ENVIRONMENTAL AND SOCIO-ECONOMIC FEASIBILITY OF SOLAR POWERED GROUNDWATER PUMPS IN DROUGHT AFFECTED AREAS OF GIYANI LIMPOPO

By

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DECLARATION

I, the undersigned hereby declare that this thesis entitled "ENVIRONMENTAL AND SOCIOECONOMIC FEASIBILITY OF SOLAR POWERED GROUNDWATER PUMPS IN DROUGHT AFFECTED AREAS OF GIYANI LIMPOPO'' is my own original work which has not been submitted to any other institution for similar purposes. Where other people's work has been used, acknowledgements have been made.

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Full Legal Name

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Signature

___05/12/2023________________________

Date

DEDICATION

This thesis is dedicated to my late grandfather- L.S. Mpambo, who believed so much in education and ensured to support us as his grandchildren in every possible way while he was still alive. He left us with a seed that remains with to this date, I know that he would have been proud of me for furthering my studies to this far. May he continue to rest in eternal peace.

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ABSTRACT

In the South African context, large portions of rural population do not have access to water supply. Shallow groundwater in alluvial aquifers of ephemeral (or dry sand bed) rivers can potentially be an alternative sustainable source of water for multiple uses. Solar-powered groundwater pumps could be suitable to reduce abstraction costs in rural areas that are often far from national grid connections. The objectives of this study were to conduct an environmental and socio-economic feasibility assessment of using solar-powered groundwater pumps in rural villages of Greater Giyani Municipality (Limpopo). The environmental assessment dealt with environmental issues associated with the use of solar pumps by analysing their emission of CO_2 as compared to alternative energy supply options such as fuel and electricity. The socio-economic aspects dealt with the capital and maintenance costs associated with the system as compared to alternative sources of energy. A cost-benefit analysis was conducted in order to determine financial benefits, returns on investment and payback periods of using solar powered groundwater pumps. A life cycle analysis of the solar powered system was conducted. The results indicated a great market strength exists for these solar powered systems and even though they have high initial costs, their running costs are lower compared to alternative sources (diesel and grid). The life cycle analysis done using OPENLCA software showed that solar powered water pumps have environmental impacts especially during their manufacturing phase.

CHAPTER 1: INTRODUCTION

Water is the most important resource and as humans we need water for our survival, we need it for our everyday use, in our daily purposes such as cleaning, drinking, cooking. It is also used in the agricultural sector for irrigation, in construction and also for the purposes of generating electricity thus making it an important element for development (Gleick, 1996). The amount of water within a region and its quality has an influence on the standard of living, for example areas with little to no access to water tend to have a poor standard of living (poverty stricken) (Jury and Vaux, 2007). Even though water is of much importance, its availability is often limited especially in remote areas that are prone to droughts. Because of this limitation, water pumps were introduced in order to pump groundwater and make it available in these locations where it is mostly needed.

Most of the water pumps which are currently used for the aforementioned purposes are powered either by diesel or electricity. However, since electricity is mainly generated through the combustion of fossil fuels such as coal and is supplied through national grid power stations, this became an issue when it came to powering pumps that supply water in remote areas where there is no grid connection (Meah et al., 2008). Also, with the rising awareness of the negative environmental effects resulting from the combustion of fossil fuels, researchers/scientists had to shift their focus and explore other alternative sources that can be used to power water pumps such as renewable energies. Renewable energy sources include but are not limited to wind, biomass and solar energy. Of the aforementioned renewable energies, solar photovoltaic energy has proven to be the most suitable option because it is a clean energy source and is abundant. It is also mostly available in seasons (hot and dry) when water is mostly needed; during the hot and dry seasons the sun's intensity is high and the demand for water also tends to be quite high (Meah et al., 2008).

The photovoltaic panels operate by generating electricity directly from the sun's solar energy, and the generated electricity is then used to power the electric water pumps. Due to the growing energy crisis and the changes in weather patterns solar water pumps have become the centre of focus by researchers because they can help lower carbon footprint which contributes to global warming. The decrease in solar photovoltaic prices due to the progress made in this technology also contributed towards it being the preferred option (Foster et al., 2014). Many aspects of solar pumps have been explored in the past such as their overall efficiency, individual components and their size optimization (Cloutier and Rowley, 2011). Many studies (Eker, 2005; Zhou and Abdullah, 2017) have been done on solar water pumps, ranging from improving their overall efficiency, to their suitability for various applications/uses (Eker, 2005; Zhou and Abdullah, 2017). However, a feasibility study on solar water pumps implementation in rural areas has not been done at a large scale and this study aims to contribute to this scientific gap by evaluating the environmental and socio-economic feasibility of implementing solar powered groundwater pumps in drought affected areas of Giyani in Limpopo.

1.2 Problem Analysis and Motivation

Extreme weather events in recent years, such as drought, flooding, veld fires, and tropical cyclones, have had serious adverse impacts on ecosystems, communities, and the economy. These events are associated with known drivers of climate variability, such as the El Niño Southern Oscillation, together with increased realisation of the consequences of climate change. Measures and interventions responding to the changing climate require the research sector to assess the expected implications of climate change and to establish plans and strategies for sectors to respond to identified risks and opportunities. These involve determining how important climatic variables are shifting, quantifying their natural variability on multi-decadal or longer time scales, improving confidence in predictions of climate to allow for better risk management, lowering the cost of managing the effects of climate change and taking advantage of potential opportunities. Within this context, the South African Water Research Commission (WRC) has identified several problematic areas and also experimented possible interventions to improve water security in light of the changing climate (WRC, 2018).

Climate change has an effect on water resources by altering the water balance. The anticipated drop in rainfall will have a negative impact on hydrological responses and groundwater recharge. The increased occurrence of extreme weather events present negative consequences for infrastructure, health, production, and economic growth. These impacts will increase water supply pressure in already water stressed environments (WRC, 2018). South Africa is extremely susceptible to the implications of climate change, both socioeconomically and environmentally. It is a water-stressed country that will face future drying trends and increased weather changes, as well as climate extremes such as drought and flood cycles. (Finnveden et al., 2009). Furthermore, these situations will affect the marginalised and the rural poor (Petja, 2017). These identified impacts advocate for a balanced planning and response while adapting to the new normal. It is critical to plan effectively for both droughts and floods while improving adaptability to these extremes. Future infrastructural development must allow for more flood water to be captured and stored. This will reduce societal vulnerability to flood impacts while saving an enormous quantity of water for use during dry periods and groundwater recharge. This current work intends to conduct feasibility assessments in identified water scarce areas prior to the implementation of sustainable water supply interventions. This will in turn contribute to improving the resilience of rural areas to a changing climate which is characterized by recurring climate extremes and also encourage sustenance of rural livelihoods.

1.3 Aims and Objectives

1.3.1 Aim

The aim of the study is to evaluate the feasibility of implementing selected water supply interventions, namely solar-powered groundwater pumping systems, in Greater Giyani Municipality, Limpopo. The study focused on the environmental and socio-economic aspects. Although it is recognized that geotechnical and engineering aspects are also fundamental to the sustainability of the system, these were beyond the scope of this study.

1.3.2 Objectives

The study has two objectives which are as follows:

1. To evaluate the environmental feasibility of using solar panel-powered pumps for abstraction of shallow groundwater
2. To evaluate the socio-economic feasibility of using solar panel-powered pumps in water scarce areas frequently affected by recurring droughts/ climate extremes

1.4 Structure of the thesis

The structure of this thesis is as follows:

- Chapter 1: Introduction and background of the study
- Chapter 2: Comprehensive literature review documenting existing information on solar-powered systems for abstraction of shallow groundwater
- Chapter 3: Description of study area
- Chapter 4: Research methodology
- Chapter 5: Results and Discussion
- Chapter 6: Recommendation and conclusions are drawn

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CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a review of literature based on the analyses of peer-reviewed articles which were obtained online. The search engine used was Google Scholar and most articles were obtained from Science Direct and other online platforms through the University of the Western Cape online library. The main searches included keywords such as “solar energy”, “solar water pumping”, “rural water supply”, “cost analysis of solar water pump”, “photovoltaic water pumping”, “solar pumping effects on environment”, “technical aspect of solar pumps”, “design of solar pumps”. The obtained articles were mainly selected with the consideration of answering the question of whether solar water pumps are feasible for implementation in drought prone rural areas. The feasibility assessment follows a themed structure with the following headings being relevant to the current study: socio-economic and environmental feasibility. The framework of the literature review is shown in Figure 2.1 below:

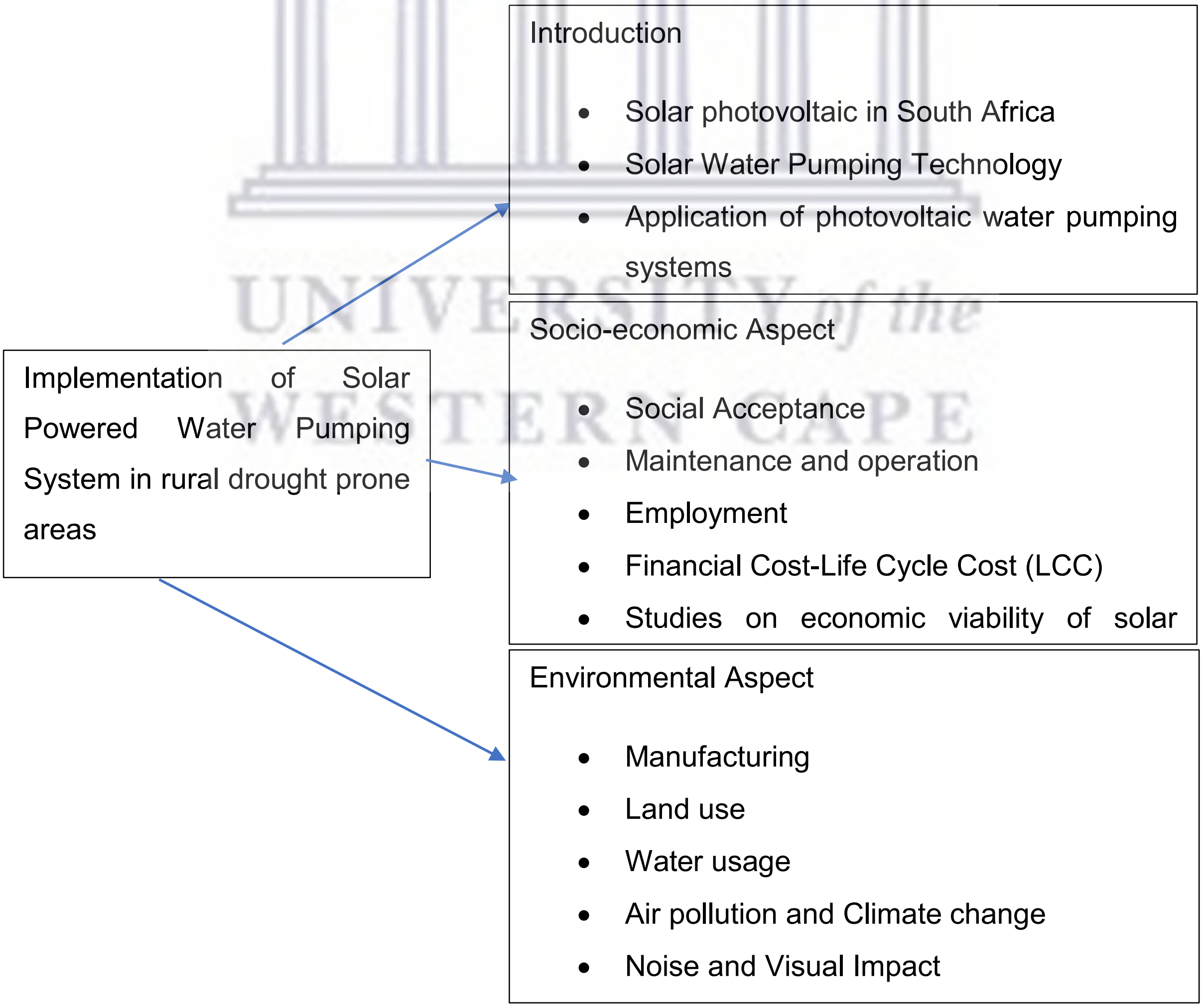


Figure 2. 1 Literature review framework

2.1.2 Solar photovoltaic in South Africa

According to the report done by the Energy Information Administration (EIA), majority of South Africa's energy consumption was dominated by fossil fuels making up 97 percent of it with the rest accounted for by nuclear and renewable energy sources (EIA, 2015). The country, just like other sub-Saharan African countries, receives a lot of sunlight with a daily average of 8.5 hours (Mwanyasi and Adonis, 2014). South Africa's solar radiation averages at more than 6.5 kWh/m^2 each day ranking it amongst the highest in the world, particularly in the Northern Cape province (Mas'ud et.al 2016). Free State, Limpopo, North West, Eastern Cape and the inner parts of the Western Cape are among the listed provinces in South Africa that have high solar radiation.

In terms of policies/ legislations of renewable energies, the South African government drafted a policy on renewable energy which resulted in the passing of the 1998 WHITE PAPER energy policy. In addition to these efforts the government made a vow to prioritise renewable energy technologies such as solar photovoltaic, wind and hydro as such; among the goals of the WHITE PAPER was improved energy services and economic development (DME, 1998). In 2003 the white paper on renewable energy was published, building up from the 1998 WHITE PAPER (DME, 2003). Since the publication of these documents, much progress has been made in South Africa regarding solar photovoltaic and, according to Ballack (2015), South Africa had 415 solar photovoltaic installations in April 2015 which had a total capacity of 36.5 megawatts. Recent studies revealed that in Upington, a town in the Northern Cape Province in South Africa, an approximate of 5000 megawatts of electricity can be generated from solar panels. This province is also home to the Jasper photovoltaic solar power plant which was completed in 2014, covering 180 hectares of land and it can produce 180 GWh of renewable energy which is enough to supply power to 80 000 residences (Jackson and Oliver, 2000).

The White Paper on Renewable Energy from 2003 was among the policy documents that established the groundwork for the development of renewable energy technologies such as solar, hydro, biomass and wind. This policy paper established a ten-year goal for how renewable energy technologies can diversify the national energy mix while ensuring cleaner energy. The 2003 White Paper on Renewable Energy had the following goals:

- Ascertain that a proportionate amount of national resources is invested in renewable technology;
- Invest public funds in the development of renewable energy technology;
- Create appropriate fiscal incentives for renewable energy sources; and

- Create a favourable investment environment for the growth of the renewable energy sector.

In keeping with the national commitment to move towards a low-carbon economy, the Integrated Resource Plan (IRP 2010), which was promulgated in May 2011, established a more ambitious objective to achieve 17 800 MW of renewable energy to be realized in the electricity generating mix by 2030. Within this 20-year planning horizon, around 5000 MW was scheduled to be operational by 2019, with a further 2000 MW expected to be operational by 2020. Ministerial Determinations are used to carry out the IRP 2010, which are governed by the Electricity Regulations on New Generation Capacity, which are based on the Electricity Regulations Act No. 4 of 2006. Using the competitive bidding process known as bidding windows, 112 Renewable Energy Independent Power Producers (IPPs) acquired 6 422 MW of power in 2017. By the end of June 2017, 3 162 MW of energy producing capacity from 57 IPP projects had been linked to the national grid.

At the end of 2010, the Department of Energy (DoE) introduced the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) in partnership with the National Treasury and the Development Bank of Southern Africa (DBSA). One of the South African government's urgent actions to improve the country's power generation capacity is the REIPPPP. Its major goal is to secure private sector investment in the creation of new electricity production capacity, thereby putting into action the governmental decision to diversify South Africa's energy mix, which was outlined in the country's White Paper on Energy Policy in 1998 (RSA, 2001). The South African government established a number of policies and strategies building up from the aforementioned papers; a summary of these policies and strategies is given in the Table 2.1.

Table 2. 1 Solar Energy Legislations in South Africa

Policy/Legislative framework	Provisions on renewables and solar
White Paper on Energy Policy of the Republic of South Africa (December 1998)	The White Paper is designed to ensure smooth implementation of economically feasible technologies and applications. The aim of the paper was to address some of the challenges the renewable energy sector has been facing. This is done by making sure that national resources are directed to the development of renewable technologies.

White Paper on Renewable Energy Policy of the Republic of South Africa (November 2003)	It sets a target of 10 000 GWh from renewable energy that would result in consumption from biomass, wind, solar and small-scale hydro energy systems by 2013.
Integrated Energy Plan 2003	The Plan expands on what needs to be done by South Africa in meeting its energy needs. The Plan is a result of The National Energy Act No. 34 of 2008. The aim is broadening sources of energy in order to improve energy efficiency.
Electricity Regulation Act of 2006	The Act resulted in the establishment of the regulatory body NERSA. The role of the body is to determine electricity traffic and grant licenses for the generation, distribution and transmission of electricity.
Integrated Resource Plan 2010-2030 (IRP) focus on electricity	The Plan recognises solar photovoltaic as a viable option that could produce 300 MW per year as from 2012. The greatest concern expressed in the plan is the degree to which energy efficiency demand-side management (EEDSM) has an impact on impending generation options.
The solar technology roadmap (STEM)	The roadmap identified the challenges that solar technologies face. It highlights the need for policies and incentives that can accelerate deployment of the technologies in South Africa. The roadmap was instrumental in paving the way for localisation efforts to enable the government to achieve its New Growth Path aspirations.
Department of Energy Draft 2012 Integrated Energy Planning Report	The aim of the Planning Report was to ensure that the country can meet current and future energy service needs. This must be done in a more efficient and sustainable way.
Green Industries Initiative	The Initiative was established to help support the New Growth Path. This is done by supporting and investing in renewable energy projects. To this end, IDC has allocated R25 billion over the five years to 2015/16 for the development of green industries within the country. The Green Industries Strategic Business Unit (SBU) will

	disburse the greater part of this funding. The Green Energy Efficiency Fund (GEEF) was established in 2011 and the Green Accord was signed in the same year. Two years later, the country witnessed the construction of the first two concentrated solar projects in South Africa through this funding.
Green Fund	The government established the Green Fund to fund green initiatives in the country. Numerous projects have been funded to date, including solar projects such as iShack in Cape Town. The project is a scalable off-grid solar electricity utility for informal settlements.
Green Industrial Policy Action Plan	To promote local economic development, the Green Industrial Policy Action was established to support green industries. The materials and the manufacturing component used in assembling solar technologies is a concern expressed in the plan.
Green Economy Accord	The accord endorses government commitment to move towards a greener economy. The accord recognises that a green economy is a driver for an equitable society that will create green jobs to grow the economy

In addition, the South African government has established a number of major agencies and projects in addition to the renewable energy strategy plan. These organizations and initiatives have various missions, but they all work together to advance the national solar energy adoption and upscaling goal. Table 2.2 provides a description of the organizations and programs targeted at supporting solar energy adoption and scaling as summarised by Nhamo and Mukonza (2016).

