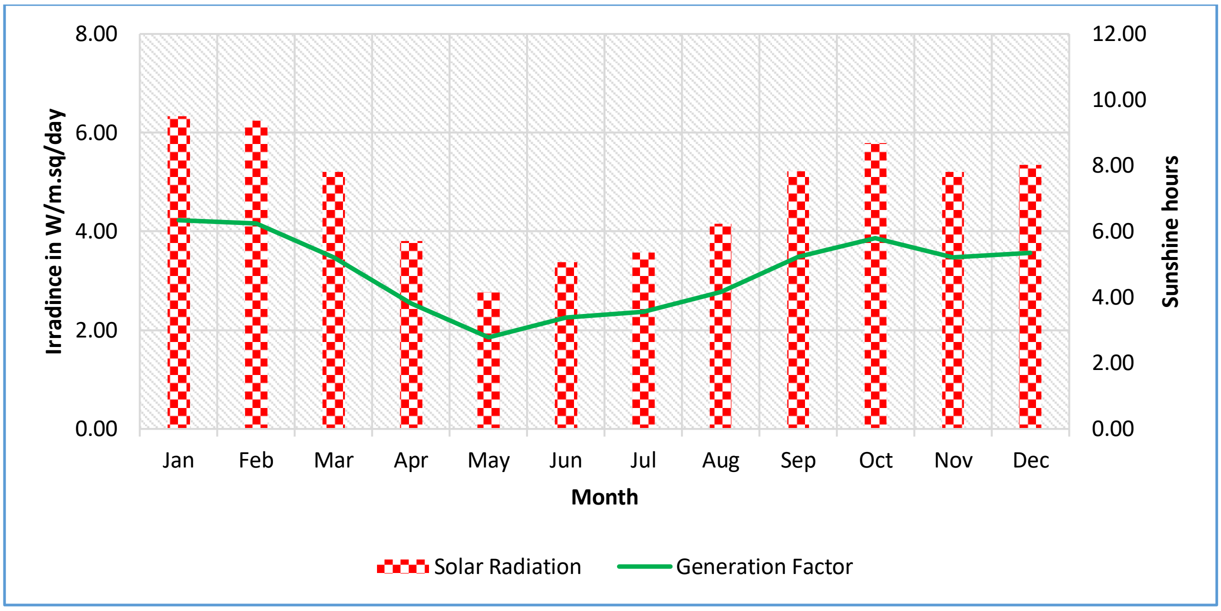


Figure 4. 5 Average solar radiation and sunshine hours for ten years

The average maximum and minimum solar radiation was observed to be 6.22 kW/m^2/day and 2.77 kW/m^2/day during January and May respectively while the maximum and minimum sunshine hours were 6 hours in January and 3 hours during may respectively.

b) Estimated water production

Total array capacity is affected by the minimum sunshine hours which in our case was taken as 3 hours, the effect of taking the maximum sunshine hours will lead into downsizing of the system. Considering equation 4 and the losses which was taken into account by watt hours per day the following table 4.3 explains the total operation hours, efficiency of the system and the amount of water which can be produced during the worst case scenario.

Table 4. 3 Estimated pump yield

STATION	*Array Capacity (kW)*	*Daily Watt Hour (kWh)*	*Pump Capacity (m^3/hr)*	*Operating hours (hrs/day)*	*Annual Water Production (m^3/yr)*
BH$_A$	9.20	27.60	21.6	3	23,652
BH$_B$	27.60	82.80	21.6	3	23,652
BH$_C$	8.32	24.96	21.6	3	23,652

However the board responded that they can produce 35 m^3/day in bad days and 70 m^3/day in good days. The storage facility has 200 m^3 volume which are the two elevated water tanks as shown in the figure 4.6;

Figure 4. 6 Storage water tanks

4.1.1.4 Financial context of the project

The financial assessment of this project is analyzed into three aspects which are the cost of the project for the three boreholes, challenges in securing loans from the bank, knowledge on financial sources as well as information on financial support to farmers.

4.1.1.4.1 Project Cost

Construction of Kirua-Kahe Solar water pumping took place in 2012 and commissioned in 2013, the investment cost of solar water pumping systems for three Boreholes at Kirua-Kahe were 365,676,395 TZS for both Borehole A and Borehole B while Borehole C cost 86,000,000 TZS. Table 4.4 below shows the equivalent value of money from 2012 to 2019 using the historical currency converter (www. fxtop.com).

Table 4. 4 Equivalent Investment cost in 2019

SWP Station	TZS in 2012	Equivalent USD in 2012	TZS in 2019	Equivalent USD in 2019
Borehole A	91,419,098.70	57 860.05	152 146 170	66 106.01
Borehole B	274,257,296.30	173 580.16	456 438 557	198 318.05
Borehole C	86,000,000.00	54 430.25	143 127 323	62 187.41

*1 USD=1580.003704 TZS (in 2012) and 1 USD=2301.548229 TZS (in 2019)

In present time implementing the same project in Tanzania for three boreholes with the same capacity will require almost 751,712,050 TZS which is equivalent to 326,611.47 USD.

Charges per unit cost: 400 TZS per unit for Public Tape, for metered households there are three categories (1) 0-15 Units costs 500 Tsh per unit (2) 15-50units costs 700 TZS per unit and (3) 50 units and above costs 1250 TZS

4.1.1.4.2 Financial Feasibility of the project

Oversizing the system can affect the unit cost of energy as well as the unit cost of water negatively, from table 4.5 it's clear that the unit cost of water is high even compared to the price of water that is being charged now at all three scales as shown in the previous section, However this doesn't provide the clear information on the Payback period because the increase in unit cost lowers the payback period, this misleads the true concept of payback period under consideration of the true price of water arranged by the government. Assuming the same system size, the same amount of water and 0.22$ unit cost of water for class 1 user that is obliged by the government, Borehole B will have the payback period of 48 years which is not even economical feasible. Borehole A and Borehole C can return back the money after 14 and 13 years respectively will start making profit and utilizing free energy.

	UNIT COST OF ENERGY ($/kWh)	UNIT COST OF WATER **($/m3)**	PBP (Yrs)
Borehole A	0.55	0.22	12
Borehole B	1.65	2.02	4
Borehole C	0.52	0.19	14

4.1.1.4.3 Challenges in Securing Loans from the bank

Implementing solar water pumping projects in most countries is quite expensive in sub-sahara countries due to poverty, some projects in the community needs funds in forms of grants or loans. Despite the fact that most development banks provides loans still there are challenges which acts like a setback to achieve SDGs goals. Figure 4.7 below shows in percentage the challenges that people or small development groups face when trying to secure loans from the bank in Kilimanjaro regions.

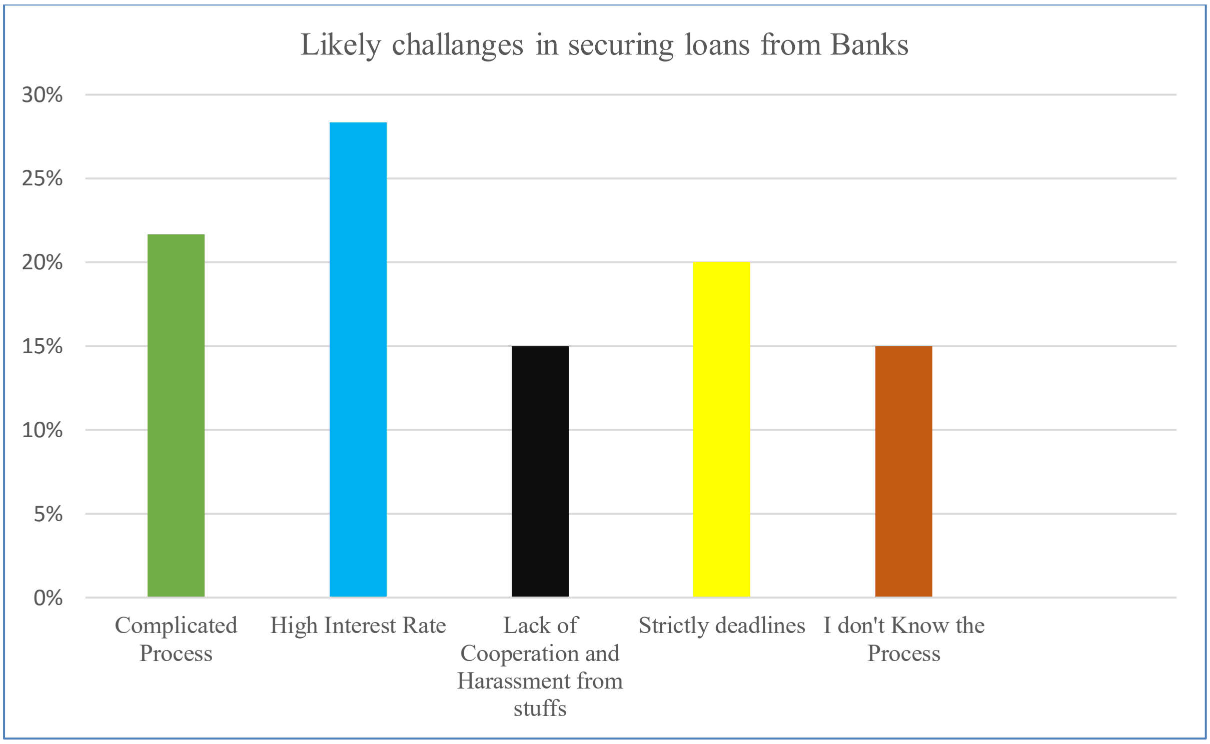


Figure 4. 7 Challenges in securing funds

High interest rate given by many banks is the main challenge that hinders the development projects in the region which was shown by 28% of respondents, others are Complicated processes in securing loans which includes tough conditions, Strictly deadlines, lack of cooperation and harassment of stuffs while 15% of people responded that the process to secure loans is unknown to them.

4.1.1.4.4 Knowledge on financial sources

The survey was done to identify if people have a knowledge about where the financing sources used to implement the Kirua-Kahe solar water pumping project in their communities came from, only 5% of respondents unconscious on where these funds come from; 28% believe the government is responsible; 22% believe that contribution from the community, bank credits or loans and grants from the government were the sources of finances; 20% know they came from the bank and government; 15% from the bank only; and 10% from the contribution from the community as shown in the figure 4.8 below.

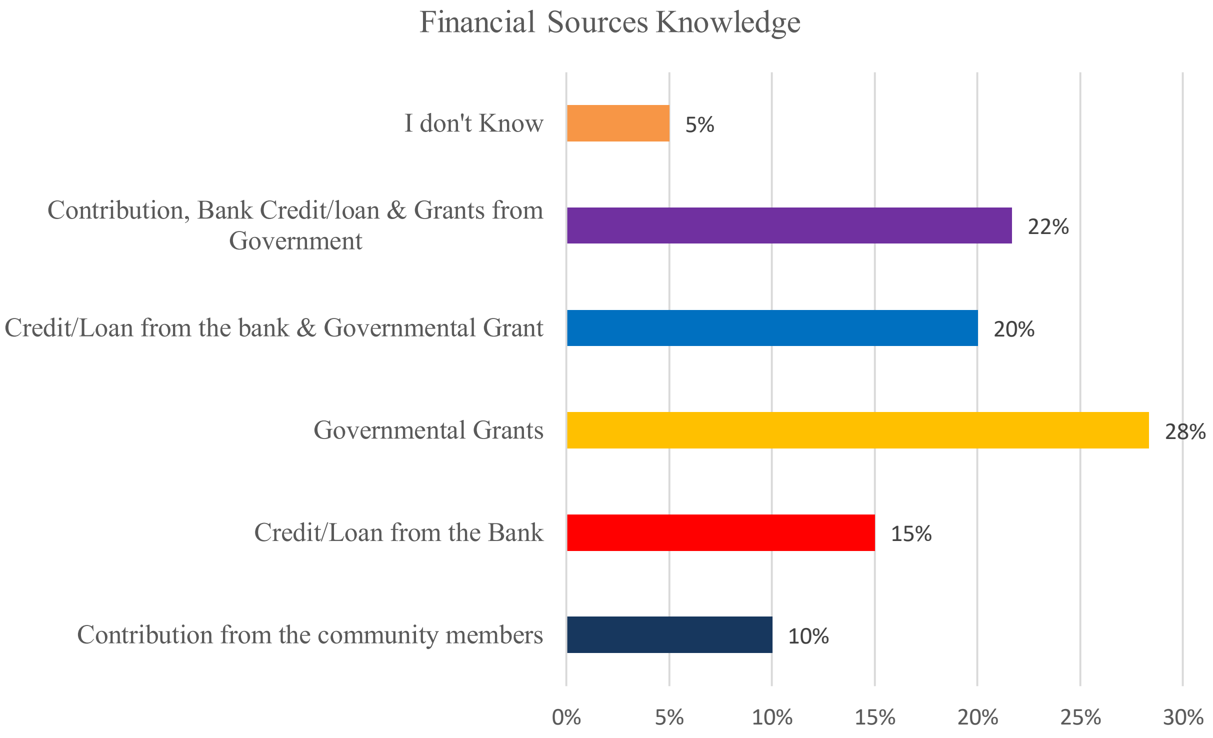


Figure 4. 8 Financial Sources Knowledge

From the information above almost 80% of beneficiaries does not have an idea what was the source of finances used to implement the project. Community participation and involvement regarding the financial sources were not done or some of respondents are new to the area due to internal movement.

4.1.1.4.5 Status of Financial support Information

To support small scale farmers and beneficiaries of water supply projects the information about where to obtain financial support should be clearly known to people, this will facilitate different NGOs, governmental bodies and other private sectors on how to apply and secure funds. From figure 4.9 it is clear that there is no information of financial support, this is verified by 83% of respondents and 8% who does not know completely about this.