Table 2.2 Description of the organizations/institutions targeted at supporting solar energy adoption and scaling

Institution	Function and role in solar energy
Department of Energy (DoE)	The DoE is the custodian of South Africa's energy policy. It is responsible for establishing a national framework that will allow

	the generation of renewable energy-based electricity in the country.
Departmental of Environmental Affairs	The role of the department is to monitor and regulate environmental impact, such as greenhouse gas emissions, ecosystem degradation, waste management and water use. The department is also responsible for Eskom and IPP operations through environmental impact assessments (EIAs). Before a project commences, it must obtain approval from the Department (i.e. license/permit) to build a power station, major power lines and sub-stations. The guiding Act of this process is the National Environment Management Act of 1998 (Act No. 107 of 1998).
Department of Science and Technology	The department develops, implements and monitors science and technology policy and programmes. It is the custodian of technology research and development (and manages the South African Energy Grand Challenge).
Department of Trade and Industry (DTI)	The DTI is responsible for the development and implementation of the up-scaled Industrial Policy Action Plan. Green industries, particularly the energy sector (solar and wind energy, solar water heating, and energy efficiency), have been identified as priorities for the national industrial policy. The aim of the policy is to promote long-term industrialization and industrial diversification of renewable energies, of which solar energy is an important component. It also aids in the establishment of a domestic manufacturing base to support the development and deployment of renewable technologies. The DTI also makes recommendations to the DoE on local content and job creation targets for all REIPP procurement projects.
National Treasury	Is involved in budgeting and financing strategic national projects like the Solar Park as well as research in carbon taxation.
Municipalities	Municipalities are responsible for securing the delivery of basic services (including energy) in urban areas and for many aspects of integrated development planning. They are also a conduit that

	channels national government subsidies directed towards energy provision.
National Energy Regulator of South Africa (NERSA)	They regulate electricity tariffs, and grant licenses for the generation, distribution and transmission of electricity.
South African Local Government Association (SALGA)	It has a stake in the implementation of renewable energy policies at the local level. It has also supported research on how ready the country is to move towards a green economy.
South African National Energy Development Institute (SANEDI)	The mandate of the Institute is to coordinate and undertake applied research in energy development and demonstration. The institute was established by DoE and the Department of Science and Technology in October 2010, as part of the state energy financing entity, the Central Energy Fund (CEF). SANEDI is in charge of developing human capital in the energy research sector and fostering an innovative culture in the energy sector.
Council for Scientific and Industrial Research (CSIR)	It is South Africa's leading scientific and technological research, development, and implementation organization that also works with solar energy.
RECORD	The institution carries out research and collaborative projects that involve mapping current and future solar technologies. Research and development are necessary to establish how the country can meet its energy needs, as outlined by the different policies in terms of the short term milestone of 2020, the medium term (2030) and the long term (2050). The institute was influential in setting up a solar measuring station project and in the release of the new solar resource map for South Africa. It is involved in the construction of MET solar stations in specific locations in South Africa. Through applied energy research, the institution has established the concept of a centre for solar technology, development and innovation.

South African Photovoltaic Industry Association (SAPVIA)	The association is comprised of key players in South Africa's photovoltaic market who possess the knowledge, experience, initiative, and determination to propel the industry forward. It promotes higher uptake of the technology and provides advice to key decision makers on sustainable photovoltaic technology.
Southern Africa Solar Thermal and Electricity Association (SASTELA)	This is a group of CSP actors from Southern Africa and the African continent. Developers, manufacturers, utilities, engineering firms, financial institutions, and research institutions are all members of the association. SASTELA's aim is to promote growth in the emerging solar thermal electricity industry.
Sustainable Energy Society of Southern Africa (SESSA)	The primary objective of the organisation is to promote the use of renewable energy (such as solar water heaters), heat pumps and green energy industries (like bioenergy and wind to hydropower). The organisation was established to support Eskom in the solar rebate programme.
South African National Energy Agency Association (SANEA)	It plays a significant role in the future of energy in South Africa by bringing various stakeholders together to identify and implement sustainable and efficient solutions.
Eskom	Eskom is a key player and the sole buyer of solar electricity; it is therefore a player and a referee in the process. Eskom has a challenge to ensure that clean electricity is produced in future to reduce the grid emission factor. Regarding the promotion of solar projects, Eskom has constructed a 100 MW CSP demonstration plant in Upington in the Northern Cape Province.
South African Renewable Energy Council	The Renewable Energy Council in South Africa is an umbrella body that coordinates and aligns the activities of its key stakeholders.
South African Renewable Energy Technology Centre (SARETEC)	The centre was established to provide training for technicians in terms of installation, operation and maintenance of solar photovoltaic and wind turbine facilities

2.1.3 Solar Water Pumping Technology

As mentioned previously, solar water pumps consist of photovoltaic panels which convert sunlight into electricity that can be used to pump water (Kolhe et al., 2002). The water pumped through these pumps is used for various purposes e.g. for crop irrigation or to provide water for domestic purposes (Girma et al., 2015). These pumps are ideal because they pump water when it is mostly needed and they can be installed in valleys, forests and other areas where there is no grid connection available. As a result, these solutions can be used in solving water scarcity problems in developing countries (Ramos and Ramos, 2009). Over the past years this technology has shown drastic growth with continued reduction in their cost prices. Figure 2.2 shows the reduction in photovoltaic cost prices ($/watt) over the years.

Figure 2. 2 Reduction in Photo Voltaic cost prices ($/watt) over the years according to Decker (2015)

A solar powered system for groundwater is composed of several parts, but a generalised configuration of these systems may consist of the following:

- Solar panels
- Mounting and solar tracking accessories
- Electronic components such as inverters and pump controllers
- Hydraulic pump and support structure

- Pipes and fittings
- Reservoir/battery
- Motors

The above system components have been described in detail in other published literature (Maurya et al., 2015; Moeeni and Alam, 2016; Ravikumar et al., 2019). Figure 2.3 is an illustration of a typical solar water pumping system set up and Figure 2.4 shows a schematic diagram representing the components of a solar water pumping system and also provides a description of how the system operates/flows from 1- 6.

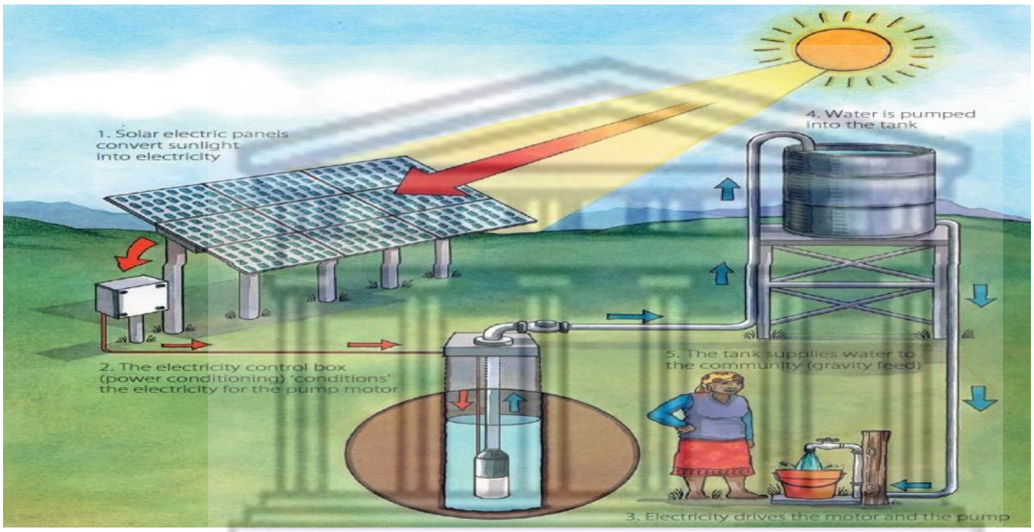


Figure 2. 3 Typical set up of a solar water pumping system, according to Energy and Development Group (2018)

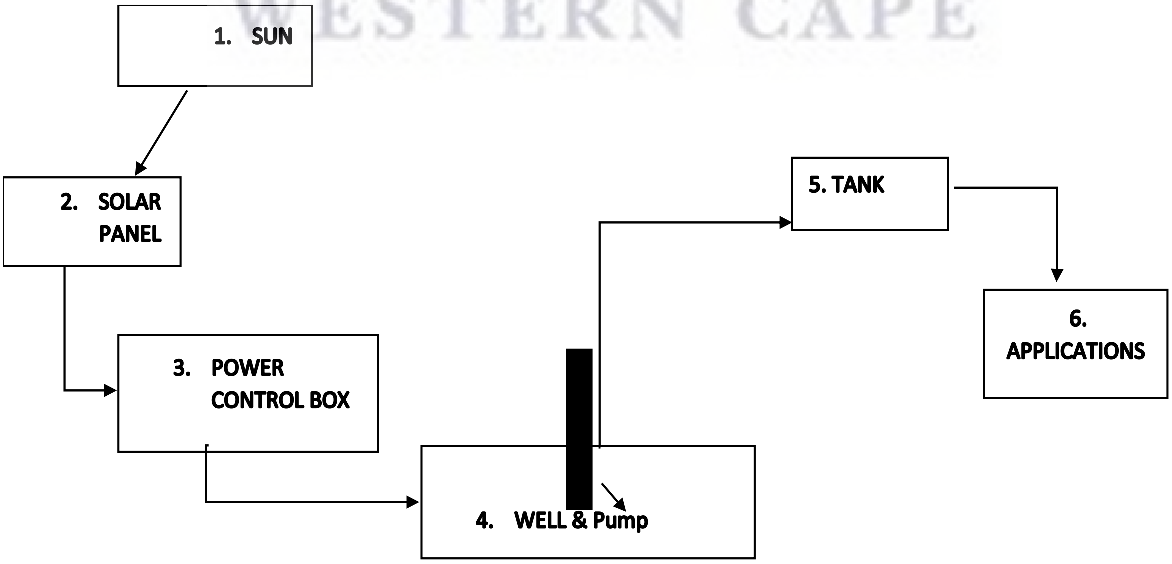


Figure 2. 4 System components of solar-powered groundwater pumping system

2.1.4 Application of solar water pumping systems

The most pressing water demands in rural areas fall into three categories: rural water supply, irrigation, and livestock supply. (Rohit et al., 2013). In arid and semi- arid environments where solar radiation is higher, solar photovoltaic pumps are usually used for pumping water for domestic use and livestock supply and in communities that rely on subsistence farming water is also used for irrigation. The use of photovoltaic technology presents various benefits especially for rural areas because it is a clean and environmentally friendly energy source (Anderson et al., 2006). The following pumps have been commonly used to pump water for rural application: hand pumps, diesel, wind and solar pumping systems. Pumping water from shallow wells has been done using hand pumps, especially in community settings. These are strong devices that are simple to maintain and have a cheap initial investment. However, they are restricted in terms of pumping volumes and installation depth, they have a hydraulic load limit of 250 m^3 per day (Dunn, 1986).

On the other hand, wind pumps can deliver water from depths up to 300-400 m, they necessitate basic skills and are labour-intensive to maintain. Wind pumps are difficult to install and require more water storage as compared to both diesel and solar (Tesfaye Bayou, 1996). Diesel pumps are efficient for use at any hydraulic head with a high discharge rate. Water pumps which are diesel-powered have been used in rural areas for quite some time but due to the rise in fuel prices, problems with transportation and the lack of skilled labourers these systems have become costly and unreliable for rural communities (Girma, 2016). The opposite is the case for solar water pumps since they require little maintenance and can operate for longer periods without any physical supervision and they do not have any transport costs once they are installed (Pelt et al., 2012). Additionally, Khatib (2010) adds that photovoltaic systems are easier to install, reliable and suitable for meeting water demand.

Solar photovoltaics can be used to power various applications; these can range from small lamps/bulbs to big solar power plants. Below are some of the known applications of solar photovoltaic (Shinde and Wandre, 2015):

1. For supplying electric power (electrification) to rural and urban residential areas
2. For powering electronics such as computers
3. For water supply; through water pumping
4. For telecommunications
5. For powering refrigerators that store vaccines

Studies about the application of solar water pumps in irrigation have been conducted by), Al-Ali et al. (2001), Pande et al. (2003), Elke (2005), Hamidat and Benyoucef (2009), Morales and Busch (2010), Yu et al. (2011) and Mokeddem et al. (2011). These studies found that these systems are suitable for use in dry areas, for low head irrigation systems, and are less costly when used to power small-scale drip-irrigation systems than overhead sprinkler systems.

2.2 SOCIO-ECONOMIC ASPECT

Energy is critical for economic growth and the provision of basic services that enhance people's standard of living. According to Sopian et al. (2011) energy is necessary for addressing all of humanity's basic needs, it also has a clear link to the Human Development Index. Additionally, energy has been described as fundamental for socio-economic development as it is needed in the production of goods and services (Shouman et al., 2016). In this section the socio-economic aspect of solar photovoltaics will be explored under these sub-headings: social acceptance, maintenance and operation, employment, financial costs and viability of these systems.

2.2.1 Social Acceptance of Solar Photovoltaic systems

Globally there have been efforts made towards increasing the share of renewable energy, putting it high on the policy agendas. There has also been a number of goals set and support mechanisms put in place to help ease the market implementation of renewable energies (Wüstenhagen et al., 2007). The degree to which these policies are successfully implemented varies in each country depending on their social acceptance. According to the description given by Nkosi and Dikgang (2016), social acceptance assesses society's reactions, their threats and benefits as far as renewable energies are concerned. There are three dimensions of social acceptance: market, community, and socio-political acceptance, each of which has a distinct impact on the adoption of renewable energy systems (Sheikh et al., 2016).

Given this background, energy can never be solely defined as a techno-economic issue. It is evident that energy also has an impact on all the aspects of societies such as culture and lifestyle and as a result, energy systems must also be examined from a cultural and social standpoint (Ruotsalainen et al., 2017). Park and Ohm (2014) did a study aimed at determining the factors that influence renewable energy support/acceptance, they compared the public's support prior and post the Fukushima incident in Japan. Their findings showed that prior to the incident there was limited support due to costs, but after the incident there was more trust and support towards renewable energy because of the risks associated with nuclear and costs were no longer an issue.

Renewables also play a role in diversifying the economy by contributing skills, knowledge and infrastructure (CERA, 2012). As part of their commitment to increasing their renewable energy share and diversifying their economy, Italy has a diversification strategy which allows for customers to pay for renewable energy through an established tariff system. Bigerna and Polinori (2014) did a study in the area to find out the willingness of the residents to pay for energy in order to increase their share of renewable energy. From the 1019 households in which surveys were conducted they found that socio-economic factors such as age, income bracket and the level of education influenced the willingness to pay by the residents as educated and young people showed more support and willingness to pay.

The impacts of renewable energy installation, whether they are positive or negative, also influence public acceptance (Hanger et al., 2016). The two studies done in China and Germany by Zoellner et al. (2008) which looked at how the costs and benefits of renewables as perceived by the public influenced their acceptance supported this, as the results from the surveys which were done in different areas and with each addressing a different renewable energy source showed that the cost and benefits of renewable technologies are the most influential factors of reported acceptance.

Similar to the issue of perceived costs and benefits is the issue of trust and procedural justice which are also a concern as they determine the acceptance of large scale renewable installations. Trust was identified as an important element to consider for the purposes of building social acceptance by Wolsink (2012) and Gupta et.al. (2012) found it to be among the most explored factors which influence acceptance. To help with the issue of procedural justice, Firestone et al. (2012) suggested a list of principles to be adhered to, which are:

- Expressing opinions freely
- Hearing out all opinions
- Ensuring full participation by the public/stakeholders
- Creating awareness about the project
- Treating all parties involved with respect
- Have unbiased decision makers

Recently many countries such as Morocco have come to understand that depending on fossil fuels has serious consequences for the energy supply as well as climate change (Pollin et al., 2015). As a result, renewable energy technologies are becoming more important for the economic and social development of communities. Those in power/governance are taking advantage of these benefits and are developing strong governmental policies and incentives that will help promote the growth and socio-political acceptance of renewable energy within their country. For instance, a study by Hunger et.al. (2016) states that the Moroccan government established a legal and regulatory framework in order to help with the implementation of its solar power project and these also aided in getting financial support for the project.

The strategies that follow can help to boost solar photovoltaic water pumping even more (Closas and Rap 2017; Sarkar and Ghosh 2017; Agrawal and Jain 2019):

1. Through the government providing easy access to subsidies and incentives for these technologies
2. Establishing lower interest rates on loans taken by farmers for purchasing these units
3. Providing adequate solar photovoltaic pump training to farmers and local technicians
4. Create seminars/talks on solar photovoltaic technology and its benefits especially in remote areas

2.2.2 Maintenance and Operation

The operation of a pumping system incurs some costs which include labour and energy cost that are associated with keeping the system operational. These costs differ depending on how the system is constructed and the purpose it is meant to serve. An example would be that of a hazardous duty pump which requires day-to-day checks for its emissions and its operational performance whereas the opposite exists for a self-regulating non-hazardous pump since it requires less monitoring. The costs incurred in the managing and safeguarding of the system also form part of the operational costs (World Bank, 2018).

A systems maintenance cost is made up of all the costs involved in ensuring the system remains operational at all times within its lifespan such as repairing all faulty parts and keeping the solar panels clean. For systems that have batteries as their storage, part of their maintenance also involves regularly inspecting the battery's condition (Solanki, 2015). It is suggested that proper maintenance increases a systems lifespan hence it is necessary that solar photovoltaic systems be properly maintained. As a result, Benbelkacem et al. (2013) recommended the use of mixed reality technology for maintaining large solar photovoltaic pumping stations. The authors created a tracking method that is able to locate maintenance personnel on site and then overlay the objects virtually; the results from using this method showed reduced accident risks, increased flexibility and also saved time.

Meah et al. (2008) write in their paper that when compared to diesel-powered systems, photovoltaic systems require far less operating and maintenance costs. Likewise, Sarkar and Ghosh (2017) did a techno-economic study in Bangladesh for solar powered water pumps where they compared maintenance costs for a photovoltaic system to that of a diesel generator. The result showed that the photovoltaic system had a total cost that was less as compared to that of the diesel generator. Gopal et al. (2013) also identified in their study that although the initial cost of photovoltaic systems is higher when compared to diesel, it is still less compared to the costs of operating and maintaining a diesel pump.

2.2.3 Employment

Apart from the role renewable power generation plays in lowering the negative impacts the energy sector has on the environment, it also supports employment opportunities in the modern day and aid in the generation of wealth (Ram et al., 2019). Jobs play a crucial role in the economic and social development space, their importance goes beyond an individual’s wellbeing and just generating income. They are also key to the achievement of any societal goals such as poverty alleviation, enhanced economic productivity and social cohesion. The creation of job opportunities by the energy sector has led to development benefits such as empowering females within the society, skills acquisition by community members and peace in post conflict societies thus making these jobs valuable not only to the beneficiaries but to the broader society (World Bank, 2012).

In recent years the energy sector has had vast contributions to the global economy including facilitating economic growth and sustaining a number of jobs (World Economic Forum, 2012). There are a different number of jobs that are and will be generated during the period of global energy transition. These jobs differ and Ram et al. (2019) summarised the type of jobs as follows:

- Manufacturing jobs: this category encompasses all the jobs that arise for the purposes or are involved in the manufacturing stages of renewable energy systems.
- Construction and Installation jobs: this category is inclusive of all jobs that are part of the construction and installation process of any renewable power plant.
- Operational and Maintenance jobs: this category covers every job that is linked to keeping/ensuring that a system remains operational during its lifetime.
- Decommissioning jobs: these are jobs associated to the dismantling of power plants at the end of their lifetime. Some parts are often recycled, opening more jobs like in the case of photovoltaic technologies.

The employment trends vary significantly with each renewable technology with solar photovoltaic technology accounting for most jobs. This is mainly because their prices keep lowering making them cost effective thus increasing their installation rate (Liko, 2019). Ram et al. (2019) conducted an assessment of job creation within the green energy sector and they discovered that worldwide jobs linked to clean energy generation are set to increase from 21 million in the year 2015 and rise to almost 35 million by the year 2050. Wethe (2015) argues that even though there is a notable decline in both oil and gas prices resulting in significant job losses, which were estimated at about 250 000 at the end of 2015, the increasing growth in the renewable sector has had a positive impact in the sector in terms of jobs. Similarly, Haerer and Pratson (2015) in their study indicate that after analysing the employment trends in US the results indicated that while fuel generated electricity decreased, the number of jobs lost due to the latter was compensated by the rise in job opportunities caused by the expansion of green energy sector. Employment within the renewable energy sector is likely to remain centred around the same technologies even in the upcoming years (Grubler, 2012).

2.2.4 Financial Costs: Life Cycle Cost (LCC)

Life cycle costs(LCC) can be defined as the overall costs and benefits linked to a pumping system throughout its operation, expressed as the current worth of that particular system (Solanki, 2015). According to Thomas (1993), the life cycle cost method is efficient for use in evaluating the financial viability of solar photovoltaic water pumping systems. Solar water pumps are believed to have a lifespan of 20+ years during which they incur a variety of costs, some at the inception and others at various points throughout the system's lifespan (Meah et.al.,2008). The following are costs considered when conducting a life cycle cost analysis for a pumping system: acquisition costs, operation and maintenance, and replacement costs. Even though photovoltaic systems are considered to have high initial costs, they do not require fuel to operate thus making their maintenance and running cost to be lower as compared to that of traditional energy sources (World Bank, 2018).

Before the start of any renewable energy project a proper life cycle cost assessment has to be done (Durairaj, 2002). As a result, numerous studies have been done about the life cycle cost assessments of different photovoltaic systems prior installation. For instance, Kumar and Tiwani (2009) analysed a hybrid system while Jakhrani et al. (2012) did an LCC of a stand-alone photovoltaic system. Mahmoud and Natherb (2003) used the LCC method to investigate the economic aspects of solar photovoltaic pumps in comparison to diesel systems, and their research discovered that in terms of cost, photovoltaic systems outperform diesel systems. Similarly, Mahjoubi et al. (2013) studied the economic viability of remote photovoltaic water systems in a Tunisian desert, the pump was meant to pump a daily average of 45 m^3 throughout the year compared with diesel generator. The results from the LCC indicated photovoltaic pumping as economic viable for use in a desert. In Nigeria, Benjamin et al. (2013)

compared the LCC of diesel-photovoltaic hybrid systems for off-grid residences. The hybrid system was compared to a stand-alone photovoltaic system and a stand-alone diesel generator; the LCC was completed by assessing the Net Present Value (NPV) and internal Rate of Return (IRR) for all three systems. The hybrid system was found to have a lower LCC as compared to the other two systems; in addition to the economic gain, it was also declared environmentally friendly.

In an economic analysis study for photovoltaic water pumping systems in Kenya, the life cycle cost method was used to analyse their economic viability. The costs of photovoltaic were compared against a diesel-powered water pump and according to the study the two systems reached their break-even point during their third year of operation. The outcomes of this study showed that the lifecycle costs of diesel pumps escalate rapidly over the years whereas the costs for photovoltaic pumps remain constant throughout (Otieno et al., 2018). Figure 2.5 illustrates the results of this study.

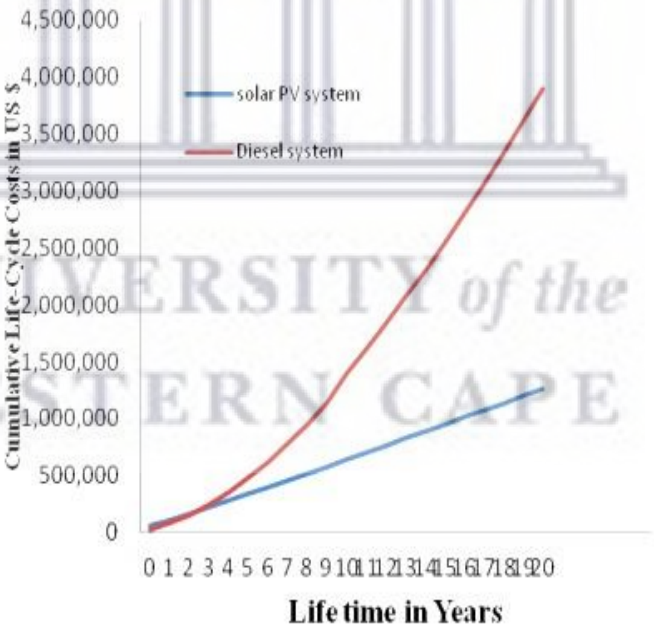


Figure 2. 5 Life cycle comparison for diesel and solar photovoltaic system according to Otieno et al. (2018)

Another life cycle cost study was performed in rural Tanzania. The data used was from existing water pumps powered by diesel generator within the area and were compared to costs of an average solar pump (World Bank, 2018). Figures 2.6 and 2.7 show the results of the study, with Figure 2.6 showing the obtained yearly costs of a diesel pump and Figure 2.7 showing costs from a photovoltaic life cycle. In Figure 2.6, the results show low initial costs and thereafter there's an increase due to the system's fuel cost as well as its replacement costs, the contrary is true for Figure 2.7 which shows that the initial costs were quite high for the photovoltaic system and a rise in replacement cost by the 10th year. But these high costs are compensated for by the steady low costs for maintenance and operation with no fuel costs.

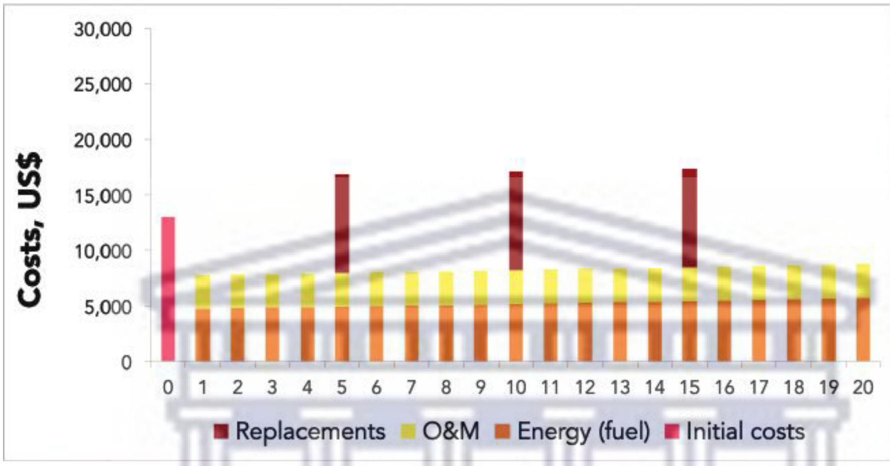


Figure 2. 6 Yearly costs of a diesel pump according to World Bank (2018)

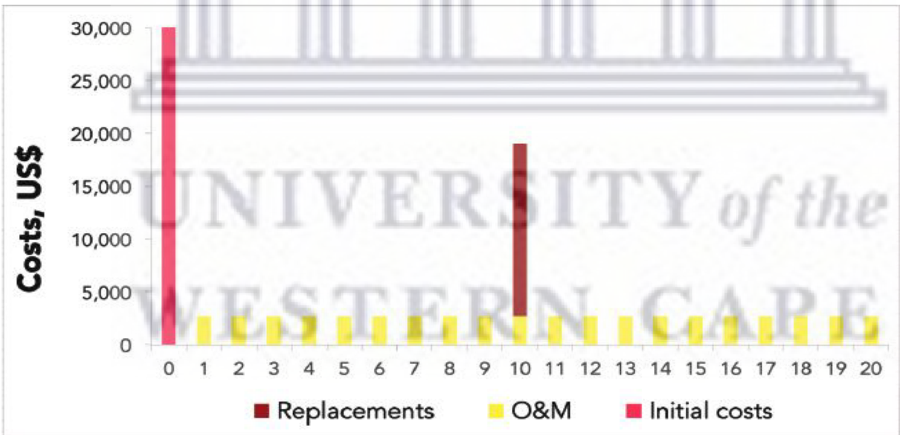


Figure 2. 7 Yearly costs of photovoltaic pump according to World Bank (2018)

2.2.5 Economic Viability of Solar Water Pumps

A study conducted by Zografakis et.al. (2010) together with Walwyn and Brent (2015) alluded to the continuous decrease in most renewable energy prices even for years to come and the benefits these low prices present for investments in renewable energy. Foster et al. (1998) performed a life cycle analysis using information from an available database; the results proved photovoltaics as being cost effective and fit for use in water pumping. Solar water pumping could be an appealing option for African developing countries. According to Chandel et al. (2015), the vast majority of people live in rural areas, and there is plenty of solar insolation available all year. The findings of Muhammadu's study (Muhammadu, 2015) indicate that solar water pumping is becoming increasingly popular in off-grid, low-income remote areas of equatorial countries such as Nigeria and in the last thirty years the technology has advanced significantly in terms of performance and cost-effectiveness.

Similarly, Mankbadi and Ayad (1998) found solar water pumps to be suitable for domestic water supply. Qoaider and Steinbrencht (2010) investigated the technical suitability of implementing solar water pumps in villages for irrigation purposes and power supply and the results confirmed the pumps as suitable. The study by Meah et al. (2008) covers the use and viability of solar water pumps in drought prevalent regions. And a number of studies such as Hamza and Taha (1995), Foster et al. (2013) and Jamil et al. (2012) found solar water pumps to be economically viable for various applications.

2.3 ENVIRONMENTAL ASPECTS

Solar photovoltaic systems are considered as a clean and sustainable source of energy since they do not generate any greenhouse emissions during their lifetime (Tawalbeh et al., 2020). Even though solar photovoltaics present a positive shift for power generation and for lowering carbon footprint, the environmental impacts linked to the manufacturing and disposal of photovoltaic modules can never be ignored. These impacts range from the extraction of raw materials, module acquisition, production of contaminates, pollution of water resources and air emissions as well as their impact on the land (Alsema and Nieuwlaar, 2000).

In the past, many studies have covered the environmental impacts of solar technology, for instance Turney and Fthenakis (2011) attempted to quantify the environmental impacts from the installation and operational period of solar power plants. The study assessed impacts from these phases under various subjects that are linked to the environment such as their impact on climate change. The outcomes from the assessments indicate that the impacts from solar photovoltaics are insignificant relative to those from diesel/oil. Further to this, the study concludes that even though removing trees to create land space may contribute significantly to CO_2 emissions, these are still low when compared to those from the combustion of fossil fuels.

Similarly, an environmental life cycle assessment was conducted by Armanuos et al. (2015) for using two kinds of water pumps: diesel and solar powered for the purposes of irrigation. The hydraulic head and cultivation area were used as factors for comparison and the results showed that for groundwater pumping, diesel pumps have the greatest impacts. In addition, Fthenakis et al. (2008) states that greenhouse gas emissions differ depending on the make/material used and that generally emissions from photovoltaics are lower than those from traditional technologies. The study also suggests that at minimum 89% of the emissions from power generation could be avoided if photovoltaics were to replace grid electricity. Drawing from such studies the environmental impacts from solar water pumps are discussed below under these sub-themes: manufacturing, land use, water resources, air pollution and climate change, and noise and visual impacts.

2.3.1 Manufacturing of photovoltaic cells

The fabrication of Photovoltaic systems is embedded within the electronic field. Chemicals that are found in electronic waste are also found in solar photovoltaic such as chromium, cadmium etc. These chemicals are used for the manufacture of solar cells, for instance cadmium is used as a semi-conductor for converting solar into electrical energy in cadmium telluride solar cells. The chemicals are known for being toxic, explosive, flammable and cancerous, as a result they are a risk to both the environment and to the health of workers (Wild-Scholten et al.,2004). The production of solar cells causes a release of some heavy metals. Furthermore, chemicals such as ammonia and hydrochloric acid are utilised in the cleaning process of solar photovoltaic, they are used to clean/remove dirt and dust that has built up on the surfaces of solar panels (Tao and Yu, 2015).

The manner in which these electronic products are discharged has become a concerning environmental problem across the world considering that recycling the volumes of waste produced during manufacturing is still a topic that is being investigated since it is energy intense, complex and can lead to greater impacts on the environment (Bogacka et al., 2017). Therefore, an alternative purifying silicon hazardous material such as silane can be explored. In addition, other chemicals such as phosphine and diborane can be used to lessen its impact; small quantities of these chemicals are usually diluted in inert gas before being used as a dope (Choi and Fthenakis, 2010). Since these gases are harmful and flammable they need to be monitored and handled cautiously (Todde et al., 2019). These gases are not harmful nor do they pose a threat during the regular manufacturing of photovoltaics, they are only emitted in the case of a spillage or leakage (Nafer, 2009). As listed by Aguado-Monsonet et al. (1998), the following are the hazardous materials emitted during manufacturing of photovoltaics: silica dust, silanes, diborane, phosphine and solvents.

2.3.2 Land use

Solar power systems are reported to have a high land use when compared to other technologies (Beylot et al., 2014). The installation of solar plants requires land space especially big solar plants for the purposes of collecting solar radiation. This results in land conflicts for solar usage as the land may not be available or be in competition with other essential economic land activities such as agriculture (Tawalbeh et al., 2020). Dias et al. (2019) reported that there has been a decrease in the amount of solar energy installations due to the land being prioritised for agricultural use. A study by Cagle et al. (2019) reported that in America alone the escalating growth of solar systems will require thousands of acres.

Beside the issue of land space, other impacts associated with photovoltaics occur during the construction phase; construction activities such as earth and transport movements can cause soil erosion thus modifying the landscape. In order to reduce the existing land conflicts there must be a proper allocation of land for all its competing uses. A number of studies have been done investigating for solutions on lowering the land used by renewables. Shiraishi et al. (2019) suggested the use of degraded areas for installing renewable technologies. Similarly, Tawalbeh et al. (2020) writes that the use of land that is already occupied such as rooftops or landfills can also help. The use of hybrid systems was proven to also help in reducing land requirements (Al-Ajmi et al., 2018). Kafka et al. (2020) proposed a dual angle solar harvesting system in order to reduce land use, the study also showed that increasing the capacity of photovoltaics requires less land.

The occupation of land by solar power plants also has an adverse effect on the wildlife and its habitat (Aman et al., 2015). The construction of these plants requires that the land be cleared of any vegetation, this greatly changes the land leading to loss of habitat for the animals (Turney and Fthenakis, 2011). This also changes the entire ecosystem of the animals as their hiding spots and food sources are altered; some animals may find it difficult to adapt to such changes as such they die. McCrary et al. (1984) studied the death of aerial locomotive animals at a solar power plant and found that yearly six birds died and hourly hundreds of insects also died. Similarly, a report from a proposed solar project in grassland and farmland areas in California found that the project will have considerable impacts on the plant and animal species found in the region (Turney and Fthenakis, 2011). The chemicals used at these facilities for cleaning and removal of vegetation cause contamination to the surrounding areas (Hawkins et al., 2003).

2.3.3 Water resources

Globally many countries have become extremely vulnerable and exposed to the impacts of climate change such as drought and/or flooding. These changes have called for more sustainable ways of water consumption (Fthenakis et.al., 2008). A study that was conducted by Meldrum et al. (2013) reviewed water usage for power generation. The study indicated that water usage throughout the manufacturing and recycling of Photovoltaic systems is relatively higher than the water used for operating these systems. The water usage on-site is associated to the cleaning and cooling of modules. Fthenakis and Kim (2010) did a review on existing studies linked to the usage of water in both traditional and renewable energy systems taking into consideration their water demand. From the outcomes of the study it was evident that progressing towards photovoltaic technology would be beneficial for saving water.

Jin et al. (2019) suggested that in order to ease the transition towards renewable energy and to better understand the safeguarding of water, water consumption of renewables must be measured precisely. Their study investigated the use of blue water in order to determine water usage. The study outlined that photovoltaics had the lowest impact in water consumption as opposed to other renewable as illustrated by Table 2.3. In addition, a study by Bukhary et al. (2018) found photovoltaics to be the most suitable for use in regions where water is limited.

Table 2. 3 Median water consumption for various renewable technologies (Jin et al., 2019)

Type of technology	Median of water consumption (L/MWh)
Biomass	850,100
Hydropower	4,961
Photovoltaic	330
Concentrating Solar Power (CSP)	1,250

2.3.4 Air pollution and climate change

One of the reasons for using solar energy is to lower the emissions of carbon dioxide (CO_2) that are associated with using fossil fuels for power generation. Solar photovoltaics are considered to be clean since their impact on air pollution and climate change is very low; they produce zero emissions of CO_2 during their lifetime (Nugent and Sovacool, 2014; Fthenakis et al.,2008). Nugent and Sovacool (2014) wrote that all life cycle phases of photovoltaics need to be considered for quantifying these emissions. Table 2.4 shows a breakdown of greenhouse gas emissions in percentages from both wind and solar energy life cycles.

Table 2. 4 Breakdown of total greenhouse gas emissions (%) from both wind and solar pumps during their lifetime.

Source of energy	Fabrication	Construction	Operation	Recycling
Solar photovoltaic	71.3	19	13	-3.3
Wind	71.5	24	23.9	-19.4

From Table 2.4 it is clear that the manufacturing phase accounts for the greatest emissions then follows construction and operation. In the manufacturing phase majority of emissions are a result of three processes: firstly, through the fabrication of steel and aluminium for purpose of building frames and support structures of photovoltaics, secondly when glass is produced and lastly during the reduction of silica to silicon for producing silicon solar cells (Alsema, 2012). Usually the main gases emitted from photovoltaic power systems are sulphur dioxide and carbon dioxide, with the latter being used as trace for greenhouse gas emission.

The installation of solar plants in forests requires for trees to be cut down to prevent them from blocking the sun from reaching the solar panels and creating a shade. These actions have negative impacts on the environment since plants/trees are known to absorb carbon dioxide from the atmosphere thus reducing CO_2 emissions through the process of carbon sequestration (Groesbeck and Pearce, 2018). Zhai et al. (2012) indicated that the use of Photovoltaic systems for generating power in America will result in a reduction of approximately 6.5 to 18.8% CO_2 emissions. Solar panels are considered as having low reflectivity which allows the panels to convert all the insolation into heat which may have an effect on climate change. With this said, Nemet (2009) conducted a study in which he examined the effect of albedo (ability of surfaces to reflect sunlight) on climate change. According to the findings of the study the rewards of using solar systems in lowering greenhouse emissions outweighs the insignificant effects of albedo that are caused by the low reflectivity of solar photovoltaics.

2.3.5 Noise and visual impacts

The World Health Organization(WHO) defines noise as an unwanted sound and because of this it is viewed as a form of pollution (Gupta, 2006). Noise is referred to as an environmental factor that leads to tension and with potential damaging effect on the health of humans (Passchier-Vermeer and Passchier, 2000). The damaging effects caused by the noise are a result of different power intensities that can also lead to a number of stresses. Photovoltaics are fixed/stationary with no moving parts for their operation as such they do not have any associated noise problems (Tsoutsos et al., 2005). But just like with most types of projects, the construction period will cause noise pollution due to the machines and vehicles used on the site. The resulting noise will affect the nearby population and wildlife by causing problems such as hearing loss for the workers involved and causing disturbances to the ecosystem in particular animals (Dehra, 2018). In most sites the noise levels are only high during the day and lower at night since there are no construction activities taking place. This is one of the reasons why these power plants should be installed far away from the residential areas.

Based on this, many projects have been declined and hindered from being implemented as the noise disturbs the visitors/tourists who paid to enjoy facilities without any disturbances. With this said, Guerin (2017) indicates that when compared to other renewable technologies such as wind, solar photovoltaic has less noise pollution and Strogen and Horvath (2013) also adds that biomass generates high noise during construction, much higher than photovoltaic and wind turbines.