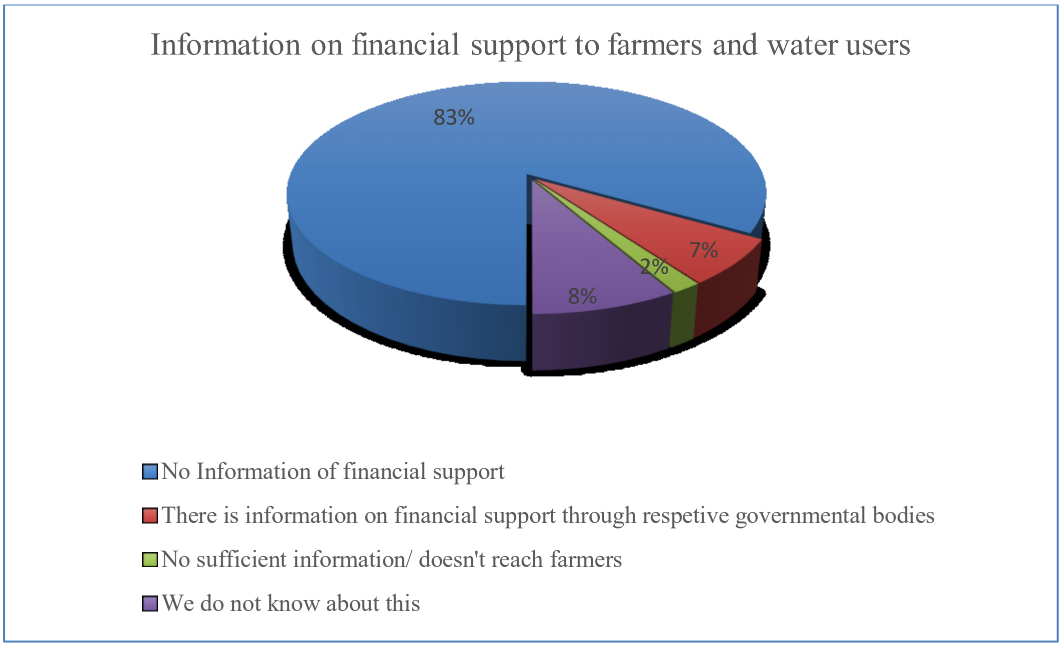


Figure 4. 9 Information status on financial support

4.1.1.5 Challenges facing the project

Challenges facing Kirua-Kahe water supply project are Intermittent flow during supper which is largely affected by the depth variation of boreholes water table, Clouds cover, Population growth which increase the quantity of water demand , communication between the authority and beneficiaries, poor capacity building and Vandalism. Figure 4.10 shows that only 25% of people at Kiruha-Kahe experiences no challenges facing the implemented project while 15% said clouds cover is the challenge, 31.67% intermittent flow during summer, 5.00% no capacity building to the community, 8.33% communication between the authority and community, 3.33% vandalism (destruction of public property), and 11.67% responded that population growth.

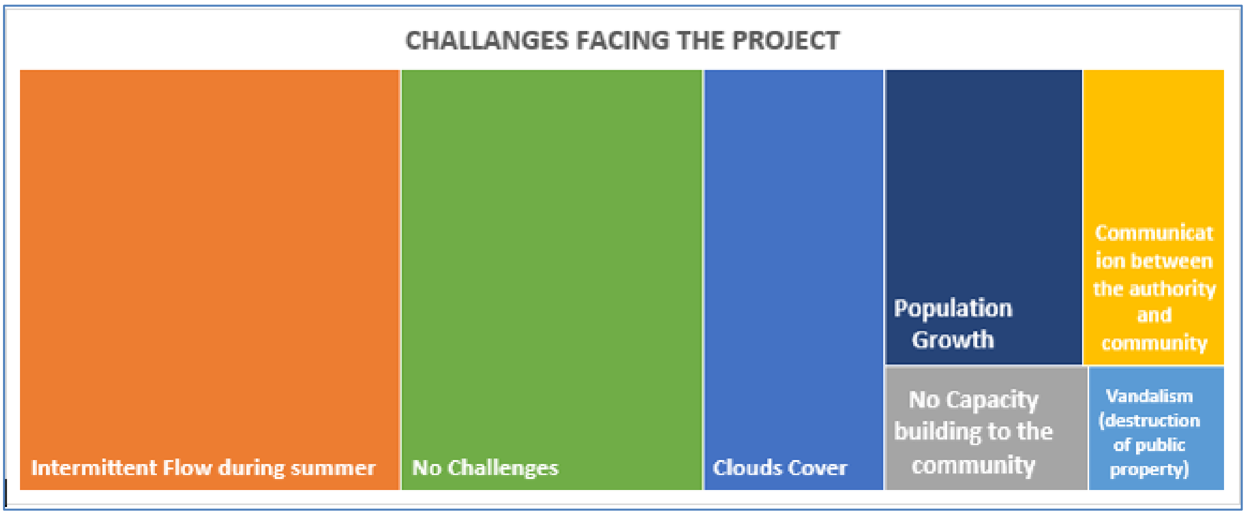


Figure 4. 10 Views on challenges facing the project

4.1.1.6 SWP adaptation Barriers in Kirua-Kahe

Solar water pumping has been commercialized and installed in different part of Africa for water supply and irrigation purposes especially in most remote areas where access to water is still a brainteaser but not yet utilized to its full capacity. Factors that contributes to the failure of adopting SWP are Lack of education and Capacity building on this emerging technology, this is supported by 42% of people interviewed as shown in the figure 4.11 below.

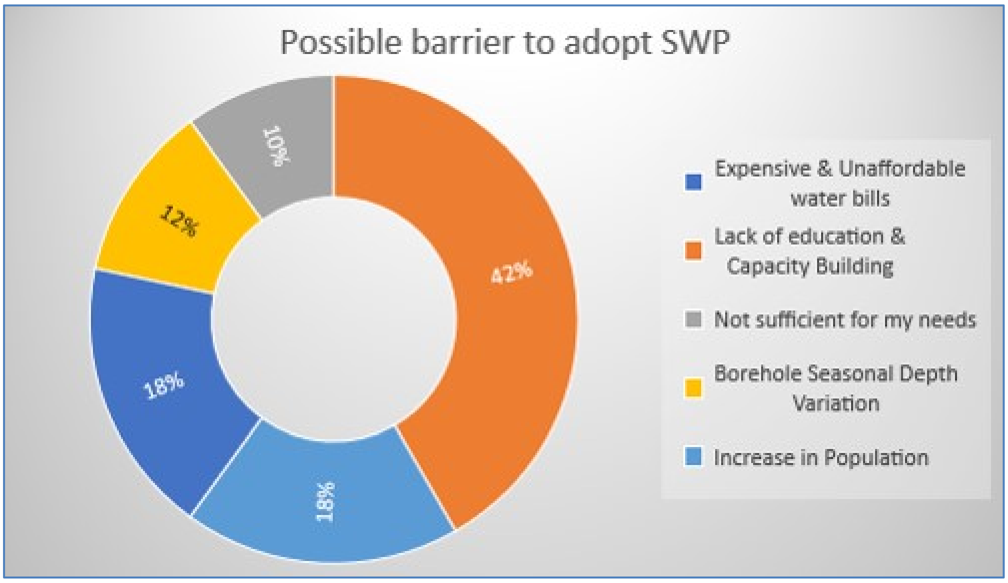


Figure 4. 11 Possible barrier to adopt SWP

Other factors are Increase in population which leads into increasing in water demand which is indicated by 18% while other 18% also revealed that the barrier to adopt SWP is the cost of the system being too expensive and unaffordable water bills once commissioned, 12% believe that the borehole seasonal depth variation is still a major problem and 10% believe that the system is insufficient for their needs. It’s clear that from the response given above knowledge on solar water pumping and capacity building is still a problem in most rural areas.

4.1.1.7 Installation Criteria for a Community Water supply Project

Best practices of solar water pumping for a community should consider all the social-Cultural aspects, Economic and Financial factors and well as the technical aspects. The following are the key criteria modified based on assessed reports;

a) Water scarce areas should be prioritized first as well as local expertise, if not available training should be done to local people.

b) Community owned projects should be established if and only if the community management possibilities do exist, this works better if the community is engaged before the first phase of SWPs construction.
c) Solar water pumping for a community will be established if and only if the water bearing layers should be below 60m, if it is above 60m Hand pumps should be considered.
d) Boreholes ought to be tested on their potential productivity and static water level.
e) Sustainable solar water pumping should supply up to a maximum of 25 litres water/person/day within a Water User Group. This has proven to be cost effective over a long period in most active projects.
f) Sunshine hours should be of at least for a half a day in installed area
g) The system should serve up to more than 100 families, this should take into consideration the energy efficiency during water distribution in vicinity.
h) In order to minimize the number of solar panels, tracking systems should be used to ensure the proper capture of energy at a reasonable cost.
i) Water quality should be checked in Chemical, Biological and physical character context before supplying them to the community, and where necessary community should be sensitized on water treatment methods at household level.
j) Self-cleaning system or access for cleaning solar panels should be incorporated to keep the panels free from dust.
k) To acquire the benefit a typical system should cost less than $50 per capita

Table 4.6 shows the evaluation of Kirua-Kahe project based on the selected standards

Table 4. 5 Evaluation of Kirua-Kahe project

CRITERIA	STANDARD	RESULTS
Water consumption	25 l/person/day	28.7 l/person/day
Per Capita system Cost	<$50	$48.17
Water Bearing Layer	>60 m	>60 m
Sunshine Hours	At least Half a day time (4hrs to 6hrs)	3hrs to 6hrs
No. of families to be served	More than 100 families	1130
Tracking System	Recommended	No Tracking Device

4.1.2 Re-design of Oversized SWP for Borehole C

Based on the observation and evaluation made to the three systems at Kiruha Kahe SWP stations, Borehole C seem to be completely oversized due to the reality that a solar array of 27.6 kW to run a pump of 5.5 kW is possible but a waste of energy. This section will try to redesign the system step by step as shown in the figure 4.12 based on the metrological data available and the size of pump identified.

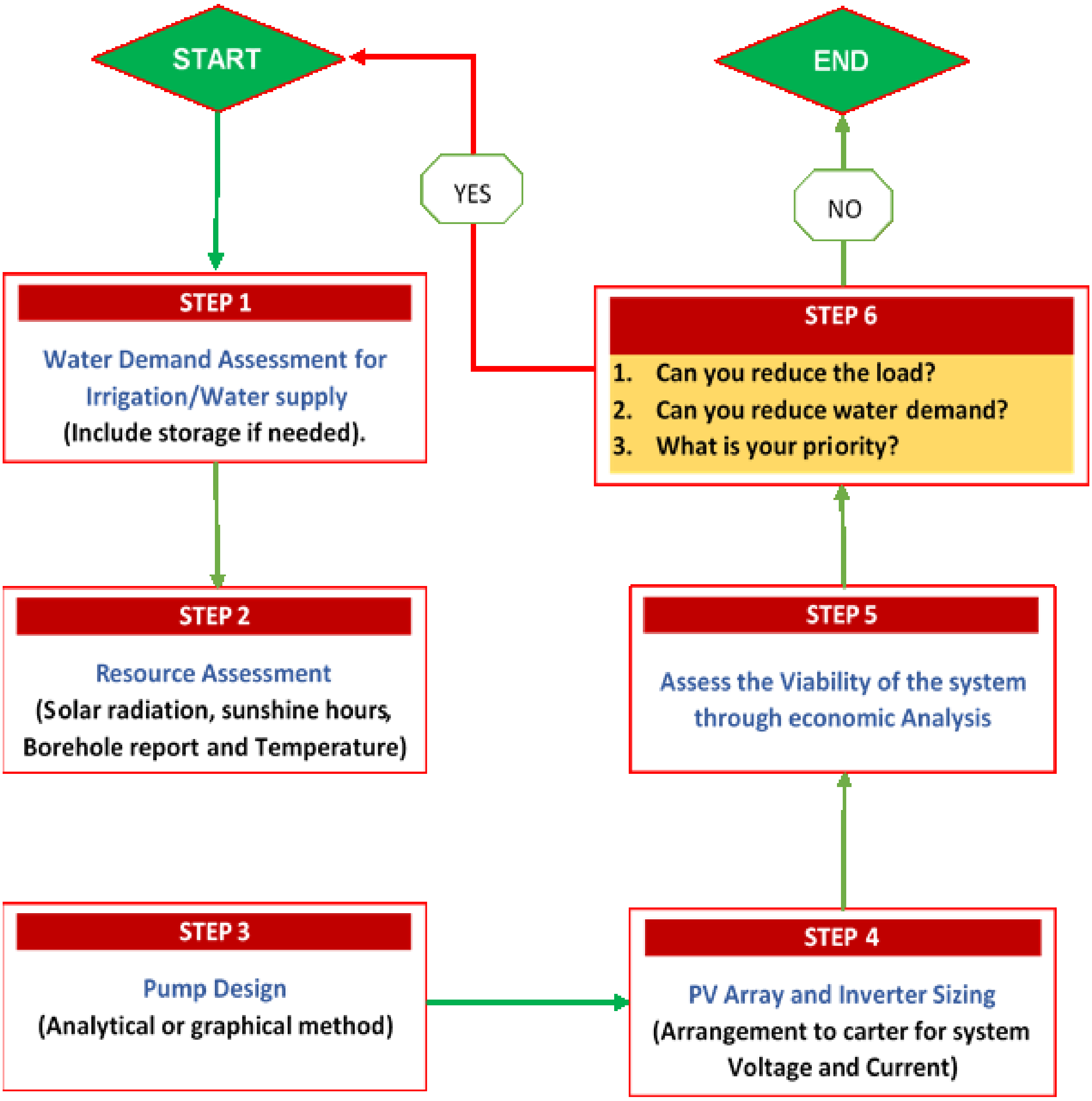


Figure 4. 12 Design Steps of Solar water Pumping system

It should be noted that from one step to another there are energy/water losses due to conversion, population, water use behaviour change or other environmental factors which will be explained.

4.1.2.1 Water Demand and Total Head

The first step in designing the solar water pump is to understand the source of water, water demand within the served community and Total head (as indicated in eq.2). Based on the survey done the following were the results in terms of water demand and total head:

a) Daily water requirement = 70 m^3/day for each pump (on good days)
b) Pump Set = 60 m
c) Static Lift Above Ground = 13 m

Assuming the pump set is below the pumping water level, then 60 m counts for the total depth from the pump set to the ground level. Then the total head of the system excluding friction losses will be 73 m.

4.1.2.2 Graphical Method of Pump selection

From equation 3 the power of the pump can easily be determined if the designer has in mind what amount of water should be pumped on hourly basis to achieve the goal, the limitation of this formula is that the solar water pump works based on the amount of solar radiation that is quite affected by number of factors such as clouds, temperature etc. which makes it difficult to estimate the actual flow with the minimum knowledge of losses, under this circumstance Grundfos product center will be used to optimize the power of solar pump based on the climatic condition of an area. The following are the input summary used;

a) Water volume (max): 70 m^3/day
b) Month for sizing: November
c) Static lift above ground: 13 m
d) Dynamic water level: 60 m
e) Sun tracking: No (fixed)
f) Location: Kahe, Kilimanjaro Region, Tanzania
g) Latitude: -3.4918 DD, Longitude: 37.4384 DD

From the Pump graph (Figure 4.13) grundfos pump SP 17-9 which is capable of working within the head of 40 m to 100 m was selected, parameters used to select the pump is the flow of 17 m^3/hr and the head of 75.05 m, the software optimized the number of sunshine hours to 4hrs based on the site location and solar radiation condition on the design month.