The large scale installation of photovoltaics results in visual intrusion; this has become a concern for quite a number of communities as well as environmentalists. The degree of visual impact is determined by the type of system and where it is situated (surrounding area), if the installation occurs in an area of attraction or with historic importance then the visual impact is expected to be high (Fernandez-Jimenez et.al., 2015; Dhar et al., 2020). Bazán et al. (2018) suggest that in order to counteract these impacts photovoltaic panels should be installed on the rooftops and the facade of buildings. Fernandez-Jimenez et al. (2015) suggested the following measures for reducing visual impact of photovoltaic plants:

- Consulting the public for acceptance
- Integrate photovoltaic panel into façade of buildings
- Establish appropriate practices for installation
- Endorsement of environmentally friendly legislations
- Properly planning and selecting suitable sites

2.4 LIFE CYCLE ANALYSIS REVIEW

2.4.1 Description

Life cycle analysis (LCA) is defined as the assessment of the environmental impact of a product (or service) from "cradle to grave" and how it affects the environment in terms of both human and animal well-being as well as the environment at a large scale. That is, from the extraction and processing of raw materials to their final disposal (Ayres, 1995). The life cycle analysis process is divided into four phases, the first being scoping where the boundary and purpose are clearly outlined. The second is defined as the collection of quantitative data on both direct and indirect material/energy inputs and waste emissions, from the manufacturing until disposal of a product or service. This is referred to as the inventory phase of the analysis. The third phase is termed the impact assessment where environmental impacts are classified, characterised and evaluated. The last phase is the interpretation of the life cycle impact analysis done during the third phase (Heijungs et al.,1992). An LCA investigation should effectively cover all environmental implications of a service or product. LCA's strength is in its holistic approach to studying the entire product/system, which allows us to prevent sub-optimization that might occur when only a few processes are examined (Bhat and Prakash, 2009). The outcomes are also tied to the use of a product, allowing for contrasts between different options.

Over the years, there has been an increase in recognition of the importance of energy in our societies, as well as the growing concern about prospective energy sources (Góralczyk, 2003). This has prompted questions about how much energy is consumed in the production of goods and services. Net energy analysis is a critical application of LCA. After the energy costs of acquiring, generating, improving, and delivering the energy have been paid, net energy is defined as the amount of energy that remains for customer usage. If a new energy technology can produce a positive net energy output when energy is limited, it should be implemented even if the financial outlook for its acceptance are unfavourable (Huettner, 1976). In order to quantify renewable energy's CO_2 reduction potential, Tahara et al. (1997) compared the CO_2 payback time of future renewable energy electric power facilities to that of commercial fossil fuel-fired electric power plants (coal, oil), Kreith et al. (1990) calculated the lifetime CO_2 emissions from coal-fired, photovoltaic, and solar thermal power plants. These CO_2 calculations are based on a net energy evaluation of operational systems as well as extensive design studies.

2.4.2 RENEWABLE ENERGY LIFE CYCLE ANALYSIS (LCA)

When comparing traditional fuel-based systems to renewable energy systems, the life cycle impact is critical. A range of dramatic contrasts in all major impact areas, in addition to the well-known price disparities between traditional fuel-based and renewable energy systems, strongly favour renewable energy solutions. Due to various advantages of the photovoltaic system, photovoltaic technology is predicted to be a major technology to solve challenges involving energy and the global environment. A comparison of the surface and material requirements of different power plants was conducted by Schaefer and Hagedorn (1992). The total energy utilized (hidden energy or grey energy) in the production and construction of solar power plants, CO_2 emissions from photovoltaic power generation, and energy payback time were all calculated. The total amount of primary energy consumed for the building of photovoltaic power plants ranges from 13,000 to 21,000 kWh/kWp, which is the present state of the art's lowest threshold.

Prakash and Bansal (1995) investigated the energy efficiency of solar photovoltaic module manufacturing in India. For the fabrication of cells and modules, India imports monocrystalline p-type silicon wafers. A mono-crystalline solar photovoltaic module's energy payback period was projected to be roughly four years in India. Additionally, Kato et al. (1997) used off-grade silicon supplied by semi-conductor businesses to examine the life cycle of single crystalline silicon (c-Si) photovoltaic cells and household photovoltaic systems. This research was carried out on a 3 kW rooftop photovoltaic system. The photovoltaic system's annual electrical output was estimated to be 3.47 MWh/year. The indirect CO_2 emissions from photovoltaic systems using c-Si photovoltaic cells made of low-grade Si were calculated to be 91 g/kWh. Alsema (2003) studied the energy consumption and CO_2 emissions related to the production of photovoltaic modules and balance of system (BOS) components for grid-connected photovoltaic systems. The energy payback period for roof - mounted installations was determined to be 2.5–3 years and 3–4 years for multi-megawatt ground mounted systems.

2.4.3 LCA Software(s)

The LCA is used for analysing a products' environmental impact during their life cycle such as procurement of raw materials, manufacture, distribution, transportation, and end-of-life disposal as standardized in the ISO 14040 series (Zhang et.al, 2017).

An LCA method comprises of four stages as listed below:

1. Determining the study's goal and scope (as defined by ISO 14040)
2. Inventory analysis: Developing a product life cycle model that takes all environmental inputs and outputs into account. Life cycle inventory (LCI) is the term used to describe this data collection activity (as defined by ISO 14041)
3. Impact assessment: Considering the environmental significance of all inputs and outputs. This is known as life cycle impact assessment (LCIA) (defined by ISO 14042)
4. Interpretation: It covers the study's interpretation (defined by ISO 14043).

Since the process involves a number of stages that need to be analysed, the use of a software is recommended for determining the inventory as well as calculating the impact assessment. This software can also be used for determining mass energy balances, emissions and energy uses of an item/product. Currently, there are many software programs that can be used to perform a life cycle assessment such as SimaPro, OpenLCA, Impact World+ etc. with SimaPro and OpenLCA being used the most (Iswara et.al, 2020).

SimaPro is a well-known or widely used software program that has been on the market for over 15 years and has a hefty licensing cost; the software is offered by Pre Consultants. It offers several advantages, like being more adaptable, being connected to numerous databases, being easy to integrate with other tools, being user-friendly, and producing transparent results, among others (Herrmann and Moltesen, 2015).

Open LCA is a well-known freeware (open source) computer program that enables the user to compute all of the stages associated with LCA. One additional benefit of this application is that it allows users to interact with multiple databases (Zoellner et al., 2008). Open LCA was originally intended to calculate the environmental effect of items and processes, but it may now include economic factors as well. It also includes a feature-rich, technically current introduction to the software (Iswara et.al, 2020). It also includes the most comprehensive collection of relevant, consistent life cycle inventory and sustainability datasets accessible anywhere in the world. The software was created by Green Delta in 2006. OpenLCA is offered at a variety of levels, including process, product system, project, and impact method database. An advantage of the program is that the process networks and graphical modelling may be generated both automatically and manually (Iswara et.al, 2020).

These software applications are highly recommended by experts due to their user-friendly interface and inclusion of a comprehensive database for various sustainability assessment methodologies such as life cycle assessment, social life cycle assessment, life cycle costing, carbon and water footprint analysis, product environmental footprint (PEF), and environmental product declarations (EPD). The software utilized in this study is explained in the research methodology section, along with a comprehensive explanation of the rationale behind its selection.

CHAPTER 3: DESCRIPTION OF STUDY AREA

3.1 DESCRIPTION OF STUDY AREA

In this Chapter, the study area is described in the context of the Limpopo Lowveld, which spans across the Levuvhu and Letaba River Basins. The Klein and Groot Letaba are the major rivers in the basin. Mopani District Municipality is located in this basin. It is composed of several local municipalities. The focus of this study is the Greater Giyani Municipality. In particular, the study sites are located within a particularly water scarce area situated between the Great Letaba and the non-perennial tributary Molototsi. The Molototsi is an ephemeral river draining quaternary catchments B81G and B81H (Figure 3.5). The Molototsi River flow is regulated by the Modjadji Dam in the upper reaches. The primary purpose of the dam is to provide water for the urban and domestic sectors. The identified impacts and activities related to runoff and effluent resulting from urbanization, as outlined in B81G, are of significant concern. These factors contributing to their large size include agricultural land, erosion, urban areas, sedimentation, grazing/trampling, and vegetation removal. The identified impacts and activities related to runoff and effluent from urban areas, as outlined in B81H, are of minimal magnitude. The agricultural land and exotic vegetation exhibit moderate characteristics, while significant impacts are observed at low water crossings, primarily caused by erosion, sedimentation, and vegetation depletion. Grazing and trampling have significant consequences. No significant impacts were identified, and no significant wetlands were indicated (DWA, 2013).

The study area falls within the Greater Giyani Municipality (Mopani District) in the Limpopo Province as shown in Figure 3.6 (study area map) under the study selection part to follow in section 3.1.6. Greater Giyani is a rural municipality which has a single semi-urban area, Giyani town. The municipality, demarcated into 31 wards, has 62 councillors and covers an area of 2967.27 km² (Greater Giyani Local Municipality IDP, 2021). The municipality consists of a total of 10 traditional authority areas, which collectively encompass over 97 villages. Giyani town represents the sole urban area within the municipality, serving as the primary hub for population concentration, employment prospects, commercial activities, and recreational amenities. Greater Giyani Municipality has a population of 256,300 with a slight tendency to decline mainly due to migration to cities. Giyani has a large number of rural settlements that are scattered and not easily accessible as the road conditions are bad and this has implications for economic activity in the municipality. Major environmental challenges are air and water pollution, deforestation, veld and forest fires, soil erosion, over-grazing, wetland protection and challenges linked to informal settlements (Greater Giyani Local Municipality IDP, 2021).

3.1.1 Climate

The climate in Greater Giyani Municipality is summer rainfall sub-tropical, although climatic conditions vary considerably due to variations in elevation. Average air temperatures are usually lower in the western parts compared to the eastern parts, along the slope from the mountainous escarpment to the lowveld. The average annual temperature exhibits variation across different elevation areas, ranging from approximately 18°C in higher elevations to over 28°C in the eastern region. On average, the temperature stands at 25.5°C. The highest temperatures are typically observed in the month of January, while the lowest temperatures are typically observed in the month of July. The region experiences an annual precipitation range of 200 to 450 millimetres, with a primary concentration during the summer season. Rainfall occurs during a solitary rainy season running from October to March, predominantly concentrated in the months of January and February. The pattern of distribution of rainfall is significantly impacted by the topographical features, particularly along the West-East gradient. The mean annual gross evaporation, as measured by A-pan, exhibits a range of 1,300 mm in the western mountainous region to 2,000 mm in the northern and eastern areas. The period from October to January exhibits the highest rates of evaporation, whereas the lowest rates are observed in June (DWAF, 2003).

Figure 3.1 depicts daily weather variables measured with an automatic weather station in Giyani from 2012 to 2020 (courtesy of the Agricultural Research Council). The weather station in Giyani (Lat: -23.32403; Long: 30.68730; Alt: 463 m) stopped operating in 2020. The Agricultural Research Council, however, is providing weather data from 2021 from automatic weather stations at Gravelotte Primary School (Lat: -23.9386; Long: 30.61899; Alt: 590 m) and ZZ2 BHB farm (Lat: -23.5779; Long: 30.14135; Alt: 671 m). Weather data collected at Gravelotte Primary School and ZZ2 BHB for 2022 are presented in Figure 3.2. The Penman-Monteith reference evapotranspiration (Allen et al., 1998) was calculated with the ETo calculator (Annandale et al., 2002).

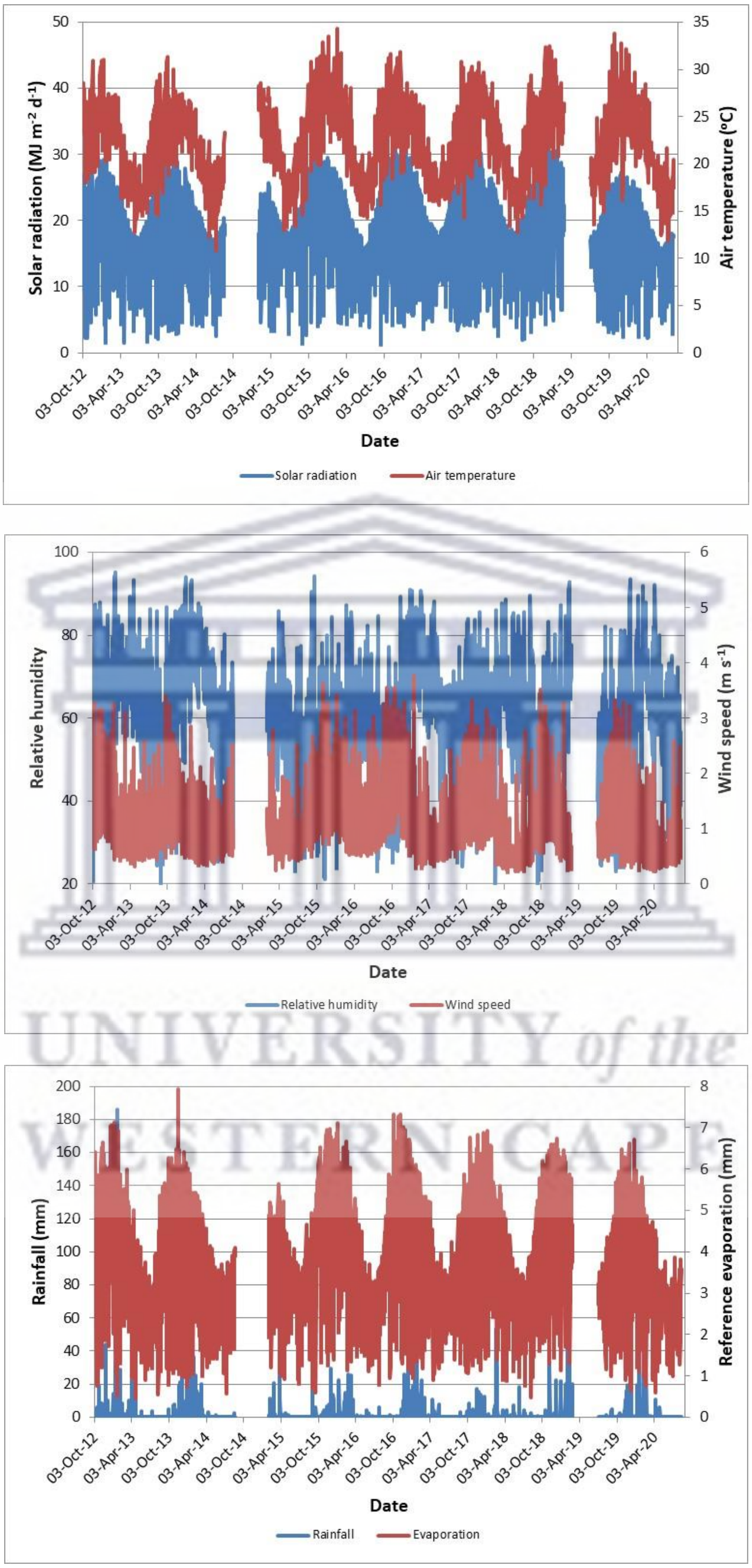
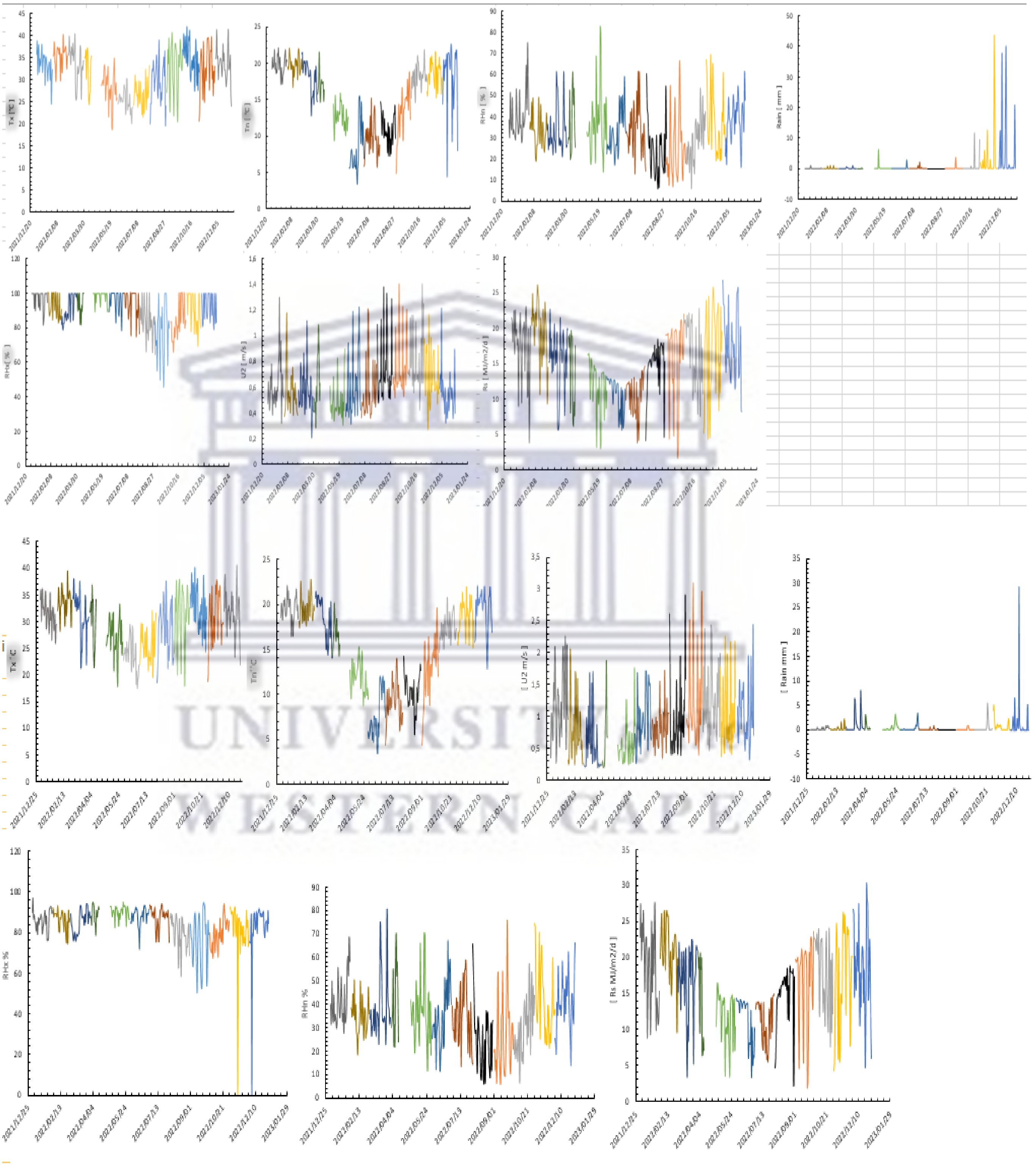


Figure 3. 1Daily weather variables measured with the automatic weather station in Giyani from 2012 to 2020 (Agricultural Research Council).



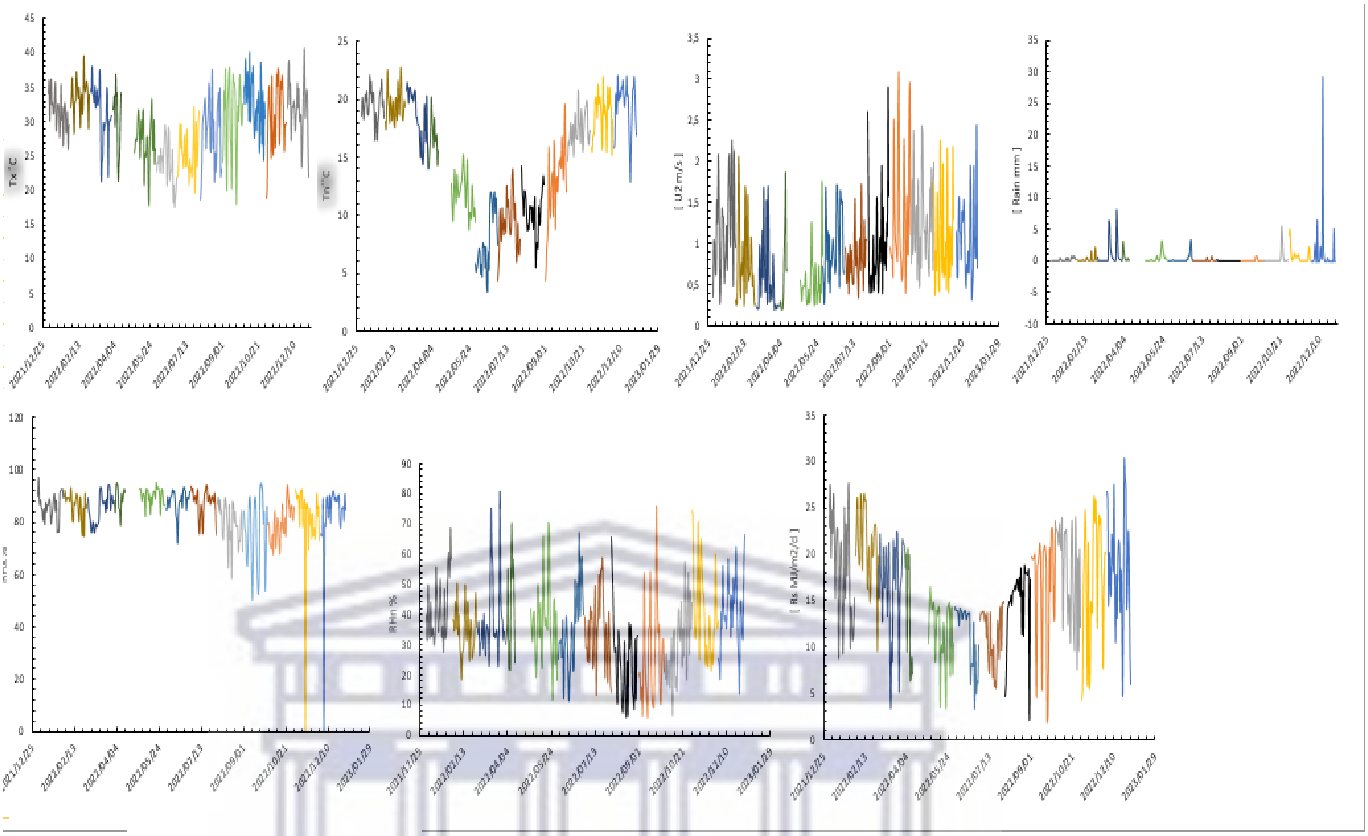


Figure 3. 2 top :Daily weather variables measured with the automatic weather station at Gravelotte Primary School during 2022, bottom : Daily weather variables measured with the automatic weather station at ZZ2 during 2022 (Agricultural Research Council).

The graphs in Figure 3.2 above depict different weather parameters which were plotted using data obtained from two weather stations; Gravelotte primary school and ZZ2. These were important factors to consider in the study as they form part of the climate around the study sites. The graphs were constructed to illustrate weather patterns around for the area. The data used to construct the graphs was 2022 as the station had most data available for that year. There are historic data available for various years which was used in the graphs previous to show weather patterns from 2012 to 2020 (Figure 3.1). However, the station stopped operating for some times and was recently reopened, still with difficulties in operating full time hence there are some gaps in some years/months when it was not operational. The climatic conditions were used in determining if the area has enough sunlight as the solar systems mainly operate on solar energy and for the design of the actual panels in terms of their surface size. Also in determining if the sites receive rainfall and around which seasons/months in the year as the farmers and villagers mostly rely on groundwater in dry seasons so there could be possible over abstraction.

For the Gravelotte station, the graphs show that the maximum temperature ranged from 37 to 41°C with a minimum temperature of 3.4° around June. The relative humidity around the sites showed a minimum of 5.78% and maximum of 100% and the rainfall received spiked around November with a maximum of 43.4 mm. The wind speed had a minimum of 0.22 m/s and a maximum 1.4 m/s, the solar radiation recorded showed a minimum of 1.8 $MJ/m^2/d$ and a maximum of 26.74 $MJ/m^2/d$. The station did not record fully for the month of April 2022 and it stopped working, this accounts for the gap in the data which can also be seen on the graphs.

For the second station, ZZ2, the graphs show that the maximum temperature ranged from 39.36 °C to 40.56 °C with a minimum temperature of 3.35° C around June. The relative humidity around the site showed a minimum of 6.22% and maximum of 97.3% and the rainfall received spiked around December with a maximum of 29.2 mm. The wind speed had a minimum of 0.22 m/s and a maximum 3.07 m/s, the solar radiation recorded a minimum of 1.9 $MJ/m^2/d$ and a maximum of 28.17 $MJ/m^2/d$. In both graphs the lowest temperatures are experienced around the month of June, in winter, while high temperatures are around December and it mostly rained around November.

3.1.2 Land Cover

According to the findings of Makhado et al. (2009), approximately 59.4% of the entire land area within the Greater Giyani Municipality was designated as cultivated areas, while woodland and bushland accounted for approximately 30% of the total land coverage. The geographical area occupied by the town of Giyani constituted 0.7% of the overall land area, whereas villages encompassed 5.4% of the total land area. The proportion of degraded areas was approximately 5.0%.

Land use/cover data are depicted on the map in Figure 3.3 for the area where the sites are situated. The data used to construct the map were obtained from South African National Land Cover (SANLC, 2020). The land use/cover is predominantly shrub land, forested land with Mopani trees, grassland and cultivated subsistence land. The main economic activities are agriculture (citrus, mango and tomatoes), tomato processing (secondary sector) and eco-tourism (tertiary sector) (DWA, 2014). Large part of the catchment consists of arable land with subsistence farming dominating over commercial farming. Communal grazing is also common. Grassland is often over-grazed due to over-stocking leading to soil erosion. The majority of the land is comprised of the former homeland, characterized by dispersed villages and subsistence farming practices. Additionally, there is significant reliance on ecosystem goods and services within this area.

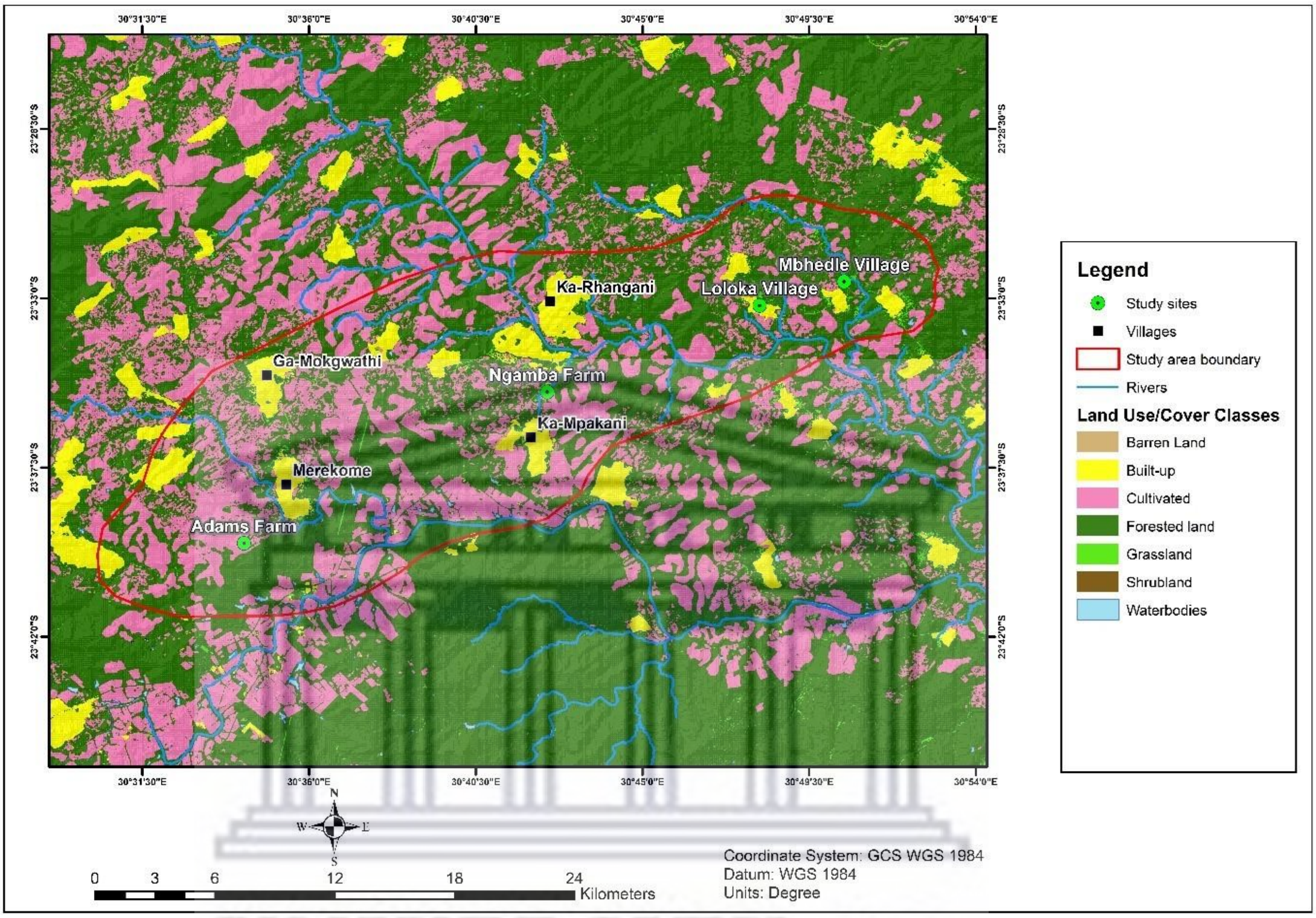


Figure 3. 3 Land use of the area where the study sites are situated

3.1.4 Geology

The geology surrounding the area where the study sites are located shows features of the Groot-Letaba Gneiss, the Letaba super group and the Gravelotte group. The area is at the interface between the granitic-greenstone of the Kaapvaal Craton and the metamorphic (predominantly gneiss rocks, but also schist) of the Southern Marginal zone of the Limpopo Mobile Belt (Holland, 2011). Figure 3.4 represents a map of the regional geology of the area where the sites are situated obtained from the South African Council for Geoscience (available at https://maps.geoscience.org.za/portal/apps/sites/#1).

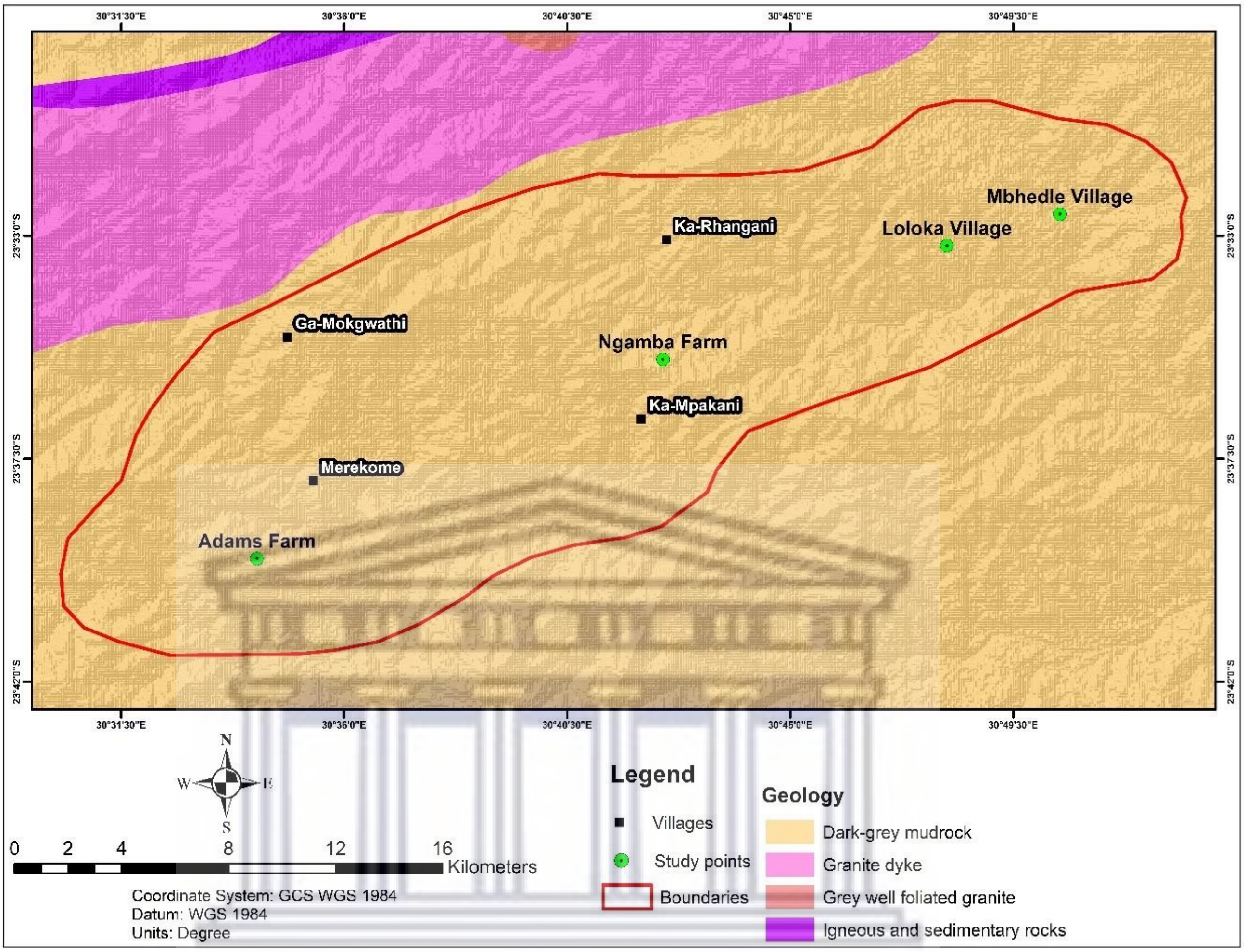


Figure 3. 4Regional geology of the area where study sites are located

3.1.4 Hydrogeology

This classification is based on the Groundwater Resource Units (GRU) framework, which considers factors such as topography, surface-groundwater interactions, and groundwater yield characteristics (DWA, 2014). A fraction of B81G is situated on the Escarpment, accounting for 11% of its total area. Additionally, a portion of B81G, amounting to 26%, is found in the Foothills and Valleys. Furthermore, B81H encompasses 5% of the Giyani-Gravelotte GRU. An extensive description of the geology and groundwater characteristics of these GRUs is available in DWA (2014).

The estimated groundwater use is 30-40% of groundwater recharge (DWA, 2014). Borehole yields are moderate to high, with 34% boreholes in B81G and 56% of boreholes in B81H yielding more than 2 L s^{-1}. Groundwater quality is good to marginal with an overall better quality in B81G compared to B81H. The groundwater contribution to base flow is negligible, and it occurs mainly as interflow. Detailed information on groundwater characteristics can be found in DWA (2014).

Based on the findings of DWA (2014), the utilization of groundwater in B81G is of moderate extent. It is suggested that the abstraction of groundwater can be augmented to reach the maximum potential during harvesting, without significantly affecting the base flow. According to estimates, the annual groundwater abstraction can potentially be raised from 5.06 Mm^3 to 6.78 Mm^3, resulting in a decrease of 0.05 Mm^3 in base flow. The utilization of groundwater in B81H is currently at a low level, but there exists the potential to enhance its usage up to the point of harvest capacity without significantly affecting the base flow. The volume of groundwater extraction can be enhanced from 2.62 million m^3 per year to 7.97 million m^3 per year, without any decrease in the natural flow of water from the aquifer. The siting and feasibility of additional groundwater production boreholes need to be confirmed.

Limited groundwater development may therefore be feasible in the Molototsi catchment, given groundwater is abstracted below harvest potential, groundwater yields and quality are reasonable, and groundwater contributes little to base flow. Based on the Resource Quality Objectives, the groundwater use in the Molototsi catchment can increase up to a sustainable level (harvest potential). The increase in groundwater use could provide the opportunity for limited expansion of water supply.

Geohydrological data for the area can be obtained from the National Integrated Water Information System (NIWIS) of the South African Department of Water and Sanitation (https://www.dws.gov.za/NIWIS2/, accessed on 1 June 2021) and from the Groundwater Resource Information Project (GRIP) database for Limpopo (http://griplimpopo.co.za/, accessed on 1 June 2021). Both groundwater levels and quality can be obtained from these databases. Most data are recent (last 10 years) with some gaps in time.

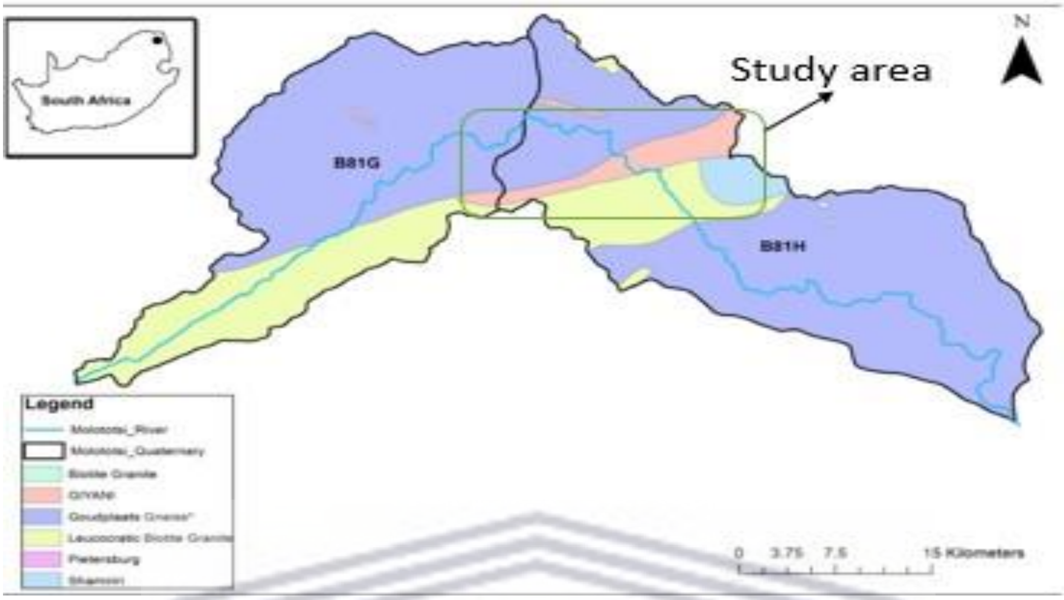


Figure 3. 5 Digital map of the geology of the Molototsi quaternary catchments (data obtained from the South African Council for Geoscience), and delineation of the quaternary catchments (Jovanovic et al., 2018).

3.1.5 Hydrology

Greater Giyani Municipality is located within the Luvuvhu and Letaba basin. The major rivers (Klein Letaba, Middle Letaba and Great Letaba rivers) all flow in an easterly direction. The main perennial river is the Great Letaba, fed by tributaries such as the Middle Letaba and Nsami. Other non-perennial tributaries of the Great Letaba are the Malatsi, Mbaula and Molototsi.

Minimum Annual Runoff (MAR) ranges from 400 mm in the eastern part to less than 20 mm in the western parts. It was found that there is a strong relationship between surface water runoff and rainfall, with regions experiencing high levels of rainfall in the Drakensberg and Soutpansberg making a substantial contribution to the overall runoff. Approximately 45% of the overall surface runoff is distributed between the Klein and Great Letaba Rivers, with the majority of this proportion being contributed by the Great Letaba River. Additionally, an additional 45% of the surface runoff is attributed to the Luvuvhu and Mutale Rivers (DWAF, 2003).

According to the Department of Water Affairs and Forestry (DWAF, 2004), the implementation of afforestation measures in the upper regions of the Great Letaba, Luvuvhu, and Klein Letaba Rivers has been found to cause significant decreases in the volume of water flowing through these rivers. The Luvuvhu and Great Letaba River catchments exhibit significant infestations of invasive alien vegetation. The impact of cultivation practices and over-grazing on surface runoff, sediment loads, and groundwater infiltration is noteworthy. Table 3.1 provides a summary of the natural minimum annual runoff (MAR) and the estimated ecological requirements for the ecological reserve component. The ecological reserve represents the minimum environmental flow that needs to be secured in order to sustain the natural ecosystem, according to the South African National Water Act (NWA; Act No. 36 of 1998).