Rated power is 5.5 kW, Voltage of 3x220-230, Rated Flow of 17 m^3/hr, speed of 2900 rpm and 73 m rated head

A 5.5 kW pump should receive an AC power from an Inverter output as an input, current output AC and voltage outputs AC are 220 V and 24 Amp from an Inverter to the Pump. From the figure 4.13 the system has considered a friction losses of 2.07 m due to pipe. The maximum temperature where the motor of the pump should work is 40^0C.

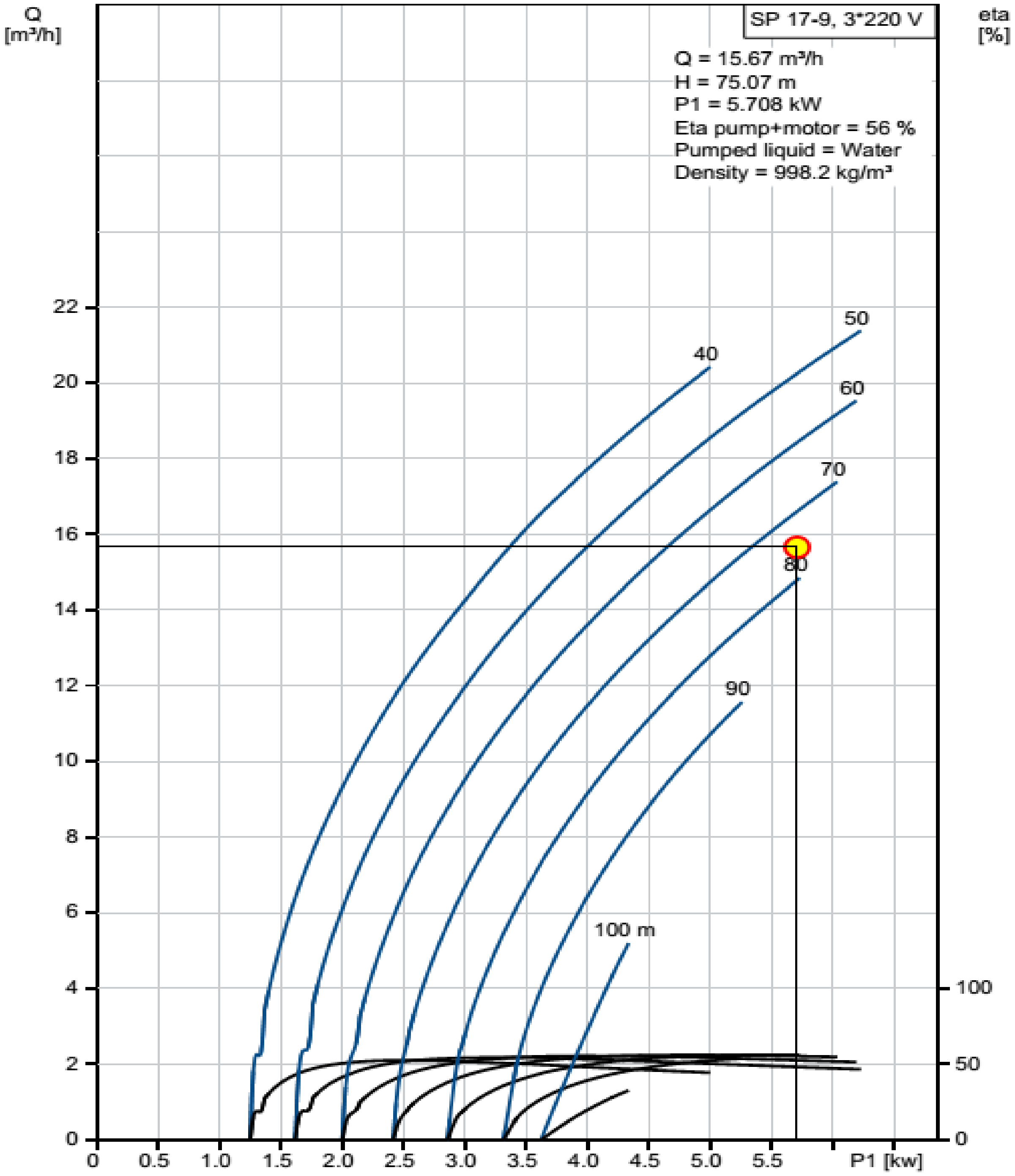


Figure 4. 13 Pump performance curve for SP 17-9

4.1.2.3 Inverter Sizing

Assuming the inverter losses 4% during conversion processes to AC power and the efficiency of 97% then the DC power input from the solar array to the inverter will be calculated as follows;

$$DC\ Power\ Input = \frac{Inverter\ AC\ power\ Output}{(1-0.04)(0.97)} \quad (11)$$

Remember the inverter AC power output is the product of AC voltage and AC current input to the pump (inverter output).

$$DC\ Power\ Input = \frac{220V\ X\ 24A}{(1-0.04)(0.97)} \quad (12)$$

The DC power input of the inverter is 5.67kW. The inverter is rated according to its power output (sustainable power to drive a motor in this case) and temperature range.

Rated power output of an inverter is 5.5 kW, Min. MPP Voltage of 230 V_{DC} and 380 V_{DC} maximum, which operated under the temperature range of -10^{0}C and 60^{0}C

Operating the inverter above the provided maximum limit of temperature will lead into shut off of the inverter. Figure 4.14 shows the proposed inverter type to run the 5.5 kW pump.

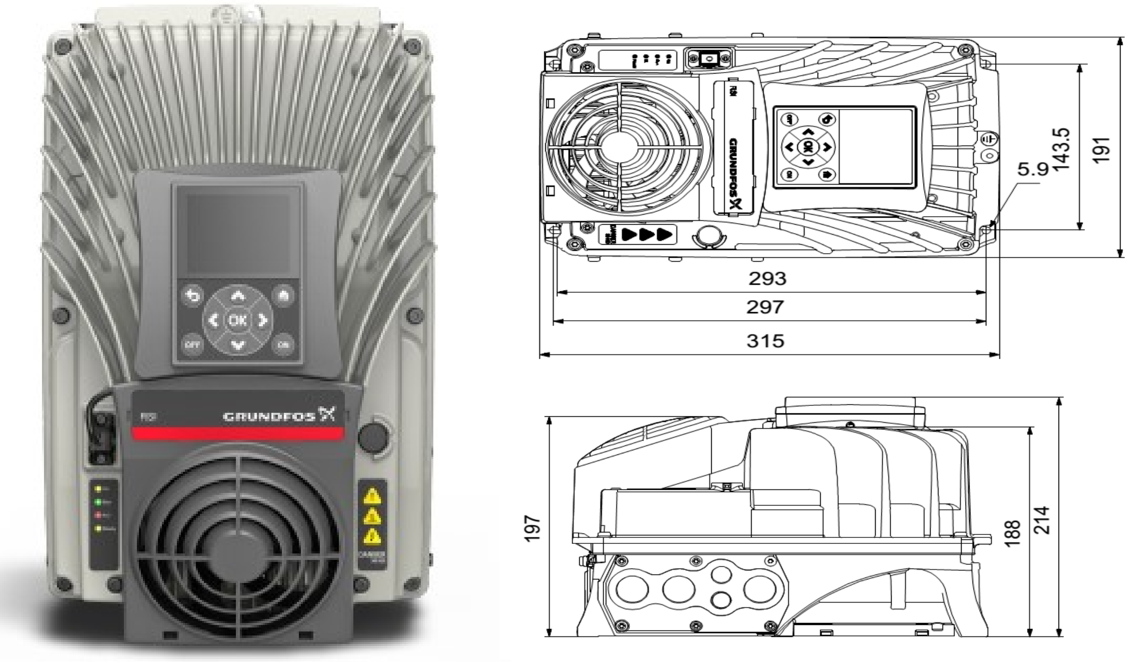


Figure 4. 14 Proposed inverter RSI 3x208-240V IP66 5.5 kW 24.2 by grundfos product centre

Note: This research is not aimed at promoting any kind of product from any manufacturer.

4.1.2.4 Solar Array Sizing

The total PV power output is considered as the total power input to the inverter with losses inclusive, to determine the array capacity of the system all losses due to temperature, soiling and cables should be considered. Since the maximum temperature does not exceed 25^0C which is the STC then the losses due to temperature will not be considered in this aspect.

The following are the losses assumed during power transfer from the PV Array module to the inverter (Photovoltaic-Software, 2019) ;

- Module Ageing 10%
- Solar radiation Variation 6%
- Module soiling and dirty 5%
- Total Cable loss 3%
- Manufacturing Tolerance and Mismatching losses 4%

Total losses are 28% which makes the performance ratio (PR) of our array system to be 0.72, thus the Array Capacity is calculated as:

$$DC\ PV\ Array\ Capacity = \frac{Inverter\ DC\ power\ Input}{PR\ of\ array\ system} \qquad (13)$$

$$DC\ PV\ Array\ Capacity = \frac{5.67\ kW}{0.72}$$

The Array Capacity will be 7.879 kW (7,875 W), Now based on the Market available products a 92 W solar panel which was used by Kirua-Kahe could lead into a total number of 86 panels with the total of 7.912 kW instead of 27.6 kW which was oversized.

From used grundfos product center the selected solar module used is GF 270 W solar module with the following Electrical Characteristics;

- Maximum power point voltage (V_{MPP}): 31.6 V
- Open circuit voltage (V_{OC}): 38.4 V
- Max power point current (I_{MPP}): 8.76 A
- Module shortcut current (I_{SC}): 9.11 A
- Maximum power output (P_M): 270 W

From the provided information Number of modules in one string (Series) can be obtained as follows in the equation 14:

$$Number\ of\ Modules\ in\ Series\ (N_{SM}) = \frac{DC\ Voltage\ input\ to\ inverter(Vm)}{Max. Power\ Point\ Voltage\ of\ Module(V_{MPP})}$$

The voltage between 230 V and 380 V will be taken as V_m, under this case a voltage of 300 V will be selected.

$$Number\ of\ Modules\ in\ Series\ (N_{SM}) = \frac{300\ V}{31.6\ V}$$

Number of modules in a series/string (N_{SM}) will be 10 modules. This string will be capable of producing a maximum voltage of 316 V across it.

Based on the voltage across the string and the power of array now the current that crosses this string (I_s) will be the ratio between the total array power and the voltage input to inverter which is 24.92 Amp. The number of panels in parallel will be:

$$Number\ of\ Modules\ in\ Parallel\ (N_{PM}) = \frac{Current\ Input\ to\ Inverter\ (I_{ma})}{Maximum\ Power\ Point\ Current\ (I_{MPP})} \tag{15}$$

$$Number\ of\ Modules\ in\ Parallel\ (N_{PM}) = \frac{24.92\ Amp}{8.79\ Amp}$$

Number of modules in parallel will be 3 modules, hence total number of modules in the system will be equal to N_{SM} X N_{PM} which will be 30 modules.

Number of solar modules (270 W each) in series: 10, in parallel: 3, Solar array rated power: 8.1 kW and Solar array rated volts: 316 V

The area covered by one module is 1.63 m^2 so the total area needed for the installation of 30 modules will be 49m^2. Total water production per year: 37600 m^3, Avg. water production per day: 102.9 m^3/day, and Average water production per watt per day: 12.7 l/Wp/day. Figure 4.15 shows the water produced on a monthly basis and design month.

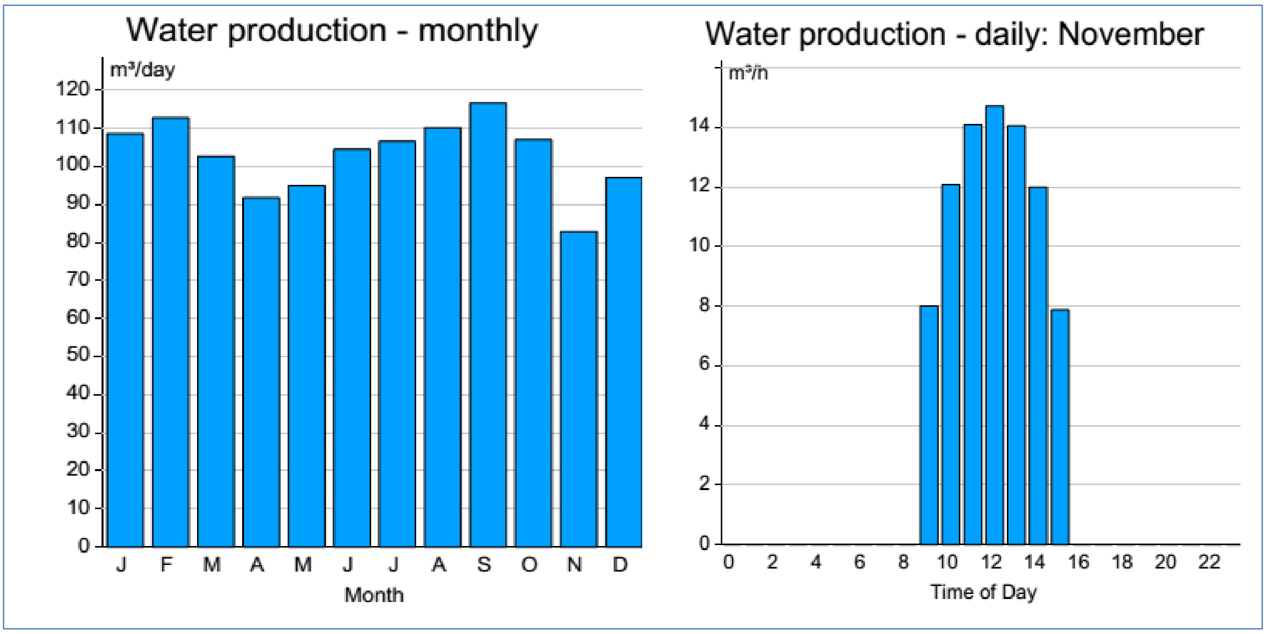


Figure 4. 15 Monthly and Daily water production of the system

4.1.2.5 Cost Estimation for the redesigned SWP installation

The redesigned SWP project for Borehole B will take into consideration all the components necessary except the Storage water tank which is shared with all three boreholes, costs used here are based on the local materials availability in the market.

Table 4. 6 Cost estimation for the redesigned project

ITEM	Units	Quantity	Rate (USD)	Total amount (USD)
Borehole				
10 inches Borehole drilling	m	90	66.00	5,940.00
8 inches BH Casing (Perforated)	m	60	180.00	10,800.00
2.5" Poly Pipe class C or D (raiser)	m	60	8.70	522.00
			SUB-TOTAL	***17,262.00***
Solar Modules and Support Structures				
270 W solar panel Polycrystalline	pc	30	187.83	5,634.90
Solar Support Structure & Painting	pc	8	173.91	1,391.28
			SUB-TOTAL	***7,026.18***
Inverter				
RSI 3x208-240 V IP66 5.5 kW	pc	1	2,069.57	2,069.57
			SUB-TOTAL	***2,069.57***
Solar Pump				
Submersible Pump 6" Grundfos SP 17-9, 12A01009, 4" motor, RP2 ½ Pump Outlet (2.5")	pc	1	2,158.74	2,158.74
			SUB-TOTAL	***2,158.74***
Installation Materials and Fittings				
6 mm^2 3-core rubber submersible drop cable	m	70	5.22	365.40
6 mm^2 4-Core underground cable	m	30	7.63	228.90
Submersible Sensor cable	No.	120	0.45	54.00
Well probe sensor	No.	1	88.70	88.70
Cable joint	pc	1	19.60	19.60
HDPE male socket fish 2.5"	No.	3	5.65	16.95
GS bend 2.5"	No.	1	45.65	45.65
GS nipple 2.5"	No.	3	3.26	9.78
GS non return valve 2.5"	No.	1	32.60	32.60
GS union 2.5"	No.	1	9.00	9.00
Cover plate 2.5"	No.	1	216.52	216.52
Manila rope 10 mm with 80 m	m	1	28.26	28.26
Amoured cable	m	20	5.65	113.00

Cable tray small	No.	1	28.26	28.26
DC Cable 30 m	m	30	1.10	33.00
Earth wire	m	12	5.90	70.80
Earthrod & surge arrestor 16 mm	No.	20	0.40	8.00
Insulation tape	No.	5	0.44	2.20
Thread tape	No.	6	0.22	1.32
			SUB-TOTAL	***1,371.94***
Labour				
Labour Cost	Sum	1	1,086.90	1,086.90
			SUB-TOTAL	***1,086.90***
Transport				
Transportation	Sum	1	180.00	180.00
			SUB-TOTAL	***180.00***
			GRAND TOTAL	**31,155.33**

After redesigning the system the cost of SWP dropped from 198 318.05 USD to 31,155.33 USD as shown in the table 4.7 above. This cost drop is about 84%, thus to utilize the rest of unused energy due to overestimation the Kiruha-Kahe gravity water supply should add other 2 boreholes which will assist into increasing the water supplied to the community. Total water production per year for this system is estimated to be 37,600 m^3/year compared to the previous system. Table 4.8 is summarizing all the technical and economic aspect before and after redesign.

Table 4. 7 Comparison of performance before and after redesign of Borehole B system

	Before re-design	**After re-design**
Array Capacity	27.6 kW	8.1 kW
Pump Power	5.5 kW	5.5 kW
Investment	198 318.05 USD	31,155.33 USD
Annual Water Production	23,652 m^3	37,600 m^3
NPV	-167697.5	41190
IRR	-7%	44%
PBP	48 Years	4 Years

Oversizing affects not only the investment cost but the greatest concern is on the return on investment and payback period.

4.1.3 SWPs in Dodoma Region

Dodoma is one of the 30 regions in Tanzania, its located at 6.5730^0 South and 36.2631^0 East Tanzania's regions. The number of surveyed systems in this region are 9 SWP.

4.1.3.1 Site Condition

Dodoma region receives an annual average solar radiation of 6.08 kWh/m^2/day (taken over 10 years of period i.e from July 2007 to June 2016). Table 4.9 below shows the average solar radiation on monthly basis.

Table 4. 8 Average Monthly Global Horizontal Irradiance for Dodoma region (Source: TMA)

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	sept	Oct	Nov	Dec
GHI	5.76	5.99	6.10	5.60	5.25	5.70	5.99	6.33	6.84	6.93	6.52	5.97
CI	0.54	0.56	0.58	0.57	0.58	0.66	0.68	0.67	0.67	0.65	0.61	0.57

GHI=kWh/m2/day and CI is the Clearness Index (0 to 1)

Dodoma region receives a huge amount of solar radiation that can be harnessed by solar water pumping and foster economic activities, the ration between the Surface radiation and extraterrestrial radiation is more than 0.5 each month, which means more than 50% of solar radiation is received on the surface. From figure 4.16 it is also clear that Dodoma has almost clear days for about half a year which starts from May 3 to November 24. Annual average temperature is 21.8^{0}C while the maximum and minimum temperatures are 23.34^{0}C and 19.96^{0}C

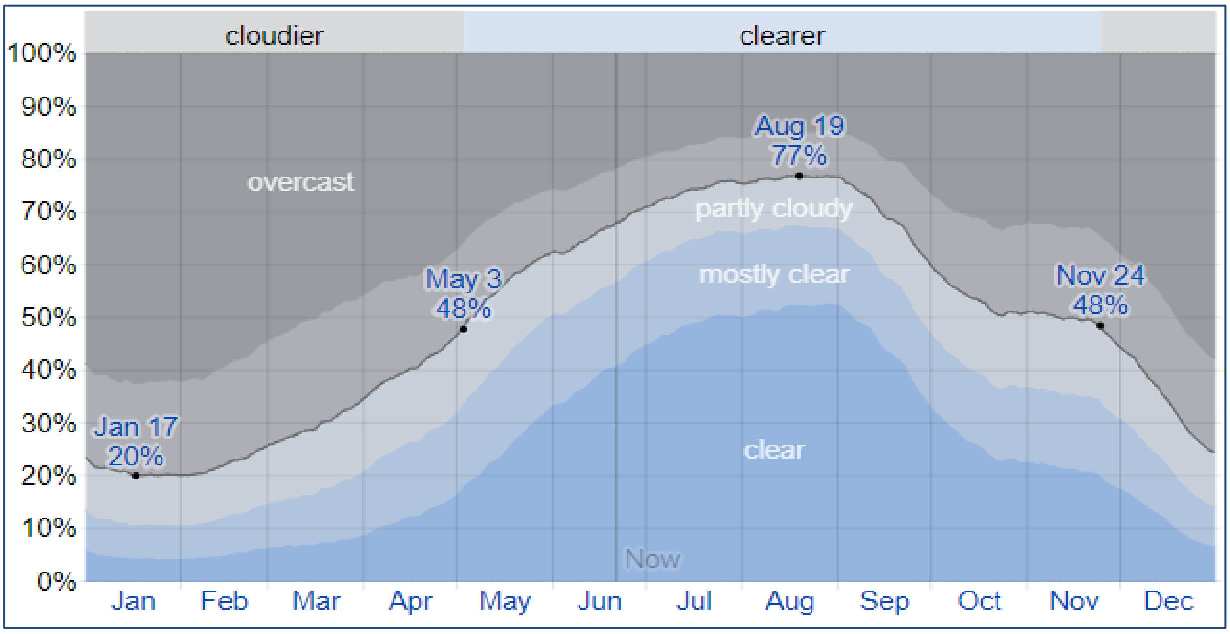


Figure 4. 16 Cloud cover categories in Dodoma (Source: www.weatherspark.com)

4.1.3.2 Installing Solar Support Structures

To maximize the production of solar energy on site solar panels were mounted on the solar supporting structures which are made up of steels, these solar structures are painted to protect them from corrosion or erosion which is the result of rusting. Engine driven welding generators can be used to weld the structure and keep it in place at calculated angle based on the latitude and hemisphere of the site. Figure 4.17 shows the installed solar support structure in Mbande Village.

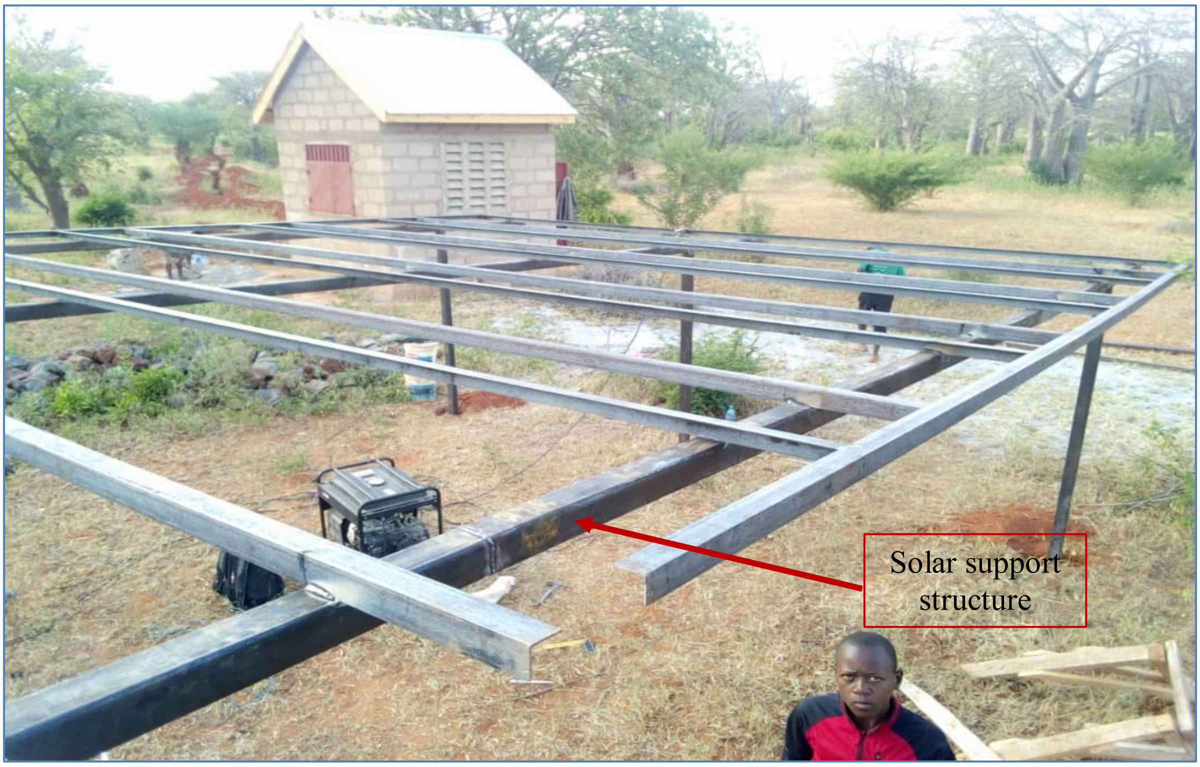


Figure 4. 17 Installed Solar support structure in Dodoma

4.1.3.3 Installing solar panels on top of solar support structure

Solar modules are installed on the solar support structure which is embedded on the ground by concrete footings. The design should consider security issues to avoid vandalism, wind and other natural calamities that may be the source of structure destruction. For the ground case the openings should be left in the middle of solar modules to allow access during cleaning. The access point should not be at the highest height if safety measures such as using ladders are not available, the best method to clean the system is through allowing water through the pipe to be poured on top of dirty panels. Figure 4.18 shows the solar modules with an access point for cleanness.

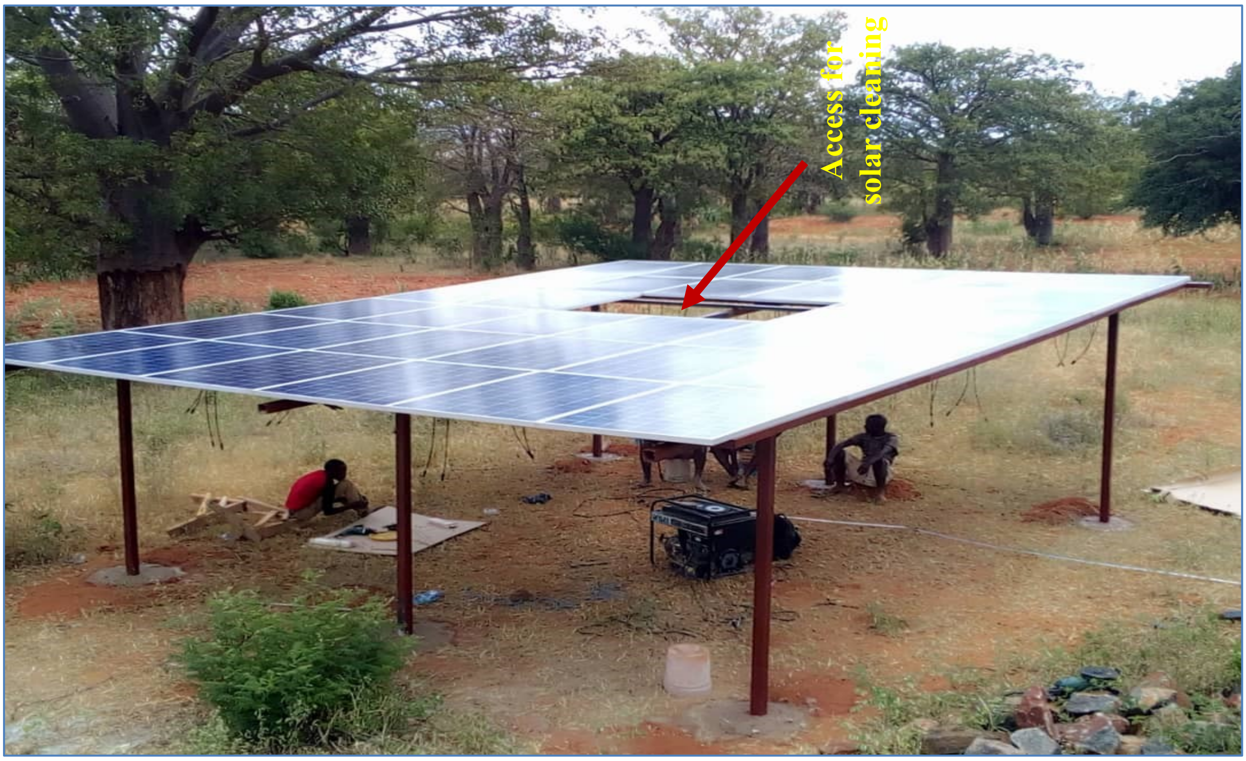


Figure 4. 18 Access point for solar cleanness

4.1.3.4 Investment Cost of systems

Based on the surveyed systems in Dodoma region the investment cost of installed solar systems are shown in the table 4.10 below, these costs excludes the cost of boreholes drilling but the cost of drilling a Borehole in Tanzania for every 1 meter is 63.5 USD, transportation charges are also charged by drillers but depends on the location of the site.

Table 4. 9 Investment Cost of SWPs in Dodoma

Location	Flow (m^3/hr)	Head (m)	Pump Capacity (kW)	No. of panels	Capacity of each panel (W)	Array Capacity (kW)	Overall System Cost (USD)
Makutopola	8	94	4	34	200	6.8	12,416.77
Mtaji Program	16	140	9.2	85	185	15.725	31,734.92
City council	3.5	105	3	26	195	5.07	11,172.43
Santoni EA Ltd.	0.8	145	1.2	6	195	1.17	9,694.37
Mbori	13	67	4	22	265	5.83	10,998.54
Mbande	9	110	4	34	185	6.29	19,562.63
dalibo	14.4	102	7.5	44	265	11.66	21,301.53
Ilangari	12.6	42	5.5	40	265	10.6	16,171.77
Kongwa	2.6	150	2.2	18	200	3.6	8,692.50

4.1.3.4 Financial feasibility of the systems

Major components in these projects are solar panels with the Life expectancy of 25years, Solar Pumps with the Life Expectancy of 10 to 20years, and BOS with 25years Life expectancy. In calculating the projects payback period based on equation 9 the total expenditure of surveyed projects is negligible thus the design period will be taken as 20years instead of 25years, the expenditure for O&M was considered to be 40 USD/kWp which includes costs such as pump repair and replacement, security etc. on annual basis. Figure 4.19 below shows the financial feasibility of the projects.