Table 3. 1 Natural Mean Annual Runoff (MAR) and ecological reserve in the Luvuvhu and Letaba catchments (million $m^3 a^{-1}$) (DWAF, 2003).

Sub-area	**Natural MAR** ($Mm^3 a^{-1}$)	**Ecological reserve** ($Mm^3 a^{-1}$)
Luvuvhu/Mutale	520	105
Shingwedzi	90	14
Great Letaba	382	72
Klein Letaba	151	20
Lower Letaba	42	13
TOTAL	1185	224

The MAR and flow requirements for the Molototsi catchment are presented in Table 3.2. The river has a minimal base flow, being of torrential nature (mostly floods).

Table 3. 2 Mean Annual Runoff and flow requirements for the Molototsi river.

Quaternary catchment and biophysical node (DWA, 2013)	Natural Mean Annual Runoff nMAR ($10^6 m^3 a^{-1}$)	Low flow required (% of nMAR)	Total flow required (% of nMAR)
B81G at node 00164	16.72	0.4	6.6
B81H at node 00171	25.84	1.0	6.5

The water quality exhibits elevated levels of nutrients, salts, algal proliferation, and turbidity, primarily attributed to the GaKgapene wastewater treatment facility, human settlements, and agricultural practices. The catchments B81G and B81H (Figure 3.5) are classified as moderate priority Resource Units (RU), given their moderate ecological and socio-cultural significance. The upper reach B81G exhibits a relatively low level of water resource use importance, whereas the lower reach B81H demonstrates a comparatively high level (Jovanovic et al., 2018).

3.1.6 Study sites selection

A number of criteria have been considered for selection of sites for the feasibility study within Greater Giyani Municipality. The criteria set can be summarized as follows:

- Availability and reliability of a water source (groundwater borehole or shallow wells in sand river banks)
- Community need (water demand) – baseline of zero and at least 25 L per person d^{-1} for drinking water supply to households; crop water requirements for small farming
- Water use diversification opportunity
- Current infrastructure gaps
- System set-up logistical complexity/ease
- Economic activity potential e.g. agriculture, value-added products (level 2 and 3)
- Access to markets – geographic access (level 2 and 3)
- Tribal and traditional support
- Health and hygiene improvements (level 1)
- Cultural activity and economic potential (tourism level 2 and 3)

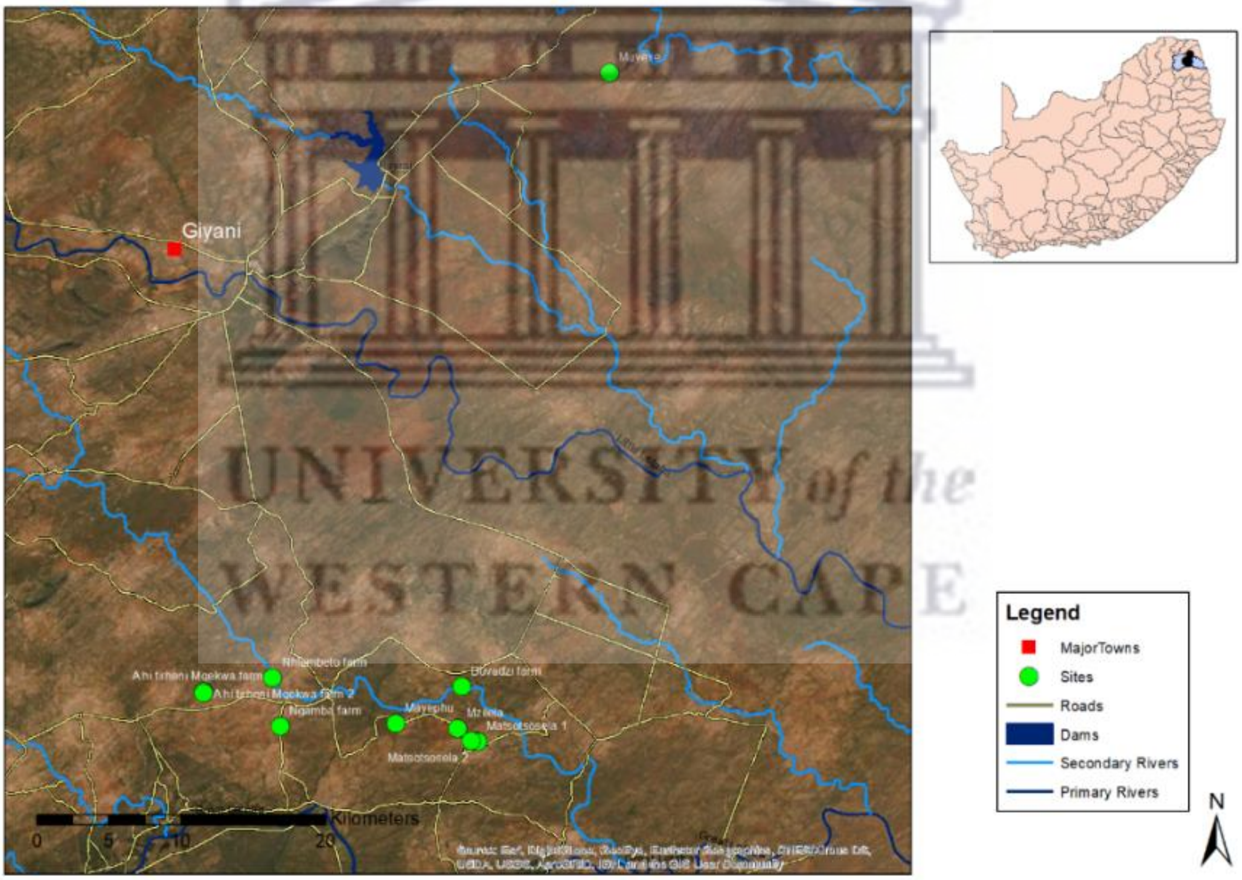
Levels 1, 2 and 3 signify the following:

- **Level 1:** Level 1 allows water access to the villages for basic domestic uses such as every-day activities.
- **Level 2:** In level 2, water is supplied to livestock and small irrigation.
- **Level 3:** Level 3 allows access to water for small farms, this allows the farm to develop and grow crops accordingly. Level 3 also uses a business component allowing the farm to supply various food stores.

Originally, nine pilot sites have been selected based on the criteria above and shown in the map in Figure 3.6(a); Water is available in these villages from groundwater boreholes or from shallow groundwater along the rivers/river banks, from an earth dam at Xihlakati, and from a water plant that needs an upgrade and booster pumps at Nwamarhanga. The water source is quite reliable given borehole yields and shallow groundwater yields from the river banks.

However, to test the scenarios for implementation of the solar-powered water pumps, two villages, and two farms were chosen as focus sites and these are shown in Figure 3.6 (b). The farms were chosen based on their sizes (large and small irrigated area). The second scenario was for two villages which were chosen based on their distance from the water source (whether its situated next to a water source or at a distance from a water source). The other sites were used for a broader project to which this study contributed to. The villages extend between the perennial Great Letaba and the non-perennial Molototsi River.

a)



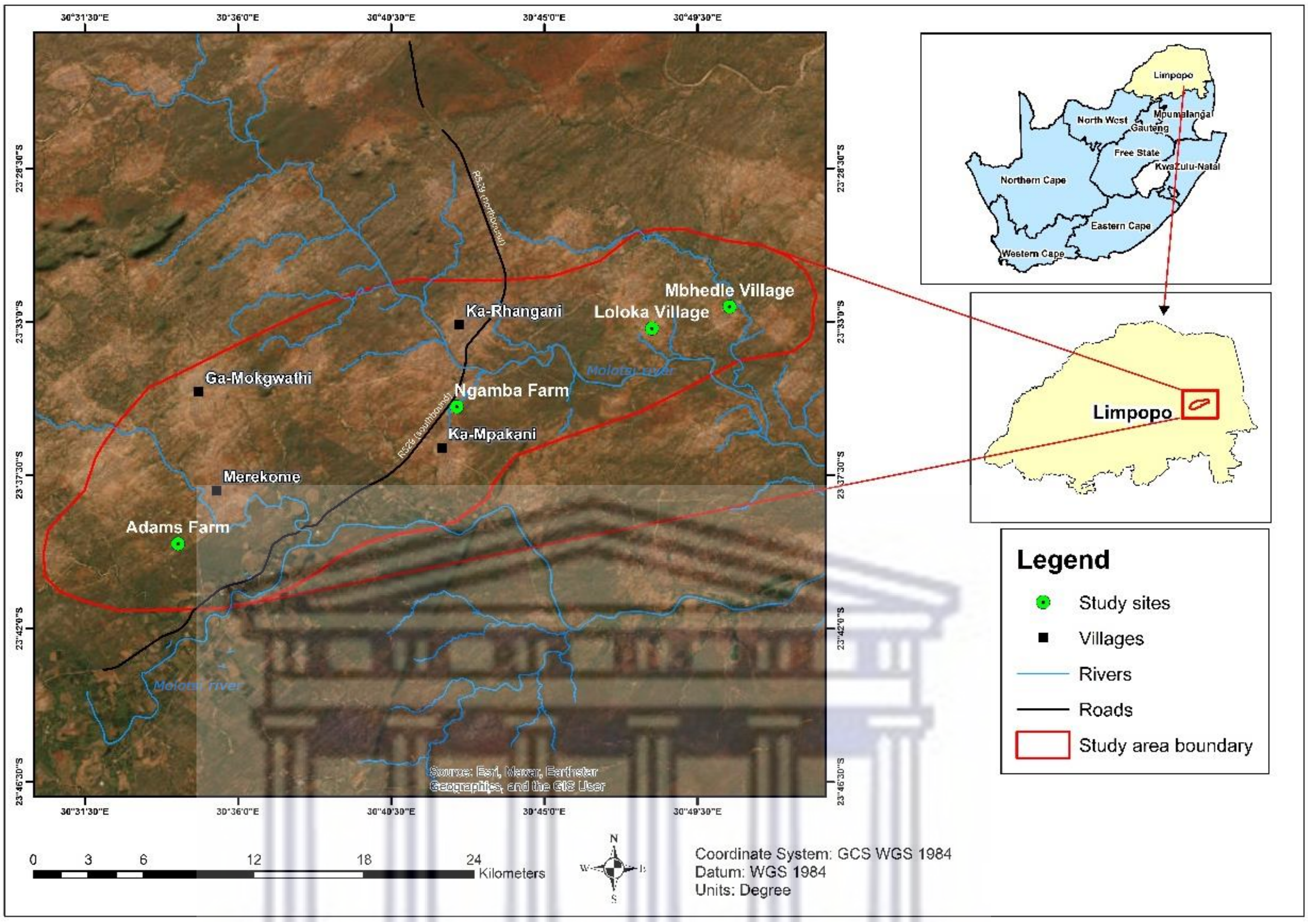


Figure 3. 6 (a)The nine pilot sites originally planned in the broader implementation project (b) The four focus study sites of the current study

CHAPTER 4: RESEARCH METHODOLOGY

4.1 INTRODUCTION

This chapter provides a comprehensive account of the methodologies and data utilized in the study. Additionally, it outlines the research design employed to effectively address the study's aims and objectives, along with the approaches employed for data collection. The main methodology follows the process recommended in the Solar Powered Irrigation System (SPIS) Toolbox (GIZ and FAO, 2021). The SPIS Toolbox was developed primarily for small-scale irrigation. The objective of the FAO and GIZ Solar Irrigation Systems Toolkit is to foster an inventive and enduring strategy to facilitate the advancement and implementation of environmentally friendly energy solutions. This, in turn, will enhance agricultural output and maximize the advantages of solar energy utilization for farmers and agro-entrepreneurs. The modules of this tool are used for assessing water needs, comparing financial viability, designing and maintaining a Solar Powered Irrigation System (SPIS), determining profitability for agricultural holdings, and calculating the payback period for an investment in an SPIS, with a focus on the key aspects of manufacturing quality. The specific tools and modules which were used from this tool box are explained below.

4.2 SPIS TOOLBOX MODULES USED:

The modules used in the current study were the Promote and Initiate, Marketing, Finance and Invest modules.

4.2.1 PROMOTE AND INITIATE MODULE:

This module offers crucial information pertaining to the promotion of Solar Powered Water Pumps (SPWPs) technology within a specific geographical region. The primary emphasis is placed on the examination of potential opportunities and risks, the identification of relevant stakeholders, and the development of promotional strategies and activities. The module encompasses two distinct tools, specifically the rapid assessment tool and the impact assessment tool. Both of these tools were employed for the purposes of this study.

4.2.1.1 Rapid assessment tool

The utilization of the rapid assessment tool facilitates the understanding of the market dynamics pertaining to SPWPs within a given country or project region. The tool offers a report template that assists the author in thoroughly assessing the pertinent aspects of the technology that necessitate assessment. In this study it was used to evaluate the pros and cons of using solar powered water pumps. The rapid assessment tool offers guidelines for compiling a 10-15 pages' report on the pros and cons of using solar water pumps in an area. The guidelines are organized into four primary categories, each encompassing subcategories that provide direction to the writer regarding the necessary information. The initial category, referred to as "background," entails a general depiction of the circumstances pertaining to irrigated agriculture, solar energy, and agricultural finance within the country or project region. Importantly, these descriptions are presented in an independent manner, without interdependence between the three subjects. The subsequent section pertains to the potential and prospects of solar water pumps. Within this section, an account is provided regarding the prevailing conditions in the country or project region, specifically in relation to the utilization of solar energy for irrigated agriculture. The paper also provides a description of current technologies, financing options, and promotional strategies. The third section focuses specifically on the promotion of solar water pumps within the country. In this section, the author is tasked with investigating whether there are any existing mechanisms implemented by the government, donors, and stakeholders in the country or region to promote the adoption of solar photovoltaic technology. The final section of the report entails a comprehensive SWOT analysis pertaining to the utilization of solar systems. Within this section, an examination is conducted to identify and evaluate the strengths, weaknesses, opportunities, and threats associated with the implementation of solar powered water pumps. This report information required (incorporated in the literature review) was obtained through online research of each heading. The report helped in understanding SPIS in a broader scale in terms of what already exists in terms of promoting these systems as well as the gaps that exist. A print screen of the rapid assessment tool report guidelines is provided in Figure 4.1

PROMOTE – SPIS Rapid Assessment Tool

This tool allows for compiling a brief report based on a rapid assessment of the pros and cons of SPIS in the country, and/or project region. The below Table of Contents serves as a guide towards this report, which should comprise 10-15 pages in total.

Chapter / Paragraph	Shortly describe
1. Background	*In this chapter the situation in the country/project region for irrigated agriculture, solar energy and agricultural finance is described generally and independent from each other* *Inserting a map picture of the region(s) described is useful to assist in reader orientation.*
1.1 Irrigated agriculture	- Important areas for irrigation, description of technologies present in the country - Relevance irrigated agriculture vs rain fed agriculture; economic - Relevant policies and strategies that promote irrigation
1.2 Solar energy	- Important areas for solar energy, description of technologies present in the country - Relevance solar energy vs other renewable energies and vs non-renewables; economics - Relevant policies and strategies that promote solar energy
1.3 Financial services for agriculture and energy	- Status quo on access to finance for agriculture, description of financial products available in the country - Status quo on access to finance for renewable (off-grid) energy, description of financial products available in the country - Relevant policies and strategies that promote the use of financial services in agriculture and/or solar energy
2. Potential and opportunities for SPIS	*In this chapter the situation in the country/project region is described in the cases where solar energy is used for irrigated agriculture. Existing technologies, financing and promotion mechanisms are described*
2.1 Experience with SPIS in the country	Experience in the country with the combination of solar energy for irrigation - Technological: Examples of SPIS systems (size, technology, since when, etc.?) - Availability: What technology options are available? What do they cost? - Is SPIS concentrated in a particular geographic Area of the country?
2.2 Market players	Short description of quality/quantity of manufacturers, main technology distributors, public/private service providers relevant in the country/project region

Chapter / Paragraph	Shortly describe
3. Promotion of SPIS in the country	
3.1 Promotion of SPIS in the country by the government	- Key Institutes promoting SPIS at national level/ project region - Subsidies, taxes and other incentives the government uses to promote
3.2 Promotion of SPIS in the country by donors and other stakeholders	Short listing and description of funding, skills or advisory services for SPIS offered by NGOs, training/education institutions or donor projects
4. SWOT analysis	
4.1 Strength	- characteristics of SPIS that give it an advantage over other alternatives in the target area
4.2 Weaknesses	- characteristics of SPIS that place it at a disadvantage relative to other alternatives in the target area
4.3 Opportunities	- elements in the environment that SPIS projects could exploit to its advantage
4.4 Threats	- elements in the environment that could cause trouble for a SPIS project
5. Conclusion	*Summarise your overall impression and make recommendations in terms of follow-up potential and requirements*
Annex: Picture gallery	*If a site visit was conducted, add pictures to the report to illustrate the current situation (pumping, storage and irrigation technology/infrastructure used, crops planted, crop fields, general natural environment, impression of the resident community, key community members consulted*

Figure 4. 1 Guidelines for rapid assessment tool report (GIZ SPIS toolbox)

4.2.1.2 Impact assessment tool

Conversely, the impact assessment tool provides a framework or a set of guidelines for evaluating the potential effects of solar powered water pumps. The provided guides pertain to the examination of socio-economic and environmental impacts, encompassing both positive and negative consequences. The impacts are categorized into seven distinct topics, which are outlined as follows:

1. Population change and Migration
2. Women's Role
3. Minority and Indigene group
4. Income and Amenity
5. Regional Effects in Country
6. User Involvement
7. Natural Resources and Environment

The impact assessment tool sheet is divided into input checklist which has questions for each of the above topics and allows for a Yes or No answer and graphs are generated in the output data sheet based on the selected answers. Then the input data tab allows for an entry of data that will provide an overview of those who stand to benefit (beneficiaries) from the project and based on the data entered corresponding graphs are generated. The tool is crucial since it helps to identify potential impacts and therefore allows for mitigation plans of the impacts. In this study the tool was used to identify the possible impacts of the proposed project; to identify who will be mostly impacted by the project. Information used for this toolbox was mainly through a discussion with one of the members of the community who is also employed at the Department of Agriculture at the Giyani office.

4.2.2 MARKETING MODULE:

The objective of this module is to conduct a market potential assessment for solar powered water pumps in a specific country or region. The module exclusively consists of a solitary tool, namely the market analysis tool.

4.2.2.1 Market analysis tool

The market analysis tool was used to conduct a market potential assessments for solar powered water pump systems in the study area (Limpopo, Giyani). For the market analysis tool, most of the information required by the tool was obtained through the links that are provided within the tool. The users are then redirected to a page where they can find answers for example, the land cover of the area was obtained from the link: ESA/CCI viewer (ucl.ac.be) accessed 25 August 2021. The link gives access to the global land cover map and the user is able to click on the location of the site on the map of the respective continent (Africa), then click on the where about in a country (South Africa) the area would be situated, then read the corresponding land cover. Other information used was obtained through reference to past project reports done in the area regarding some geophysical and general understanding of the area (Jovanovic et al.,2018). This tool takes into account fundamental geophysical parameters and offers guidelines and weighting factors for assessing parameters that contribute to the establishment of a conducive business environment for (SPWPs). The market analysis spreadsheet consists of four input sheets that have specific questions that need to be considered for determining if an area has a good/ poor potential for SPWPs. Appropriate parameters were chosen from drop-down lists and by making use of links to web sites provided within the tool to extract general information from global reports and databases. The relevance was selected based on given categories (inconsequential, slightly important, important, very important and critical). Below is a description of the aforementioned sheets:

Input Pre-Check: this tool has questions that allow for first checking the suitability for SPWPs before proceeding with the assessment. There are questions that serve as a guide for determining the suitability. The list focuses on the critical geophysical parameters that must be present for an area to be considered as suitable for SPWPs such as land cover and annual solar radiation.