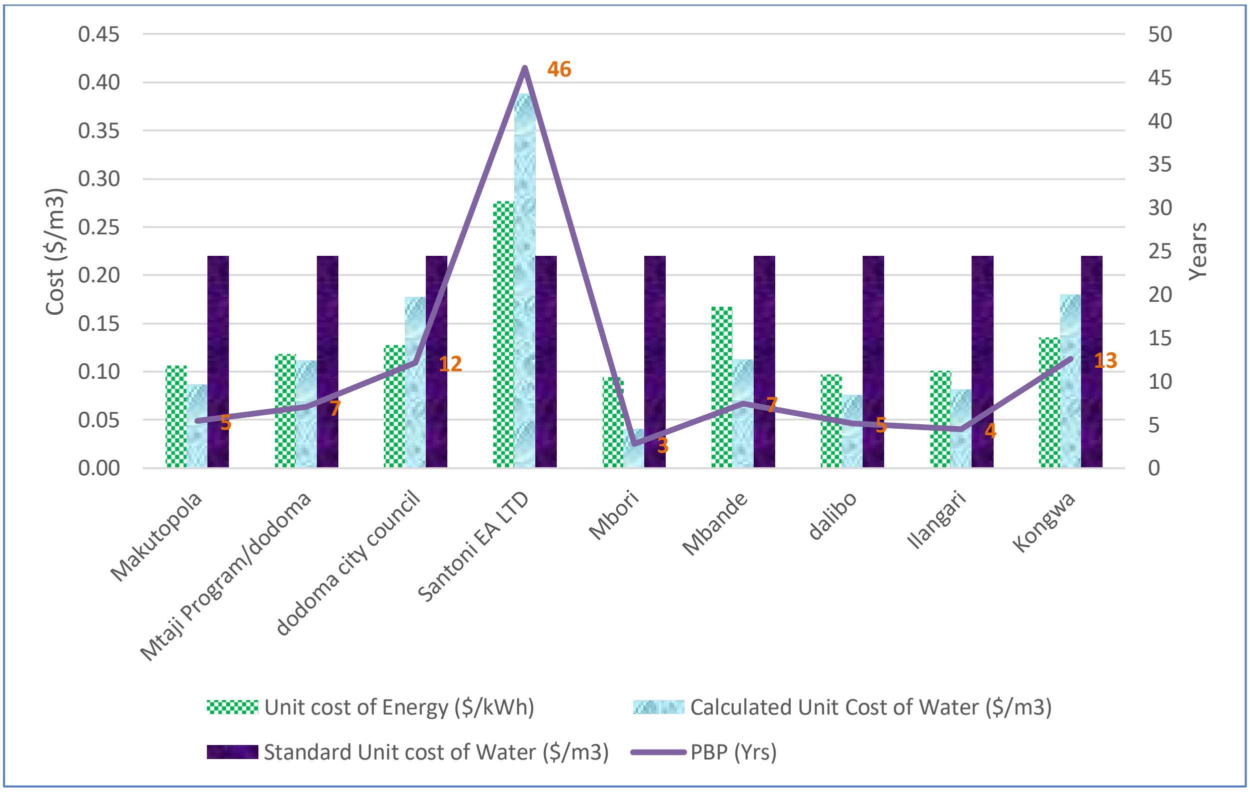


Figure 4. 19 Financial feasibility of surveyed projects in Dodoma Region

Eight out of nine projects indicates that the standardized unit cost of water is higher than the calculated unit cost of water which attracts more profit compared to the Santono system which is operating under loss, such projects as Santoni if they are serving the community the government and funders should be able to subsidize the price to facilitate their profitability. Calculated unit cost of energy should not exceed the unit cost of water by any means, the amount of cost of energy should be paid back by the products of the system i.e water. The highest PBP for the feasible projects is 13 while the smallest period is 3 years for Mbori system. Santoni Project can return its own invested cost after 46 years, this is mainly associated with the low capacity of the pump which hinders the production of water.

4.1.4 Nanyamba SWP Projects

Nanyamba is the district in Mtwara region located at 10.6878^{0}S and 39.7987^0 E. Nanyamba water supply project supply water to 12 villages and collectively there are 5 installed water pumps in Namahukula, Nachuma, Maendeleo, Kilimahewa and Ziwani Juu.

4.1.4.1 Site condition of Nanyamba

Nanyamba receives an annual average solar radiation of 5.25kWh/m^2/day (taken over 10 years of period i.e from 2007 to 2016). CI index is more than 47% and less than 60% which can still be good for utilization. Table 4.11 below shows the average solar radiation on monthly basis.

Table 4. 10T Average Monthly Global Horizontal Irradiance for Nanyamba (Source: TMA)

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	sept	Oct	Nov	Dec
GHI	5.20	5.30	5.20	5.03	4.91	4.80	4.77	5.10	5.65	5.80	5.77	5.45
CI	0.47	0.49	0.50	0.52	0.57	0.60	0.58	0.56	0.56	0.54	0.53	0.50

GHI=kWh/m2/day and CI is the Clearness Index (0 to 1)

Nanyamba district has 7 months with good days beginning from April 11 to November 28 as shown in figure 4.20, throughout this period solar radiation can reach at the surface without being reflected or absorbed by clouds. Annual average temperature is 25.8^{0}C while the maximum and minimum temperatures are 26.74^{0}C and 24.97^{0}C. Temperature can be used to check the efficiency of solar panel when exceeding the standard condition of 25^{0}C

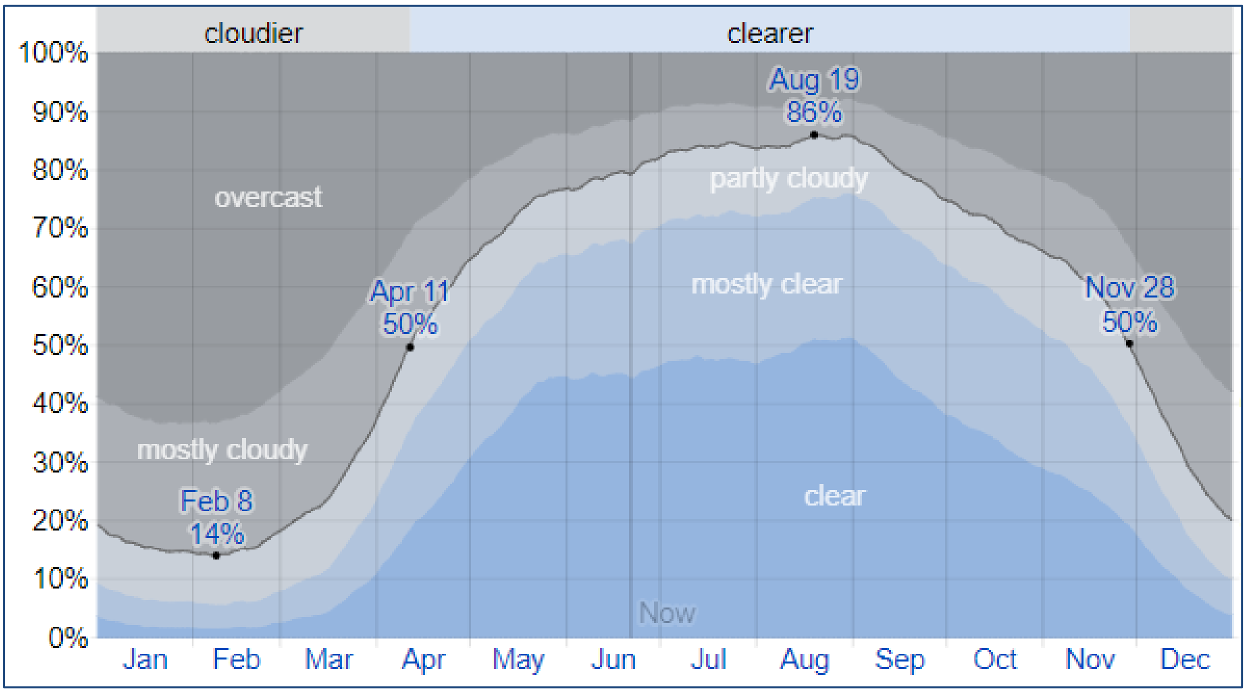


Figure 4. 20 Cloud cover categories in Nanyamba (Source: www.weatherspark.com)

4.1.4.2 Capacity assessment of systems

The largest system visited in Nanyamba has 5.76kW, these solar pumping systems have different capacities together with their solar arrays as shown in the table 4.12 below;

Table 4. 11 Installed pumps and solar arrays in Nanyamba Village

LOCATION	PUMP CAPACITY	NUMBER OF PANELS	SOLAR ARRAYS CAPACITY
NAMAHUKULA	Pump and motor P2-4000 C-SJ3-32 with H= 170m, Q= 4 m^3/h (4 kW)	32@180 W	5.76 kW
NACHUMA	Pump and motor P2-4000 C-SJ3-32 with H=170 m, Q=4 m^3/h (4 kW)	32@180 W	5.76 kW
MAENDELEO	Pump and motor p2-4000 C-SJ3-32 with H= 136 m, Q= 24 m^3/day (4 kW)	28@180 W	5.04 kW
KILIMAHEWA	Pump and motor SQF2.5-2 with H = 89 m, and Q = 18 m^3/day	36@85 W	3.06 kW
ZIWANI JUU	Pump and motor SQF2.5-2 H=89 m, and Q = 18 m^3/day	36@85 W	3.06 kW

4.1.4.3 Installation Phases

In order to construct a solar pumped statin at least five major steps were followed by installers in Tanzania, i.e Site survey and clearance, Solar support structures installation, Fixing solar panels on top of solar structures, borehole drilling and pump installation. Figure 4.21 shows the installation of solar support structures in Nanyamba and how was transported to the site.

Figure 4. 21 Transporting and Installing Solar structure supports

Welding generators are commonly used to fix the solar support structures in off-grid areas where there is no electricity, after installation of solar support structure painting is then applied on the structure to avoid the structure from erosion and corrosion as the result of rusting and then are fixed panels on top, see figure 4.22, these panels are not completely connected.

Figure 4. 22 Fixed solar panels on top of support structures

Figure 4.23 below shows a completed solar array which is oriented toward the northern direction and at 20^0 to obtain the optimum solar radiation.

Figure 4. 23 Connected solar array in Nanyamba district

4.1.4.4 Investment Cost of systems

The investment cost of 5 systems took into account all the cost of solar panels, balance of materials, installation costs, transportation, Labour, transportation and pump cost and pump's accessories. The table below shows the costs of all five projects in Nanyamba but it has to be noted that the Value Added Tax is not charged to Solar Modules in Tanzania.

Table 4. 12 Capital Cost of the system in USD

	Namahukula	Nachuma	Maendeleo	Kilimahewa	Ziwani juu
Modules	4,881.36	4,881.36	4,271.19	3,989.57	3,989.57
Pump	3,093.22	4,201.43	4,201.43	2,444.59	2,444.59
BH Drilling	11,082.14	11,082.14	9,126.47	5,867.01	5,867.01
BOS Cost	2,838.29	3,458.13	2,622.44	5,000.43	3,073.12
Labour	434.59	434.59	434.59	434.59	434.59
Transportation	204.26	204.26	204.26	204.26	204.26
18% VAT	3,177.45	3,488.50	2,986.05	2,511.16	2,164.24
TOTAL COST	25,711.31	27,750.41	23,846.43	20,451.62	18,177.39

Balance of System (BOS) comprises of the cost of site preparation, structure support, battery (if applicable), and electrical system costs.

4.1.4.4.1 Financial feasibility of the project

From the figure 4.24 below all 5 sites sells the water to a price lower compared to the calculated unit cost of water, the cost of energy needed to produce wateris quite higher compared to the standard cost at which the water is supposed to be sold at. This affects the payback period of the project as stipulated in the figure. The PBP ranges from 35 years to 86 years, this can be even worse when involving the LCA of the projects which will need replacement of the components such as Solar panels which last for 20 to 25 years, pumps and BOS.

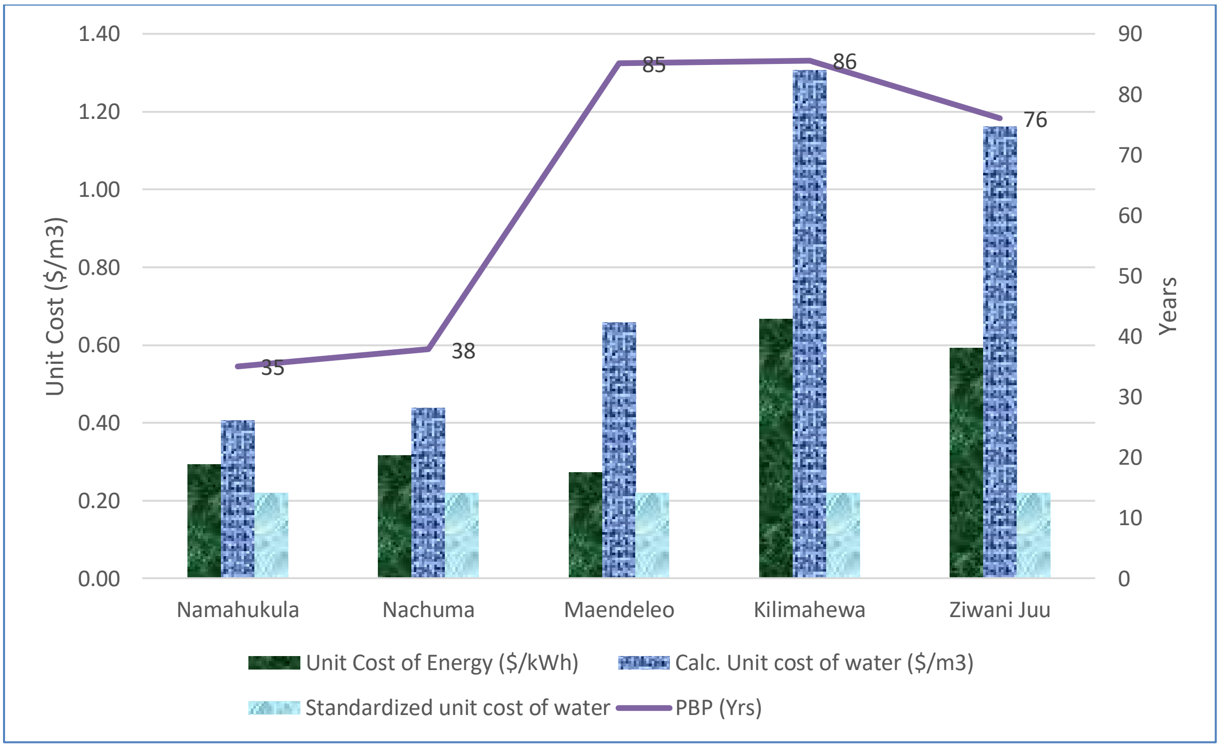
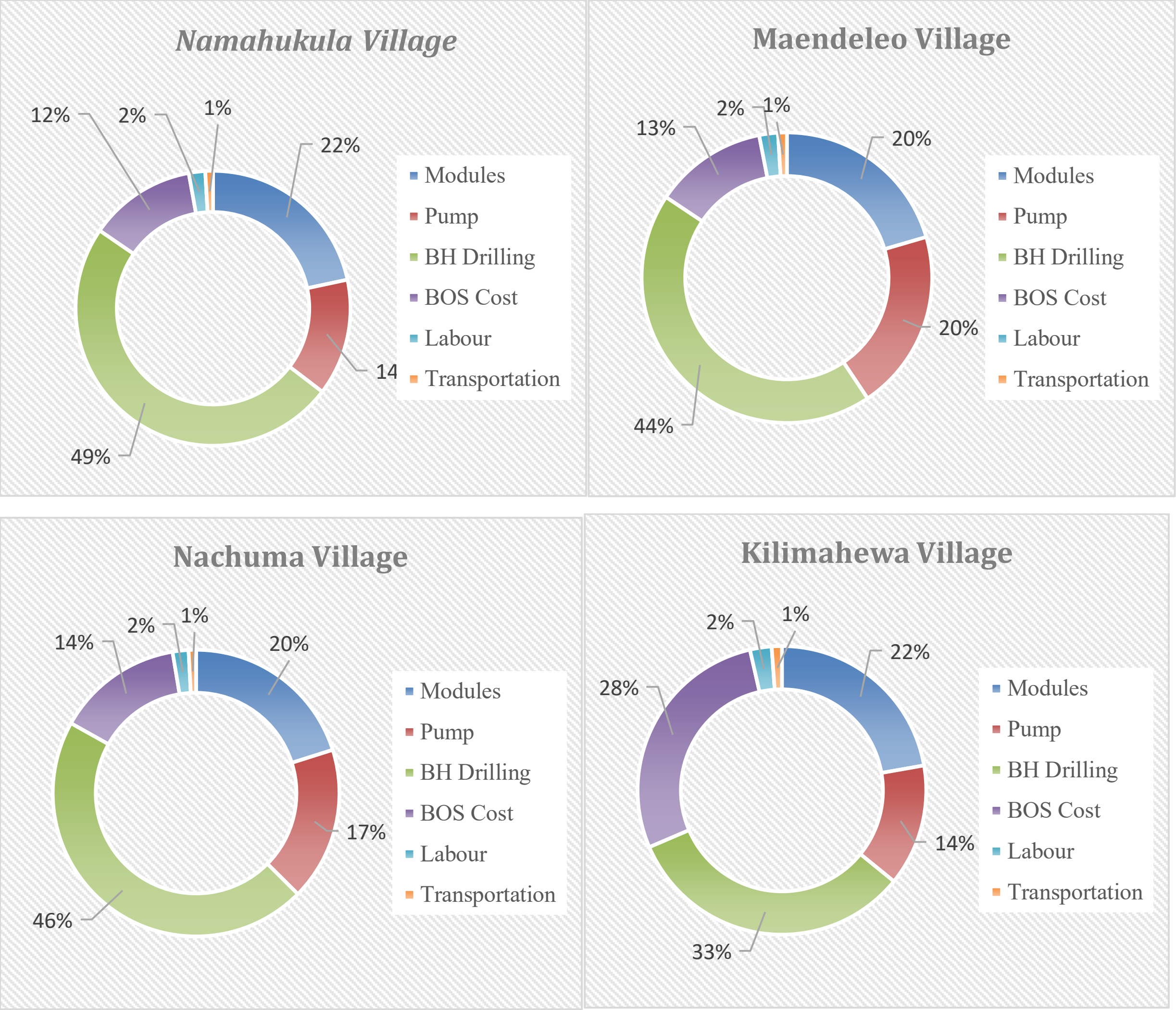
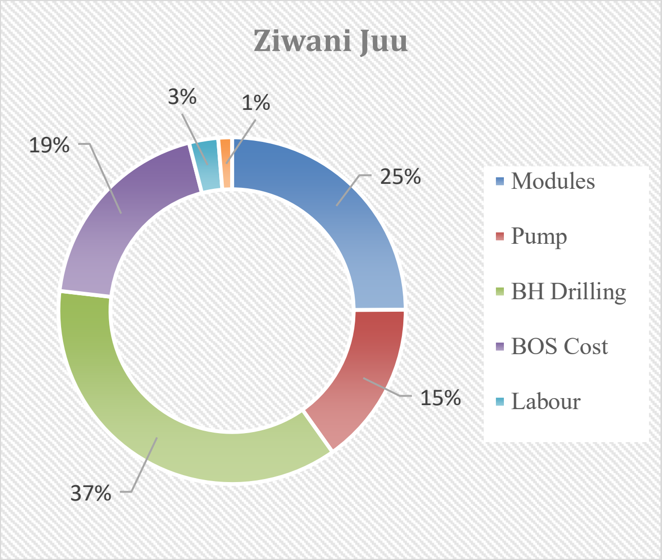


Figure 4. 24 Payback period and Unit costs of energy and water for Nanyamba project

4.1.4.4.2 Investment Cost Distribution

The cost distribution for all five systems in Nanyamba shows the percentage distribution of all components before Value added tax of 18%. This gives a clear indication of what components consumes most of the fund and it will help identifying which component and at which construction phase should it be considered. Looking at the nature of distribution, it is clear that 30% to 49% of the investment cost is located into Borehole drilling and pump test, while 20% to 25% goes to solar modules, 15% to 20% goes to pump, BOS takes 12% to 20% (exceptional for kilimahewa which had a lots of installation materials to be replaced), 2% to 3% goes to labour and 1% should be located to Transportation. It should be noted that the percentages should add up to 100% despite the ranges provided which just gives an idea of how initial costs should be distributed





The percentage distribution of BOS for Kilimahewa and Ziwani juu is little bit higher than the cost of the pump due to low depth of Borehole i.e 89 m, thus keeping the same prices for BOS while the pump price goes down due to low head and drilling cost becomes low due to decrease in drilling meters.

Figure 4. 25 Cost distribution for Nanyamba Projects

4.1.5 Overall Financial Cost Benefit Analysis (CBA)

Based on the estimates provided by NREL analysts in 2018, O&M costs range from 0 to 40 USD/kW$_{DC}$, this cost takes into account all the expenditures that the system will be using in terms of maintenance and operations such as but not limited to solar array cleaning, security, and insurance. The OPEX and Investment cost are used to calculate the IRR and NPV of the project to determine its feasibility. In this case 40 USD/kW was taken as the O&M cost and the results are as in the figure 4.26.

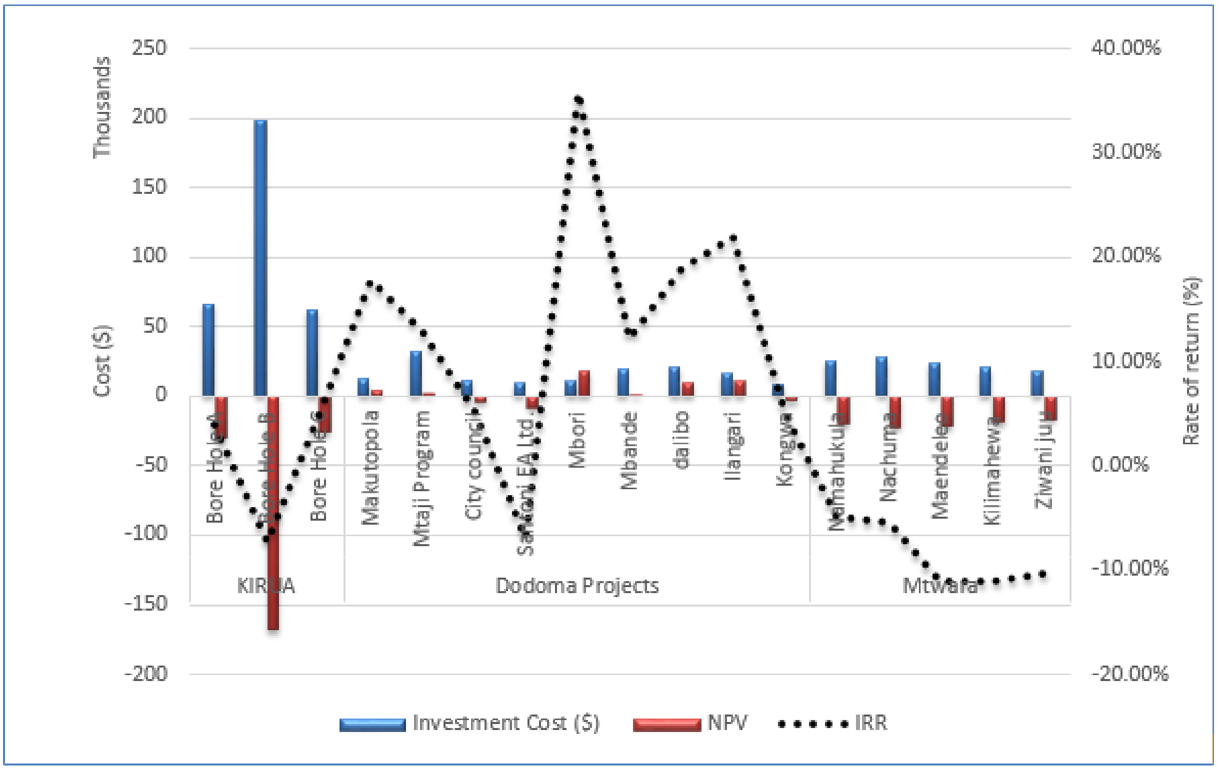


Figure 4. 26 IRR and NPV of evaluated projects

The higher the IRR the more profitable the project will be and vice versa is true. 11 projects out of 17 projects have the negative NPV which indicates that there is no gain in the project i.e the value of cash flow is less than the investment cost of the project for the duration of 20 years, Borehole B with oversized PV array is even operating under loss compared to the two boreholes. 6 projects indicates that the cash inflow is higher compared to the cash outflow. The same projects with negative NPV has negative IRR, thus accumulated amount of cash flow for the 11 projects with respect to the investment cost is less than the amount of invested amount at 12% interest rate in 2017. These values are affected directly with the Expenditures, number of operating hours of the system which leads into less or more production of water, generated income which depends on the amount of water generated.

4.1.6 Competence level of SWP in Tanzania

The most key application of solar water pumping systems in Tanzania has been cited as the domestic water supply compared to irrigation water. Twenty different professionals from universities, TAREA and Solar companies were asked to rank the competence level of the independent solar water pumping installers in the fields of Technical, economic analysis and O&M, the following table 4.13.

Table 4. 13 Competence level of the independent SWP installers

0=None 1=Some (Fair training) 2=Good (Knowledge only) 3=Full Proficiency (theoretical background and practical)	**Rating Scale (0-3)**
Technically trained about Solar water pumps including proper pump selection.	1.25
Knowledge about economic analysis of the systems.	0.80
Able to include all the necessary components in the system.	1.50
Able to install and maintain solar water pumping systems.	1.75
Able to troubleshoot and repair broken system.	1.85

It is clear indicated that there is none or fair knowledge of economic analysis of solar water pumping systems to most installers in Tanzania, this lacking knowledge helps to identify the feasibility of installed systems and optimize which to be taken and which to be left during design period and implementation. Apart from competence level also TAREA ranked the knowledge and skills level in solar water pumping for small scale irrigation schemes in Tanzania as moderate. TAREA, REA and other governmental and NGOs plays the role to raise awareness about renewable energies including SWPs through radios, seminars, trainings and launch of Renewable energy courses in universities. On top of that currently TAREA and EWURA ensures that all technicians and engineers must be certified and registered by EWURA as the energy solar systems installers in Tanzania, failure to do so companies will not take part in installation.

4.2 EXPERIENCE OTHER COUNTRIES IN AFRICA

To the best of my knowledge most of the solar water pumping systems in rural areas faces different challenges in both technical and social aspects, designs are undersized or oversized based on different approaches that were considered in coming up with the design, software used most of them has an outdated database of solar radiation, temperature and wind speed. This section will summarize few SWP projects found in working papers, reports and from local companies.

4.2.1 Regional Rice Value Chain in Burkina Faso

The aim of the project is to reduce the high importation rate of rice and enhance economic growth through improved production, processing, and marketing, and enhancing private sector participation. The expected results are 8200 ha of land under rice cultivation; Rice productivity increase from 3Ton/ha to 5 Ton/ha (lowland), from 5 ton/ha to 8 ton/ha (Irrigated land); Increased in rice National production by 20%; and increased in rice self-sufficiency from 11% to 25%. The scope of the project includes four components namely (i) raising rice production and productivity; (ii): Strengthening the links to markets, (iii): Policy and institutional support, and (iv): Project management and coordination. Human and institutional capacity will be a cross cutting intervention. In order to scale up the project and achieve the expected output the following five steps goes hand in hand to accomplish the project more precisely and efficiently.