Input Weight Setting: this tool gives a description of important geophysical parameters to be considered for the successful of SPWPs in the respective area based on its prevalent geophysical conditions; the tool also allows for weight adjusting of these parameters. The user is able to choose from a drop down menu whether the parameter can be ignored, inconsequential, slightly important, important, very important and lastly critical. Based on the weighting chosen a corresponding percentage is given and a score.

Input Geophysical Parameters: this tool defines the prevalent additional geophysical conditions of the study area such as the groundwater table and the topography of the area. The tool provides a set of questions to be answered and allocates a score based on the provided answers.

Input Business Conditions: this tool defines business relevant conditions of the solar photovoltaic technology in the targeted/study area. This is applied by answering the prescribed questions regarding awareness about the technology, government interventions, financing, land use rights and ownership, transportation & communication infrastructure and the significance of agriculture in the local economy. The aforementioned are important to consider for determining whether there is a business market potential for solar technology in the area or not.

4.2.3 FINANCE MODULE:

The finance module provides an overview of financial services that may be accessible to farmers seeking to implement solar-powered water pumps. Within this module, there exists a specific tool called the finance deployment tool.

4.2.3.1 Finance deployment tool

The finance deployment tool is intended for determining the optimal financial products that are currently accessible in the market for the implementation and adoption of a solar-powered water pump. The tool offers a sheet that was used to assess various financial services that are available for SPWPS that can be used by the local farmers'/community members. The sheet has a set of 19 questions that serve as a guide for selecting/determining which financial option will most suit the customer/user. There are nine different financial options provided by the sheet, the selection of a financial option is dependent on the responses from the set questions; as one selects an answer from 1-19, depending on the answer, some financial options will start to disappear, meaning the customer does not qualify for those options thus narrowing down the options to those that will best suit the individual and their prevailing circumstances.

Figure 4.2 shows a print screen of how the spreadsheet from the finance deployment tool looks like and the questions it entails. These questions were asked during interviews with the local community and farmers in the study area; these questions helped to determine the financial option available for them.

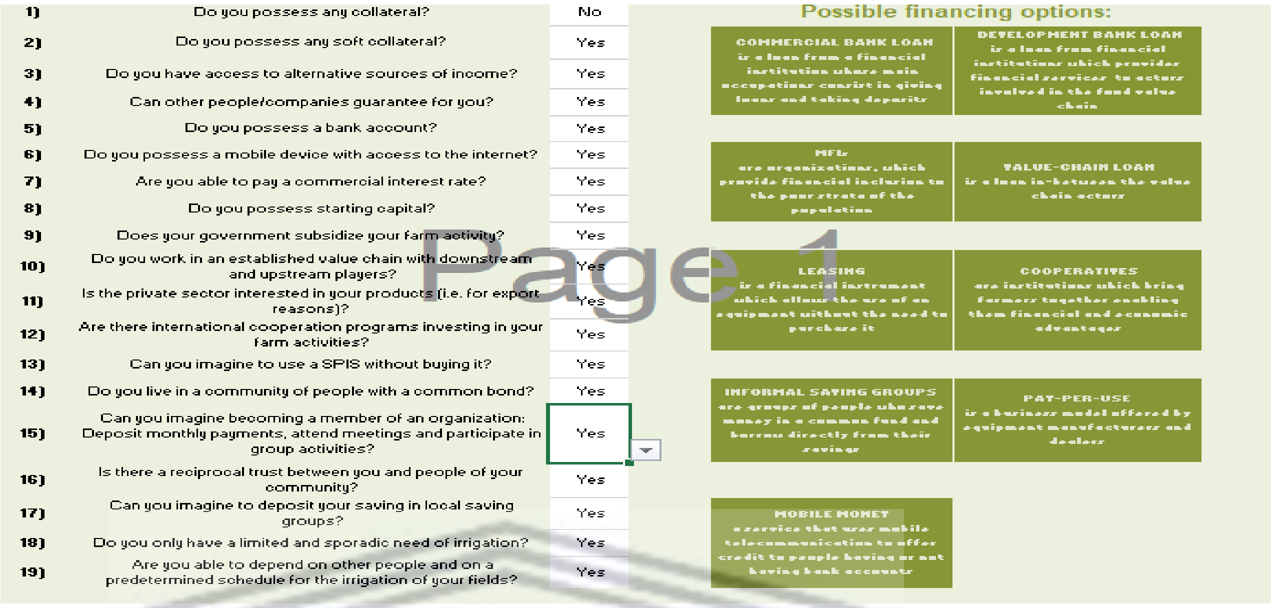


Figure 4. 2 Print screen for the finance deployment tool spreadsheet (GIZ and FAO, 2021)

4.2.4 INVEST MODULE:

The invest module offers guidance to financial service providers involved in the financing or prospective financing of (SPWPs). The module is designed to cater to stakeholders at the managerial level who are responsible for making decisions regarding credit policies. Additionally, it also targets loan officers who are tasked with evaluating individual loan applications for the purpose of financing SPIS. The module provides users with two distinct tools, namely the farm analysis tool and the payback tool. In this study, the invest payback tool was employed to assess the financial feasibility of a solar-powered water pumping system (SPWP) and to compare it with alternative pumping systems such as diesel and grid power. The Farm Analysis Tool was also used to calculate the Gross Farm Profit per Year that is an input in the Payback tool.

4.2.4.1 Payback tool

The investment payback tool facilitates a comparative evaluation of income generated by three distinct options for irrigation/domestic pumping: solar energy, electricity, and diesel. The essential data necessary for utilizing this tool encompasses the investment and operational expenditures associated with various pumping systems, projected revenue derived from agricultural production (as computed in the farm analysis tool), and fundamental economic factors such as the inflation rate. The tool comprises of two spreadsheets, the first being the input sheet which facilitates the input of anticipated income and expenditure for pumping technology. The subsequent sheet serves as the output spreadsheet, facilitating the analysis of automatically generated results derived from the input sheet. The output sheet of the payback tool summarizes the results of the financial feasibility in tabular and graphical format for Internal Rate of Return (IRR) and Net Present Value (NPV) over 25 years, accumulated cash flow after 25 years, system life cycle costs for 25 years, years of payback, yearly loan repayment (if applicable) and yearly CO_2 emissions of the three systems.

The financial viability of the three pumping options was evaluated by determining the initial costs, which include the system's components cost and the running cost. The running costs include costs incurred for operating the system as well as for the maintenance of the system per year, and also the replacement costs incurred. Other critical information which was used for the financial study includes the life span of each component as well as the subsidy percentage or amount. The life span duration is important because it helps with estimating replacement costs as well repairs; the subsidy amount if available will aid in determining how much of the capital cost is due from the farmer. Lastly the type of loan taken and its interest rate were considered under the financial costs of each system. The type of data or information required as input for the invest payback tool in order to estimate the costs of using a solar water pumping system for rural water abstraction as compared to the two alternatives (diesel and grid power) is discussed below.

For the purpose of this study, local manufacturers/suppliers of these systems were approached in order to get an estimate of the cost of each component as well as the running costs involved (Appendix B). All the costs collected were entered and served as input data in the toolbox; from these data the toolbox generated an output in the form of graphs. The cost assumptions for diesel also consist of capital costs, running costs; their costs differ from those of solar water pumps in that they require fuel for operation, therefore they incur fuel costs. The same costs apply for grid powered pumps with the addition of electricity connection costs since their power supply is from a national grid connection. Figure 4.3 shows print screens of the cost spreadsheet for solar water pumps and the two conventional alternatives (diesel and grid power).

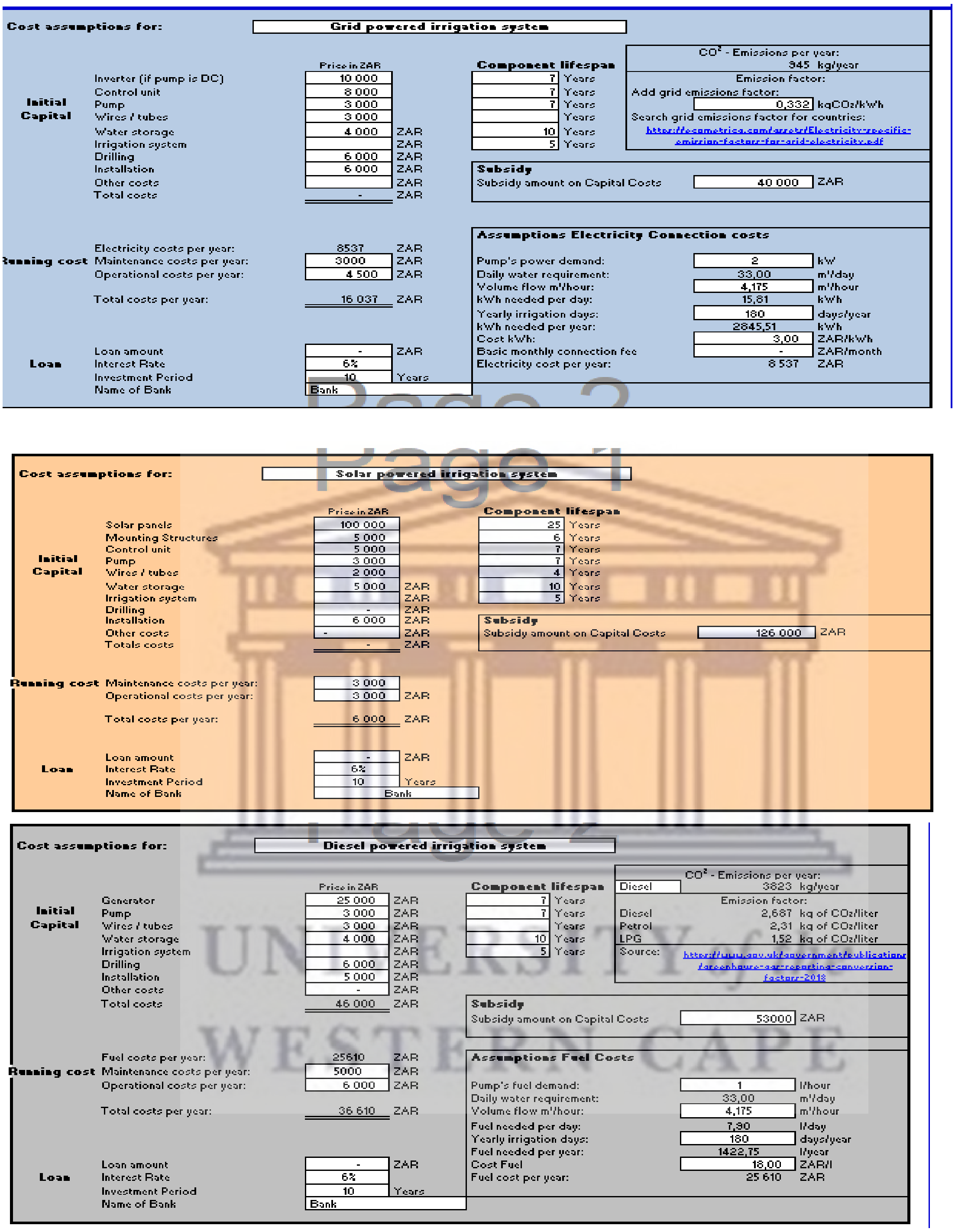


Figure 4. 3 Print screen of cost assumption sheet for solar, diesel and grid powered water pumps (GIZ and FAO, 2021)

4.2.4.2 Farm analysis tool

The farm analysis tool was employed to evaluate the farm's productivity and profitability by examining its average annual agricultural production. The aforementioned tool serves as a valuable resource for evaluating the effects of intended investments. It enables a solar water pump advisor to assist a farm enterprise in identifying superfluous expenses, determining the most advantageous agricultural activities, and accurately quantifying various farm inputs. The farm analysis tool comprises of different Excel spreadsheets which are used for assessing the farm productivity and profitability. The spreadsheets are as follows:

Quick check: It allows for a basic assessment to calculate a loss or profit; the sheet allows for the listing of the annual expenses and also the annual income. The loss/profit is then calculated by subtracting the expenses from the income; the software does these calculations automatically but an option for doing the calculations manually is also available.

General information: Once this is done the next sheet to fill in is the general information spreadsheet which requires basic information about the farm's identity such as its location/area.

Equipment and assets: The equipment and assets sheet is where all current assets and equipment owned by the farm are listed; using the information provided, the annual depreciation is automatically calculated.

Seasonal crops: this sheet allows the user to add current or projected sales of seasonal crops such as rice or vegetables, the by-products and the related variable expenditure.

Perennial crops: this sheet enables the user to add current or projected sales of perennial crops such as fruits, the by-products and the related variable expenditure.

Livestock: this sheet enables the user to add current or projected sales of livestock, poultry and by-products and the related variable expenditure.

Other income: this sheet calculates additional income besides the income from crop or livestock production such as the sale of water or renting out of equipment.

Financing: this sheet calculates the annual loan repayment based on the available credit information. This can be done automatically through the excel spreadsheet or done through the manual calculator provided.

Fixed and Variable costs: this sheet adds up all the general costs; these costs are classified into fixed or variable costs each calculated separately. The costs for seasonal crops, perennial crops and livestock are exported into the sheet as they had been obtained from the farmers (Appendix B).

Farm income statement: this sheet requires no entry but it provides the results/summary of the gross profitability of the farm enterprise. The amount calculated known as gross profitability is required and used in the payback tool when calculating the financial costs of the pumping systems.

The data collection for the study was done firstly through stakeholder engagements with community members to the relevant study sites whereby discussions about the water challenges experienced by the community were held. These challenges were noted and recorded for use as scenarios for the feasibility study. Secondly, sites visit took place where data related to the existing water infrastructure in the villages were collected. Online research was done to identify existing vendors within the solar energy industry that are manufacturers of solar water pumps; information from these vendors were used to collect data required to populate the SPIS payback tool. Various farmers in the villages and agricultural extension officers were approached about all the information (costs and benefits) required to populate the spreadsheets in the SPIS farm analysis tool (Appendix A).

4.3STAKEHOLDER ENGAGEMENT: COMMUNITY WORKSHOPS

A stakeholder engagement trip was undertaken to Giyani in Limpopo in September 2021. The purpose of the trip was to visit potential study sites for the feasibility assessment of using solar powered ground water pumps which are located within Greater Giyani Municipality. These study sites consist of different villages which were identified based on their problems with access to water as Giyani is a water scarce area. As a result, water supply in these villages is through the abstraction of water from boreholes/wells. The specific villages visited were chosen based on the severity of their water problems as discussed with the stakeholders involved and the leaders/ councillors of the villages.

The visitations were scheduled over a week and each day community workshops were scheduled for different villages. In each village, a presentation to the stakeholders involved in the project was done. The stakeholders involved were the Water Research Commission (WRC), Department of Forestry, Fisheries and Environment (DFFE), Department of Rural Development and Agriculture (DRDA) and the University of the Western Cape (UWC). The Water Research Commission is a state entity which falls under the Department of Water and Sanitation, and for this project its involvement was through the climate change section which deals with conducting research to find interventions for dealing with climate change. The representative from the Department of Forestry, Fisheries and Environment was from the climate change adaptation unit which deals with finding ways to build climate change resilient communities that are able to adapt to the changes brought by climate change such as water scarcity. Lastly there was a representative from the Department of Agriculture who has been working with the local farmers in Giyani, he also educated farmers on how they can get assistance from the department once their water problems have been resolved. He also specified the importance of farmers obtaining a Permission to Occupy (PTO) for the land they use for farming prior to them installing solar panels for the water pumps. Representatives from Tsogang Water and Sanitation (Tzaneen, South Africa) were the facilitators of the meetings held in the various villages, and arranged with community leaders of the villages to gather people for the representations.

Covid-19 protocols for face-to-face engagement gathering were followed according to regulations (wearing of masks, measuring body temperature, social distancing etc.). During these presentations, the above mentioned stakeholders were each given a slot to talk about their role in the project. The programme was arranged in a manner of presentations first, then followed by a questions and discussion session where the community members would be given a chance to ask or seek clarity from the panellists based on the contents of their presentation. Apart from asking questions, each village was given a chance to state/list their water challenges and indicate how they wish these challenges to be resolved. To conclude the meeting, the locals were also allowed to comment on their views about the proposed project of using solar powered water pumps; if they are in support of the project or not. The last activity of each day was for the panellists to be taken to view the existing boreholes that are currently being used for water supply in each of the villages.

There were nine sites (seven villages) that were visited which formed part of the broader project that this study falls under and from these villages only four were chosen as a reference for this study. A summary of the engagements at the seven villages is presented in Appendix A. From the seven villages, four sites were chosen as possible scenarios for the current feasibility study on implementing solar powered water pumps. The four scenarios included two villages (Loloka and Mbhedle village) and two farms located in Dzumeri (JDN trading and Ahitirheni Mqekwa Agricultural Primary Cooperative farm) and they are described in detail under the subheading scenarios for GIZ toolbox (section 4.4).

The site visits and engagement with stakeholders assisted in terms of understanding the material conditions which exist in these villages and how the implementation of solar powered pumps would be best suitable for which villages exactly, depending on how extreme the water challenges are in a village. The data collected also assisted in finding the suitable intervention(s) needed to better the water conditions of these villages by coming up with possible scenarios based on what is already available in the villages in terms of water infrastructure.

4.4 SCENARIOS FOR GIZ TOOLBOX

During the community workshops, data were collected to establish different scenarios for the socio-economic feasibility to test out the effectiveness of the interventions. The data specifically collected for the feasibility study and for use in the toolbox can be summarised as follows:

- Power supply currently in use
- Costs of the current power supply(s)
- Village/ farm conditions
- Water use/availability
- Water supply systems/ equipment available

The toolbox was applied to the following scenarios: small farm vs big farm and the relevant data were collected through face-to-face interviews with each farm owner. The farms were chosen based on their sizes (large and small irrigated area). The second scenario was for two villages which were chosen based on their distance from the water sources which were mainly boreholes (whether they are situated next to a water source or at a distance from a water source). The responses for the Finance Deployment and Farm Analysis tools were solely from the interviews with the farmers whereas the payback tool which compares the cost of solar power to that of diesel and electricity required direct information from the suppliers/manufactures of the systems. A supplier known as AF Solar installer (Reg no.: 30646 Maluleka street Mamelodi East) was approached for quotes with the relevant costs.

Some of the questions in the market analysis tool which were more specific to the town's (Giyani) demographics were obtained from the Limpopo Department of Agriculture and Rural Development. They also assisted with obtaining the required data for the impact assessment tool as they deal mostly with the farmers in the villages. The rapid assessment tool was populated through online research for articles that cover different topics on the pros and cons of using solar powered water pumps such as the potential and opportunities that exist in a country/region for these systems (more information is given in toolbox description). References for the articles used were included in the report for the rapid assessment tool which has been included in the literature review part of the thesis (chapter 2) under the heading titled Solar photovoltaic in South Africa as the information was better suited for that section.

The questions from the GIZ toolbox were used for evaluating the social acceptance for the proposed solar systems by the community as well as farmers so they mostly evaluated how knowledgeable the community members were of their current water supply systems. The purpose was to evaluate the existing water supply systems in terms of reliability, costs and availability and lastly questions based on solar water pumping systems to test the knowledge and understanding of villagers about these systems/technology. The four scenarios for feasibility assessment of SPWS were based on reality cases and they are described in section 4.4.1 and 4.4.2

4.4.1 Farms

4.4.1.1 JDN Trading (small farm)

The first scenario was a farm that was started in 2015 and it is located in the village known as Dzumeri in Limpopo. The farm is a family business owned by a local who is a former school principal and his family. The name of the farm is JDN Trading (-23.591533°,30.706566°); the farm land was attained through the Permission to Occupy license obtained from the traditional authority; this allows the farmer to use the land with the understanding that it does not belong to him. Besides the farmer principal, his wife and their son, the farm has six temporary workers that are paid R1500 per month. The farm grows various crops such as tomatoes, chillies, cabbage, which are sold at the market and to the locals. The cultivated portion of the farm covers about three hectares of land with tomatoes covering the most land. The farmer makes use of drip irrigation for all his crops and he irrigates in the evenings. Most of the boreholes within the farm are no longer functional, only two are operational and these do not pump enough water for crop irrigation; the little water pumped is stored into a storage tank (Jojo tank).