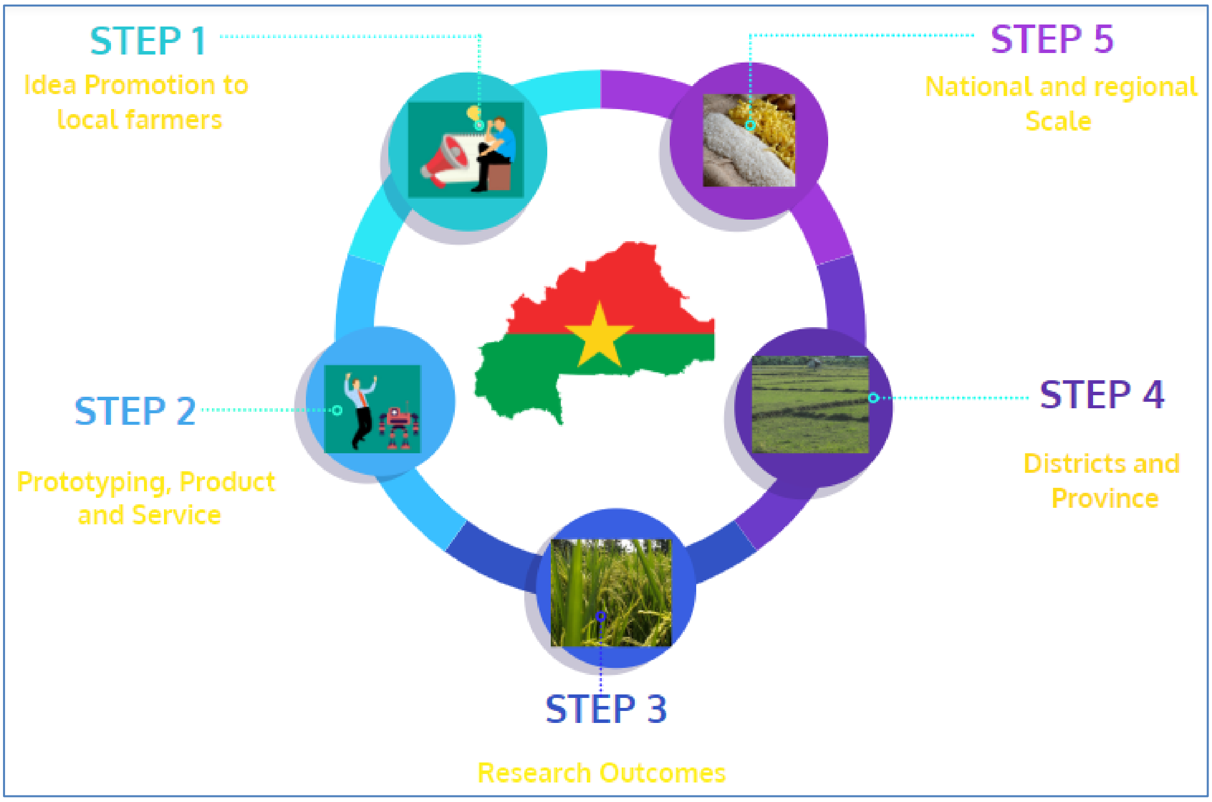


Figure 4. 27 Rice value chain for DANGOMANA Projects (Source: Author)

4.2.2 Small Sahelian producers in Mali

This is the project which benefits about 100 farmers in Mali with 0.24 Ha which is under community ownership. The main sources of water supply are river and wells. The adaptation of solar water pumping system was due to the fact that it is less polluting, it consumes less energy and is practical as stated by Dr. Abdoulah Kane from Sotuba Center. The system consists of 1 kWp of solar array, CSJ 5-15 submersible solar pump immersed in a 50 m deep well with a diameter of 160 mm and static water level being at 10 m. The pump is capable of umping 7m3/hr and operates 8hours on a daily basis. In order to manage water the farm has small water distribution tanks as shown in the figure 4.28. For security reason the solar plates are in galvanized boxes that can be closed by the padlock to avoid theft.

Figure 4. 28 Okra production under drip irrigation in Dibougoucoura village

(Source: Mr Daba Coulibaly, University of Ségou)

The total investment cost for the project is 27,700 USD, taking into consideration the daily water production of 2000 liters per day and 3.46 USD as unit cost of water the PBP of the project will be 10 years and eleven months. This is much higher than normal and can be reflected by the difference between the array capacity of 1kW and the pump capacity of 1.8 kW, the actual yield of the pump based on the design (7 m^3/hr) and the daily system production of 2 m^3/day as stated by project officers. Apart from technical shortcomings this project have achieved the following in making sure agriculture solves the common problems among farmers; knowledge transferred to more than 500 small market gardeners. The yield of tomatoes have increased from 45.9 t/ha (manual watering) to 63.10 t/ha under drip irrigation, and water productivity increases up to 63.32%, thus solar water pumping can be applied to such distribution networks which serves water; FAO and Mali signed partnership to introduce technology to vegetable women's groups due to successful methodologies used; saving of water allowed livestock farmers to increase from

1000 to 5780 herds, income improvement 574.25%, and lastly he income have been improved at family levels.

4.2.3 Summary of solar water pumping projects

Different authors have been trying to evaluate different solar water pumping systems in Africa in terms of Economic and technical aspect, the following table 4.14 summarizes different solar water pumping in different parts of Africa.

Table 4. 14 Summary of Solar water pumping projects in Africa

Country	Author	Application	Solar Array (kWp)	Pump Size (kW)	Capital Cost (USD)
Kenya	(Ismail, Soh, Cronin, M. Lisewski, & Vagani, 2012)	Domestic Water Supply	0.84	0.7	4,078.12
			0.84	1.7*	2,587.22
			1.04	1.8*	4,352.89
Rwanda	(Nshimyumuremyi, 2015)	Domestic Water Supply	4.32	3.5	54,098.90
Morocco	(LORENTZ, 2013)	Irrigation	10.00	2@4.0	16,800.00
Cameroon	(Deli, Djongyang, Njomo, & Tamba, 2018)	Irrigation	8.87	7.5	43,842.92
Egypt	(Shouman, 2016)	Irrigation	11.94	5.0	24,742.30
Ethiopia	(Girma, et al. 2015)	Domestic Water supply	0.50	0.3	3001.90
			0.34	0.24	2691.10
			0.44	0.24	2832.70
Malawi	(King, et al. 2010)	Domestic Water supply	0.36	0.30	3367.50
	(Phiri, et al. 2015)	Domestic Water Supply	1.00	0.75	15,489.41
Burkina Faso	(Alokore, et al. 2018)	Irrigation	2.40	2.20	18,755.50
			3.12	3.00	21,973.70
			3.20	3.00	41,487.70
			4.16	4.00	47,845.50

4.2.4 Capital Cost and Array Ratings relationship

From 17 surveyed solar water pumping stations in Tanzania and 16 projects from different parts of Africa, data show that the investment cost of the system increases with an increase of array capacity. One system with 27.6kW in Kirua-Kahe, Kilimanjaro seem to overshoot in terms of capital cost, this is due to oversizing of the system.

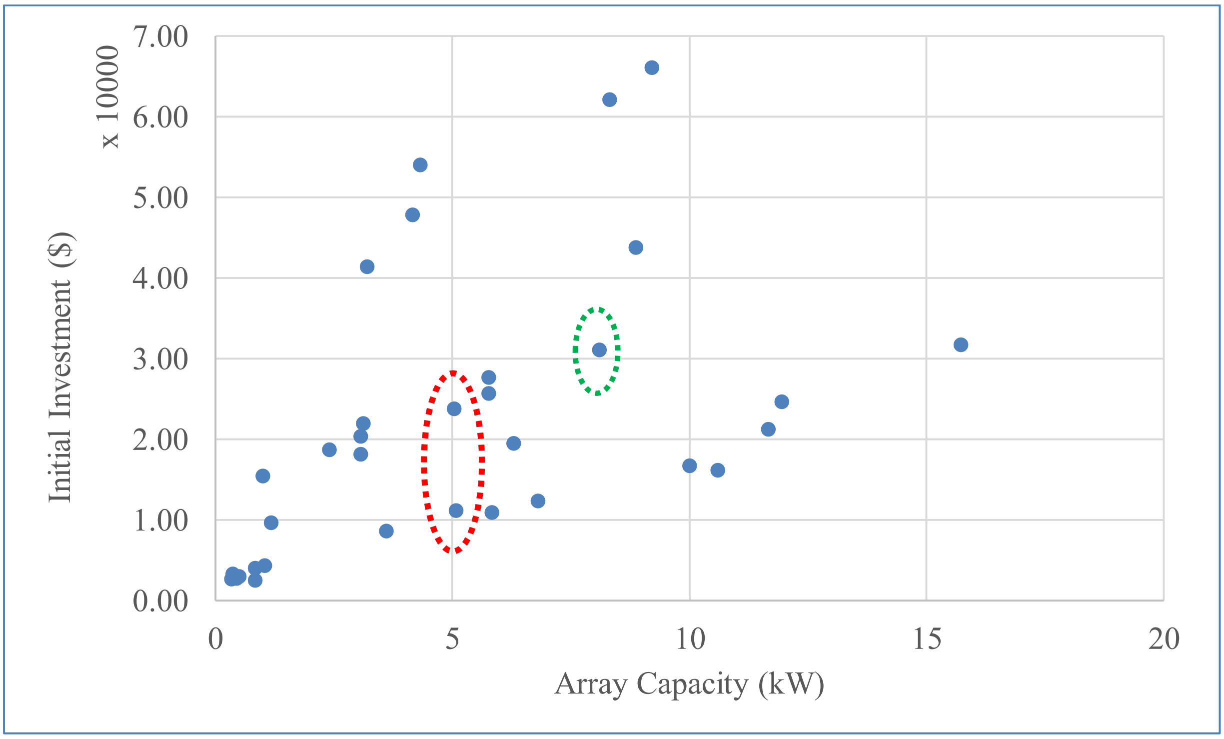


Figure 4. 29 Relationship between Investment Cost and Array Capacity

Yunus et al. identified that systems with storage tanks in Burkina Faso has the negative NPV since most of plastic tanks are manufactured in Ghana and exported to Burkina Faso which highly increase the cost of storage tanks, this cost contributes to 45% up to 63% of investment cost. The green oval shape marks the system which was re-designed and from 26.7 kW to 8.1 kW which in returns lowers the initial cost from 198 318.05 USD to 31,155.33 USD while the red oval shape represents the set of systems with almost the same array capacity but different initial cost which is contributed to different prices of components in different countries or number of incorporated components.

4.2.4 Installed Cost per Watt

There are different metrics used to compare the cost of the electricity energy producing systems, one of them are LCOE and cost of a unit watt. In this part the installed cost per watt is discussed in details based on the findings as shown in the figure 4.30.

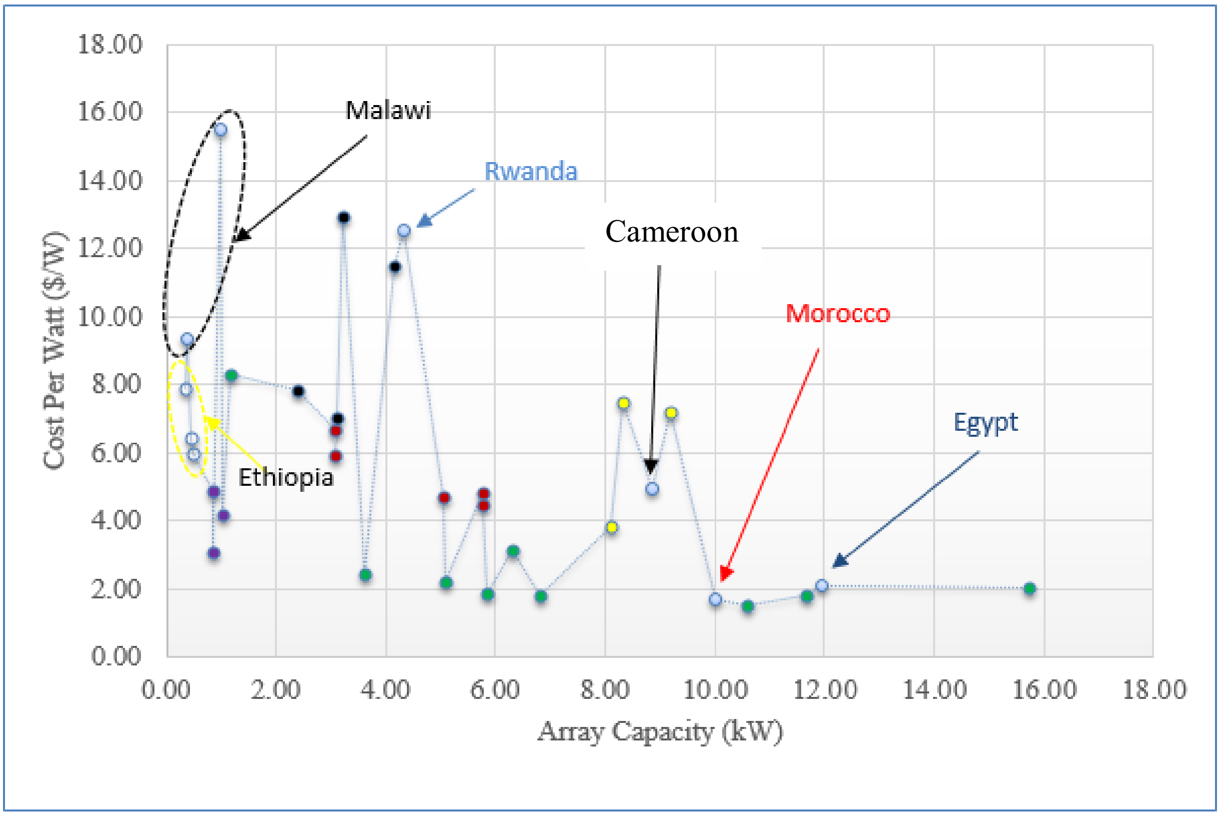


Figure 4. 30 Cost per watt of installed system

Unit cost in not the only factor to consider while trying to choose the best option of energy since it is affected by different parameters depending on the location, taxes, labour cost and installation cost which vary depends on the size of the system. From the figure Kirua-Kahe project (in yellow mark), green mark of dodoma, red from Nanyamba Projects and Violet from Kenya depict that there is no costant unit cost of installation, however systems installed in the same areas with the same installers shows that the installation cost per watt is decreasing with the increase in array capacity, this should not be confused with the fact that this is supposed to be the same for a customer to select the good deal of the system. While according to IRENA the global unit cost of PV system is averaged to 1.80 USD per watt but in Africa it has fallen to 1.30 USD per watt (IRENA, 2016), the average cost per watt of surveyed installed systems in Africa is 5.6 USD per watt, and this may vary from one country to another due to different external factors as mentioned above.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Water supply for domestic use have been well organized at community level but the lack of knowledge on how to tackle the challenges that faces the system acts as the setback to achieve system's sustainability in economic and technical aspects.

Agriculture and small emerging businesses in rural areas contributes most to the income of the communities but these activities are not utilizing the opportunity of SWPs to create values in agriculture and water supply to facilitate the trade within communities.

This research found out that the system oversizing and downsizing hinders the economic performance of the system, the profitability and cost of solar water pumping depends on the size of the system, oversizing increases the investment cost and leads to high PBP and negative NPV or less profitability.

Solar water pumping adaptability in Africa is much hindered by the lack of knowledge about the solar systems, high initial investment cost and poor capacity building or after sales service from local suppliers and installers.

Lack of knowledge on where to obtain funds to develop SWPs is a major financial challenge that faces most farmers or water users in Africa, apart from that challenges such as clouds cover, population increase and variation in borehole water depths hinders the performance of these systems.

5.2 Recommendations

Subsidies, tariffs, exemption from taxes and funding for Renewable energy technologies for both small scale and large scale solar irrigation systems should be put in place to promote the technologies in rural areas.

Design of Solar water Pumping systems in rural Africa should focus more on value creation such as engaging more on producing high value crops and selling surplus power to the grid which will end up boosting the economy of the communities, in line with this the government should ensure the existence of market and infrastructures are in place.

Education and capacity building about solar water pumping especially their technicalities and economic benefits should be initiated in rural areas to ensure that these projects are accepted and supported by communities around Africa.

To improve the performance of solar PV modules tracking systems should be used to track the maximum amount of solar radiation as well as self-cleaning systems should be incorporated to keep the panels free from dusts.

Information on financial sources should be advertised on radio and Television to all citizens apart from the websites, social media and emails through professional members. This will speed up the development of community based projects in energy and water sector.

Improving the pump efficiency will save the significant energy and consequently improves the capacity of array which in return reduces the investment cost. All designs should take into consideration the proper sizing of pumps which is site specific.

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APPENDIX

APPENDIX I: DESCISIONS MAKERS QUESTIONNAIRE

IsDB
البنك الإسلامي للتنمية
Islamic Development Bank

PAN-AFRICAN UNIVERSITY
INSTITUTE OF WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

PAU
Nurturing Quality, Exemplifying Excellence

QUESTIONNAIRE FOR DECISION MAKERS
(TANZANIA/NIGERIA/CAMEROON/BURKINA FASO)

Prepared by:

Frank PROSPEROUS

SOLAR PUMPING SYSTEM FOR RURAL WATER SUPPLY
AND SMALL SCALE IRRIGATION SYSTEM IN AFRICA

ORGANIZATION NAME: TANZANIA RENEWABLE ENERGY AGENCY
RESPONDENT NAME: ....
JOB TITLE: ....
ADDRESS: ....
TELEPHONE NUMBER: ....
EMAIL: ....

Disclaimer:

The information collected is strictly for research purpose only, therefore it should not be used beyond this purpose. Information will secretly be treated as strictly confidentially and will be presented in the form of statistic report only.

GENERAL QUESTIONS

1. How do you rank your knowledge and skills level in solar water pumping for small scale irrigation schemes and water supply in Tanzania? (Please cross "X" what applies)

High	
Moderate	
Low	

2. How do you rank the competence level of the independent solar water pumping installers in the following fields?

0=None 1=Some (Fair training) 2=Good (Knowledge only) 3=Full Proficiency (theoretical background and practical)	**SCORES (0-3)**
Technically trained about Solar water pumps including proper pump selection.	
Knowledge about economic analysis of the systems.	
Able to include all the necessary components in the system.	
Able to install and maintain solar water pumping systems.	
Able to troubleshoot and repair broken system.	

3. Are there or were there plans for community awareness raising about solar water pumping systems for rural areas in Tanzania? (YES/NO). If Y**ES** please list the methods used.
   a) ……………………………….
   b) ……………………………….
   c) ……………………………….
   d) ……………………………….
   e) ……………………………….
4. Please cite the most key application of solar water pumping systems in your country. (Please cross "X" what applies)

Agriculture	
Water supply	

5. Does the private sectors/individuals needs approval from the government prior to the installation of solar water pumping systems? (YES/NO). If YES please briefly describe.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………

6. What is the total installed capacity of solar water pumping systems in rural areas that have been recorded so far?

Application	Total Capacity (kW)
Agriculture	
Water supply	
Both of them	
Others (Specify)	

7. Which regions in your country have the highest installed capacity of solar water pumping systems?

   ………………………………………………………………………………………………

8. How do you ensure the quality of products used for solar water pumping in your country?

   ………………………………………………………………………………………………

9. Is there any enabling environments to support this kind of project intervention in your country the following fields? (YES/NO). If YES briefly explain.

Government support	
Legal Framework	
Socio-Cultural acceptance	
Financial arrangements	
Institutional Arrangements	
Skills and Capacities	

10. Is there any information that were not covered in this questionnaire that seem so important to be known (or any documented information on the status of SWP in Tanzania).please provide details below.

APPENDIX II: HOUSEHOLD QUESTIONNAIRE

IsDB
البنك الإسلامي للتنمية
Islamic Development Bank

PAU
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PAN-AFRICAN UNIVERSITY
INSTITUTE OF WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

QUESTIONNAIRE FOR USERS
(TANZANIA/NIGERIA/CAMEROON/BURKINA FASO)

Prepared by:

Frank PROSPEROUS

SOLAR PUMPING SYSTEM FOR RURAL WATER SUPPLY AND SMALL SCALE IRRIGATION SYSTEM IN AFRICA

RESPONDENT NAME: ………………………………………………………………………………………

VILLAGE: ………………………………………………………………………………………

JOB TITLE: ………………………………………………………………………………………

ADDRESS: ………………………………………………………………………………………

TELEPHONE NUMBER: ………………………………………………………………………………………

EMAIL: ………………………………………………………………………………………

Disclaimer:

The information collected is strictly for research purpose only, therefore it should not be used beyond this purpose. Information will secretly be treated as strictly confidentially and will be presented in the form of statistic report only.

ECONOMIC, SOCIAL AND FINANCIAL ASSESSMENT

1. What are the Economic activities conducted in your village (tick where applicable)
   - ☐ Fishing
   - ☐ Livestock
   - ☐ Agriculture
   - ☐ Business
   - ☐ Other specify……………………………………….
2. What are the other potential economic projects in the community?

   ……………………………………………………………………………………………

3. Household income per month
   a) $2 - 100
   b) $100 - 300
   c) $300- 500
   d) more than $500
4. What source do you know that can be available for financing such projects in your country?
   a) Contribution from the community members
   b) Credit/loan from Bank
   c) Governmental Grants
   d) B and C
   e) A, B, and C
   f) I don't know
5. What challenges did you face in this project?

   …………………………………………………………………………………………….

6. What are the likely challenges that you face in availing loans from the bank?
   a) Complicated process
   b) High interest rate
   c) Lack of cooperation and harassment from stuffs
   d) Strictly deadlines
   e) I don't know the process

7. What kind of ownership would you suggest to farmers or water users for this kind of systems?
    a) Individual ownership
    b) Joint ownership
8. Please give the reason for the option you have chosen above.

   ……………………………………………………………………………………

9. Is clear information on financial support readily available, particularly to solar water pumping for producers and communities?

   ……………………………………………………………………………………

10. What do you think would be the possible barrier to adopt solar water pumping system?
    a) Expensive & unaffordable water bills
    b) Lack of Education and capacity building
    c) Not sufficient for my needs
    d) Borehole Seasonal Depth Variation
    e) Increase in Population

APPENDIX III: INTERVIEW FOR FGD

PAN-AFRICAN UNIVERSITY
INSTITUTE OF WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

INTERVIEW GUIDE FOR FOCUS GROUP DISCUSSIONS WITH WATER USERS GROUP REPRESENTATIVES (TANZANIA/NIGERIA/CAMEROON/BURKINA FASO)

Prepared by:

Frank PROSPEROUS

SOLAR PUMPING SYSTEM FOR RURAL WATER SUPPLY AND SMALL SCALE IRRIGATION SYSTEM IN AFRICA

PROJECT NAME: ....

NUMBER OF REP: ....

Disclaimer:

The information collected is strictly for research purpose only, therefore it should not be used beyond this purpose. Information will secretly be treated as strictly confidentially and will be presented in the form of statistic report only.

A. SOCIAL ASPECT

1. What are the main functions being undertaken by you as the representatives of your villages?

2. Are you interested in this technology?

3. What do you think will be the challenges that will hinder the sustainability of this project?

4. Do you think there is an importance of expanding this scheme to serve more villages around?

B. ECONOMIC ASPECT

1. What is the estimated average income per household in your community?

2. Can your community afford the full capital cost for this solar technology? (YES/NO) (What percentage could they cover?)

3. Can your community afford to pay for a major repair?

4. Are poor households who cannot pay excluded?

C. LEGAL, INSTITUTIONAL, ORGANISATIONAL

1. How is the Management system of a community water point?

2. Would it be adequate for this technology? If not, what should be improved?

D. SKILLS AND KNOWLEDGE

1. Are you familiar with this kind of technology?

2. Do you think the community has the necessary capacities to carry out O&M on this technology?

E. TECHNOLOGICAL

1. Is the amount of water that this system provides satisfactory for you?

2. Would you be satisfied with what this technology delivers?

APPENDIX IV: INTERVIEW FOR FGD

PAN-AFRICAN UNIVERSITY
INSTITUTE OF WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

QUESTIONNAIRE FOR WATER AUTHORITY (TANZANIA/NIGERIA/CAMEROON/BURKINA FASO)

Prepared by:

Frank PROSPEROUS

SOLAR PUMPING SYSTEM FOR RURAL WATER SUPPLY AND SMALL SCALE IRRIGATION SYSTEM IN AFRICA

RESPONDENT NAME: ……………………………………………………………………………………
EDUCATION LEVEL: ……………………………………………………………………………………
JOB TITLE: ……………………………………………………………………………………
ADDRESS/VILLAGE: ……………………………………………………………………………………
TELEPHONE NUMBER: ……………………………………………………………………………………
EMAIL: ……………………………………………………………………………………

Disclaimer:

The information collected is strictly for research purpose only, therefore it should not be used beyond this purpose. Information will secretly be treated as strictly confidentially and will be presented in the form of statistic report only.

A. GENERAL INFORMATION

1. What is the total number of households served in this community?

   ☐ Houses

2. How many people are served by this project?

   ☐ People

3. What’s an average per capital water consumption taken under consideration?

   ☐ L/cap/day

4. What are the main sources of water in your community? (Tick where applicable)

   ☐ River
   ☐ Wells
   ☐ Rain water
   ☐ Dam

5. What is the type of this project ownership? (Tick where applicable)

   ☐ Individual/Private Ownership
   ☐ Government Ownership
   ☐ Community Ownership

6. Are the solar structure designed to endure damage and theft? (YES/NO)
7. Is there any security arrangements against theft and vandalism? (YES/NO)

   If YES, Please Explain:…………………………………………………………………..

   ……………………………………………………………………………………

B. TECHNICAL INFORMATION

1. How deep is the water table from the surface in this area?

   ☐ m

2. How much yield does your system produce on daily basis?

   ☐ Litres/day

3. Do you have any common water storage facility at your community? (YES/NO)
4. If YES what is the volume of the storage facility?

   ☐ m^3

5. What is the Power usage period of your system? (Tick where applicable)

   ☐ Day-time
   ☐ Night-time
   ☐ 24-Hour system

6. Please provide the following technical details

I. Photovoltaic			
Module Type		Model	
Total Power (kWp)		No. of Modules	
Life Expectancy		Module Power	

II. Energy Storage (Battery)			
Manufacturer		Model	
Capacity(Ah)		No. of Batteries	
Life Expectancy			

III. Borehole/ Surface Water source information			
Depth of well		Well diameter	
Static water level		Drawdown	
Pump set point			

IV. Pump Information (Load)			
Manufacturer		Model	
Type of pump		Op. hrs (hr/day)	
Voltage (V)		Phase	
Total Head (m)		Power (Hp)	
Capacity (m^3/hr)		Life Expectancy	

C. ECONOMIC, SOCIAL AND FINANCIAL ASSESSMENT

1. What was the investment capital of your solar water pumping project?

   ☐ TZS

2. How much do you charge your service (Per unit cost)?

   ☐ TZS/Litres

3. What are the likely challenges that you face in availing loans from the bank?
   a) Complicated process
   b) High interest rate
   c) Lack of cooperation and harassment from stuffs
   d) Strictly deadlines
   e) I don't know the process
4. Please give the reason for the option you have chosen above.

   ……………………………………………………………………………………………

5. Is clear information on financial support readily available, particularly to solar water pumping for producers and communities?

   ……………………………………………………………………………………………

6. Were tax reliefs offered to you during the whole process of purchasing, transportation and installation?

   ……………………………………………………………………………………………

7. What do you think would be the possible barrier to adopt solar water pumping system?
   a) SWP is expensive & unaffordable
   b) Don't wish to change my existing pump
   c) Not sufficient for my needs
   d) Diesel pump is more handy and mobile
   e) Fear of theft
8. What was the source for financing purchasing of solar water pumping system including borehole drilling if any?
   a) Savings
   b) Credit/loan from Bank
   c) Friend/relative
   d) Credit from money lender
9. What challenges did you face in implementing this project?

   ……………………………………………………………………………………………

10. Is there any national subsidies, credit interests and grants received for investments in your system? (YES/NO). If yes please mention how much in terms of percentage or other way.

    ……………………………………………………………………………………………

    ……………………………………………………………………………………………

D. *OPERATION AND MAINTENANCE & CAPACITY BUILDING*

1. Who carries out O&M work, including electrical installation?

   …………………………………………………………………………………………

2. Who is responsible for the knowledge capacity building?

   …………………………………………………………………………………………

3. Are training plans continuing to exist until now?

   ....…………………………………………………………………………………

4. How many times have you done repair or maintenance?

   ..…………………………………………………………………………………………

5. How are operations and maintenances of the installed system done?

   ....……………………………………………………………………………………….

6. What are the typical routine activities do you consider during Maintenance?
   a. ………………………………………………………….
   b. ………………………………………………………….
   c. ………………………………………………………….
   d. ………………………………………………………….
   e. ………………………………………………………….
   f. ………………………………………………………….

7. What would be an average direct cost of system operation and maintenance?

   ……………………………………………………………………………………….

8. What would you improve about your system? (Add battery/Generator/Security etc?)

   ……………………………………………………………………………………….

APPENDIX VI: RESEARCH COST

S/No.	Item	Unit	Rate (Local)	USD	Amount
(A)					
1	Internet Charges	N.A	5000N	15	15
		N.A	195000TSh	114	114
2	Stationery, printing and photocopying excluding 2 final document	N.A	759800Tsh	338	338
				SUB TOTAL	**467**
(B)					
1	Data collection expenses (Questionnaires and Meteorological data)	N.A	2864851.2TSh	1274	1274
2	GPS	N.A	440000TSh	195	195
				SUB TOTAL	**1469**
(C)					
1	Flight ticket and (Round Way)-Burkina Faso/Tanzania/Nigeria	N.A	118075DZD	993	993
2	VISA fee (STR VISA), Abuja, Nigeria (For Nigeria only)	N.A		139	139
3	Bank Transfer Charges	N.A	-	-	-
				SUB TOTAL	**1132**

A	**MATERIALS AND SUPPLIES**				467
B	**EQUIPMENTS**				1469
C	**TRAVEL + VISA COST**				1132
				TOTAL EXPENSES	**3068**

NOTE:

a) *Transfer charges to my bank account in Tanzania should be communicated to me for modification and justification.*

b) *Final version printing charges and publication of two research papers should be included after defense.*