The farmer expressed that the farm does not make enough money to be able to pay workers, maintain the farm and keep buying fuel to power the water pump. The pipes which were used are old and leaking, which wastes the little water he is able to pump. The borehole which pumps the most water is situated at a far end corner within the farm, also at a distance from where the storage tank is situated. The farmer seeks a solution that will cut him costs on the money spent on fuel and to restore his irrigation system. A proposed solution to the farmer's challenges was to test out a scenario of how the installation of new pipes and a larger storage facility (in which both boreholes can pump water into) will help with saving water and to avoid pumping directly to the irrigated plots. The evaluation scenario included the following:

- Installation of new drip-irrigation systems

- Bigger storage tank
- Replacing diesel pump with a solar water pump

4.4.1.2 Aritirheni Mqekwa farm (big farm)

The second scenario is farm Aritirheni Mqekwa Agricultural Primary Cooperative owned by a local farmer situated in Dzumeri, Daniel Ravalela village (-23.57025°, 30.65841). The farm is quite big covering about 10 hectares of land with approximately 6.5 hectares of the land being used for seasonal crops such as tomatoes and cabbage. The other 3.5 ha is a mango orchard. The land is also under the Permission to Occupy license (PTO) since it is state-owned land. The farm has employed different people from the neighbouring villages to where the farm is situated. There are nine workers employed at the farm excluding the family members; of the nine employees, four of them are males and five are females. The workers are paid R1700 every month, working Monday to Saturday. The farm has been existing for some time and has many boreholes all around it that have been drilled, which are supplying the farm with water. The pumps are powered by electricity. The farmer complained about the monthly electricity bills being too high. The farmer was eager to find a cheaper alternative source to using electricity. The farm currently has boreholes that are powered through grid electricity. The proposed solution to this scenario was to switch the boreholes to be powered through solar energy. Given that everything else is to remain the same and just change the form of the power supply, the scenario tested how much solar power supply will decrease the monthly bills. This was tested out using the following:

- Installing/connecting the boreholes to solar powered water pumps
- Keeping the same pumping days/times
- Using the same pumping equipment

4.4.2 Villages

4.4.2.1 Mbhedle village

The Mbhedle village has six boreholes in total and one of them has dried up. The village only has one operational borehole which has no reticulation system in place, as a result the water pumped from the borehole cannot reach the village. This leaves the community members with no choice but to travel long distances to get water from the borehole. The groundwater pumped in the village is also used for livestock supply. The diesel engine used to power the pump also has to be transported each time water is being pumped for security reasons. The community members expressed that the water pumped is not enough for supplying the entire village therefore some members get water while others are left without water. This causes conflicts among the community members as they end up arguing about who should get the water. The conditions of the village were used to assess how will the use of a solar powered water pump with its own reticulation system impact the community in terms of water availability and the distance travelled to the water source as the solar water pump will have its own reticulation system. Having a proper reticulation system would mean water would reach each part of the village and reduce the need for travelling; this time would be used for other productive activities (e.g. subsistence farming) which would improve the lives of the community and resolve conflicts arising as a result of water shortages. This was tested as follows:

- Installation of booster pump
- Proper connection of reticulation system (in place, but not used)
- Connecting the pumps to solar panels

4.4.2.2 Loloka village

Loloka is a village with about 700 households. The village has four boreholes of which only one is working. Two boreholes of the four were never operational, the one that is operational was utilised by the community as a source of water, however water from this borehole does not reach the entire village; there are parts/areas within the village that do not receive water at all. As a result, people in these areas have resorted to buying water from those who have managed or are fortunate enough to have boreholes drilled privately in backyards. This has resulted in three groups of people within the same village, since there are those who receive water directly from the borehole, those with access to water through their private boreholes and those who are left with no access to water unless they have money to buy it. Even though the village is faced with all these water challenges, the community members alluded to the fact that groundwater availability was not an issue, the boreholes do have water available, it is just technical issues such as power supply and pipelines not connected properly that cause them not to be functional. The village is also close to the non-perennial Molototsi River which can also be used as an alternative source of water. The characteristics of the village (water equipment available, water demand) were used to evaluate how the abstraction of water from a nearby water source (about 5km) impacts the costs associated with pumping water using solar power. The water abstracted from the river (sand alluvium) can be alternated with the borehole water to prevent over pumping either by allowing enough recovery time for each source, or have someone monitor the water level to decide how to alternate. The scenario was evaluated by considering the following:

- Connect/ change boreholes power supply to solar energy
- Install additional pump that will pump water from the river to the village as an alternative
- Properly connect / install pipes for water transportation and reticulation system

4.5 WATER QUALITY

The quality of water is vital for the environment, as it has an effect on the health of ecosystems, aquatic life and the human population. Water quality has an influence on the whole ecosystem's health and balance including species biodiversity, crop irrigation, and drinking water supply. As part of the study, the quality of water in the study sites was tested; in every site samples of water from the existing boreholes were taken and labelled accordingly. The samples were taken in May and November 2022 and sent for analysis in the lab. The water was analysed for the following constituents:

- EC: Electrical Conductivity
- pH: Potential of Hydrogen
- TDS: Total Dissolved Solids
- Colour
- F: Fluoride
- Cl: Chloride
- SO_4: Sulfate
- PO_4: Phosphate
- NO_2: Nitrite
- Br: Bromide
- NO_3: Nitrate
- Na: Sodium
- NH_4: Ammonia
- K: Potassium
- Mg: Magnesium
- Ca: Calcium
- TOC: Total Organic Carbon
- Al: Aluminium
- Mn: Manganese
- Fe: Iron
- Cu: Copper
- Zn: Zink

4.6 ENVIRONMENTAL FEASIBILITY

This part of the study evaluated the environmental impacts of solar photovoltaics by using the OpenLCA software (Iswara et.al, 2020). The software is free and it was used in many parts of the world to do similar studies (Iswara et.al, 2020). The cradle to grave approach was followed, the assessment evaluated carbon emissions of solar photovoltaics from the extraction of raw materials used to manufacture the cells, during the manufacturing phase, transportation, their use and disposal. Over the last four decades, a variety of proposed and viable solar photovoltaic technologies have emerged, ranging from traditional single-crystal (s-Si) and multi-crystalline silicon (mSi) panels to second-generation panels such as amorphous silicon (a-Si), cadmium telluride (CdTe), and cadmium indium gallium selenium (CIGS). Even as late as 2014, conventional silicon technology (e.g. m-Si) dominated the photovoltaic industry, accounting for more than 90% of global yearly photovoltaic output. The most common material used in solar cells is crystalline silicon. Crystalline silicon cells have a life expectancy of over 25 years without degeneration, making them excellent for industrial solar power generation. They have the highest energy conversion efficiency of all the existing mass-produced panels, up to 22% (Wild-Scholten et al., 2004). It is on this basis that polycrystalline solar panel were chosen for the life cycle assessment.

4.6.1 LIFE CYCLE ANALYSIS

4.6.1.1 Scope and Goals

The goal of the analysis was to determine the environmental impact of solar photovoltaics by looking at their carbon emissions during their life cycle. The analysis was done for the purpose of making decisions regarding their impact on the environment; this referred to a unit of polycrystalline solar panel under South African conditions. The analysis was done with the OpenLCA software as the software is free and it can be accessed at any time; it also allows the user to interact with various databases in computing the stages involved in life cycle analysis (Iswara et al,2020, Pamu et al.,2022).

4.6.1.2 OPENLCA Description

OpenLCA is a software application that is both open source and freely available, designed specifically for the purpose of conducting sustainability and life cycle assessments. This software operates within the same league as commercially available life cycle assessment (LCA) software such as SimaPro, Gabi, and Umberto. Nevertheless, it possesses unique characteristics that set it apart. The aforementioned topics have been addressed in Chapter 2, specifically in Section 2.4.1, which pertains to the literature review of the software in question (Iswara et al., 2020). The software can be downloaded from website at https://nexus.openlca.org . The user needs to enter credentials such as name and surname, country, organisation.

There are two download options offered, the first one being a zip file in which one is able to use the software without installing and the second option is the installer version in which the user installs the software and is able to use it at any time of choice. The second option was chosen for the download in this case. Before installing the software, the user is required to select a preferred language which was English in this case. The installed software requires no internet connection for operation purposes. The version installed for use in this study was version 1.11.0 (windows 64 bit).

Once installed, on the welcome page of the software there are several options available to help the operator get started as well as for navigation of the software (Figure 4.4). On the top left side in the welcoming page, there are four tabs which are used during a life cycle impact analysis. These are as follows:

- Save option which allows the user to save all the work done on the software preventing any loss of work. The users can access any saved work and continue from where they left off.
- The second tab is the database, this allows the user to either create a new database to work on depending on their impact analysis; alternatively, a database can be imported into the software from the OpenLCA website. There are various databases available on the website; some are freely available and some require a downloading fee. The user chooses the database based on its description and suitability to their impact assessment. For this study's analysis, the ecoinvent_37_lcia_methods database was imported for use. The database provides a variety of impact analysis methods for assessing environmental impacts, making it the most widely utilized Life Cycle Assessment (LCA) database globally. It boasts a user base of approximately 4,500 individuals across over 40 countries. The database encompasses comprehensive international industrial life cycle inventory data pertaining to various sectors, including energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, and transport services. The transparency and consistency of the database are highly evident. The data sets are presented in the form of individual unit processes and combined system processes (https://ecoinvent.org/the-ecoinvent-database/ accessed 15 August 2022). The selected method for impact analysis was the Recipe Midpoint (H) method. According to Iswara et al. (2020), characterization factors at the midpoint level are situated along

the impact pathway, typically occurring after the point where the environmental mechanism becomes consistent for all environmental flows assigned to a specific impact category. The characterization of the midpoint exhibits a more robust correlation with environmental flows and a comparatively reduced level of uncertainty.

- The third tab is a tools tab which has additional tools for assisting the user with calculations performed in the software such as a formula interpreter which helps in interpreting formulae used in the software
- Lastly there is also a help tab in which the user may click to attain online assistance to manuals of different versions of the OpenLCA software and how they are navigated.

Figure 4. 4 Welcome/home page of the OpenLCA software

In performing the impact analysis, a new database was created to work on. In the database created there were three folders that were used for the analysis. The first folder was the flow in which the input data and output data for the raw materials were entered. These were chosen from a list in the database provided by the software. The database has lists of items/materials that a user can choose from depending on what they will be analysing e.g. for the study we had cadmium as raw material used in manufacturing phase of solar panels, this was chosen directly from the database provided. For the transportation phase oil and energy were the raw material inputs, in the usage stage ammonia was the raw material as it is used in the cleasning of the panels during their usage and lastly in the end of life stage the raw material for analysis was the energy used in recycling or discarding these panels. The flows work as a guide on how the analysis will be done. From these flows, a process named emissions was created in the software for analysis of the actual environmental impacts during the cradle to grave of the cells. A product system of the emission process was also created as the last stage in which the actual calculation of the impacts was done using the recipe midpoint method.

Once the method for calculation (Recipe midpoint method) was selected the software automatically generated results based on the selected method for calculation and the environmental impacts as each method has specific environmental categories. It traces impacts for e.g. in this study climate change was one of the impact categories analysed for trace, meaning the software analyses for impacts that are related to climate change. The results showing the impact analysis per category from the software are presented and discussed in the next chapter.

CHAPTER 5: RESULTS

In this Chapter, the results obtained from the SPIS toolbox using the scenarios discussed in chapter 4 are presented. This is followed by the results obtained for the life cycle assessment with the OpenLCA software.

5.1 IMPACT ASSESSMENT TOOL

For each question in the input checklist, the user is given the option of choosing whether impact occurs (Yes or No), the weighting of the impact (Low, Medium or High) and the magnitude of the impact (Positive impact very likely, Positive impact possible, Neutral, Negative impact possible or Negative impact very likely). The Input checklist sheet was filled with information based on the long-term research and experience gained in the study area, as well as based on feedback from stakeholder engagement during field visits. Sources of data and information were added to the 'comment' fields in the spreadsheet. Some fields in the input checklist were not investigated in the project and/or not relevant to the specific study sites, such as population migration, legal aspects of gender issues, cultural heritage issues, socio-political organization, sea water intrusion etc. In that case, the weighting of the impact was chosen to be low and the magnitude of the impact neutral to avoid bias in the calculation. Figure 5.1 resents the output graphs obtained from the Input checklist sheet by categories.

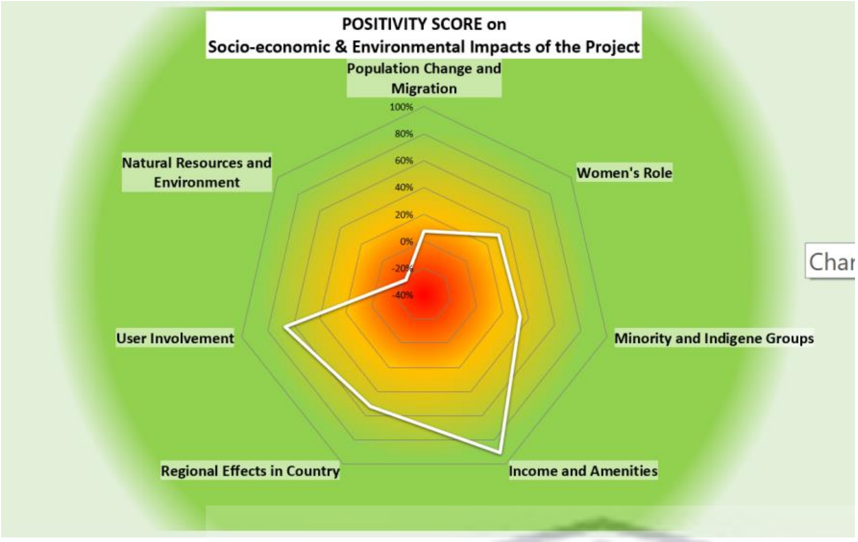


Figure 5. 1 Results from the impact analysis toolbox.

For the category on population change and migration (Figure 5.1), demographic changes in population due to migration were not investigated in this study. However, the establishment of water supply systems will undoubtable ensure improvements in employment and economic opportunities, which may contribute to a decrease in population migration from the study area. Concerning women's role (Figure 5.1), the role of women in relation to heritage, inheritance, marital status, land tenure and gender impacts on downstream users were not investigated. However, the project is expected to positively impact on gender equity both for women working in households, employed women and women farmers. The social status of women will improve through the provision of water supply and service, market opportunities, integration and equitable access to resources and institutions, time relief for other activities such as education, leisure and training. Similarly, the study will impact positively on the lifestyle, livelihood of minority and indigenous groups (Figure 5.1), although the impacts on socio-organizational, cultural and heritage issues were beyond the scope of investigation.

A major positive impact of the study is expected in terms of income and amenities (Figure 5.1). The study will contribute to economic changes, improving of livelihoods, well-being, equitable distribution of income and business opportunities with spin-offs in terms of diversification of production, technical services and markets, creation of agricultural services, employment opportunities and building of infrastructure. The study is not expected to impact substantially political changes and social harmony. The study is expected to impact regional effects in the country to a lesser extent (Figure 5.1) because it is still in its feasibility phase, however it can provide a good demonstration for upscaling. Institutional efficiencies at local and regional level have been considered through the involvement of key stakeholders that have a mandate to influence policies. Although the improvement of food supply is targeted to local communities, there is a realistic chance that produce be marketed outside the study area, in markets in Giyani, Limpopo and other Provinces. The study will also contribute to strengthening the agricultural products value chain (transport, marketing and processing), although this is not the primary target of the study. Particular attention was devoted to User involvement (Figure 5.1) through the engagement of key stakeholders from funding organizations, local government and affected communities. Public participation was ensured through workshops and field visits, during which credit and marketing opportunities were discussed. The views, needs, preferences and traditional practices of stakeholders were also discussed. Training of communities and relevant stakeholders in the use of the solar-powered water supply systems is also an important component of the study in order to ensure successful and sustainable implementation.

5.2 FARM ANALYSIS TOOL

The farm analysis tool was used to calculate the farm gross income, and the farm profit which is the profit made by the farm after the expenses have been deducted. The gross farm income includes all income/money the farm receives. The Farm analysis tool was used specifically to calculate Gross Farm Profit for use in the Payback tool, all costs and expenses are expressed per year. The Farm analysis tool was not applicable for the two scenarios for drinking water supply to villages.

JDN Trading farm results

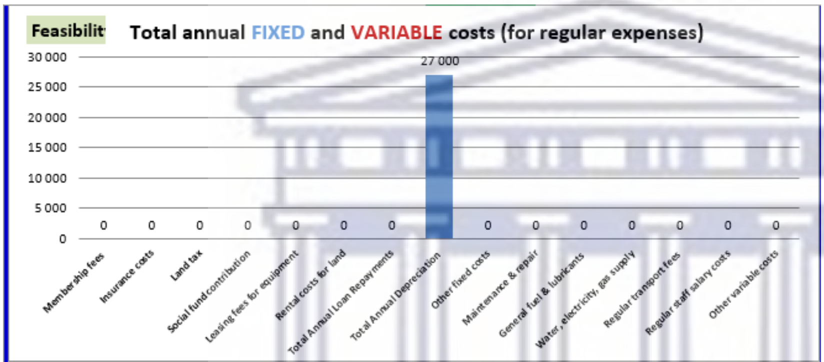
For the JDN trading farm the income came from sales of the seasonal crops, renting out of the equipment (truck hiring) and from the by-product of crop production as seen in Figure 5.2. The variable costs for crop and livestock production were calculated and these included costs such as buying seeds, fertilizers etc. The results indicated that the farm income was R319,600 per year with a total of expenses of R85,300. The average profit per hectare of seasonal crops was R168,333 as there were no perennial crops on the farm. For variable costs the results also showed that, for labour, the cost was quite high followed by infrastructure, then irrigation/water supply and traction/ mechanization respectively. The farm used in the scenario (JDN Trading) is only crop based, it did not have any livestock so there was no average profit per head of livestock. The farm's total gross profit at the end was calculated as R234,300 per year as shown in Figure 5.2. This amount is required in the payback tool under basic assumptions.

INVEST – Farm Analysis Tool

8 FARM INCOME STATEMENT

Farm code: Feasibility farm 1

+	Gross value of seasonal crop production	300 000	ZAR	+	94%
+	Gross value of seasonal crop by-product production	10 000	ZAR	+	3%
+	Gross value of perennial crop production	0	ZAR	+	0%
+	Gross value of perennial crop by-product production	0	ZAR	+	0%
+	Gross value of livestock production:	0	ZAR	+	0%
+	Gross value of livestock by-product production:	0	ZAR	+	0%
+	Gross value of other income:	9 600	ZAR	+	3%
-	Anticipated losses of total sales (reduction factor)		%		
=	**GROSS FARM INCOME**	**319 600**	**ZAR**	=	100%
-	Total fixed costs	0	ZAR	+	0%
-	Total general variable costs (for regular expenses)	27 000	ZAR	+	32%
-	Total specific variable costs for crop and livestock	58 300	ZAR	+	68%
=	**TOTAL COST**	**85 300**	**ZAR**	=	**100%**



=	**GROSS FARM PROFIT**	For period 2021 to 2022	234 300,00	ZAR
		Farm Profit Margin	73%	
		average profit per ha of seasonal crops:	168 333	ZAR per ha
		average profit per ha of perennial crops:	no crops	ZAR per ha
		average profit per head of livestock:	no livestock	ZAR per head
		total crop area under cultivation:	1,5	ha

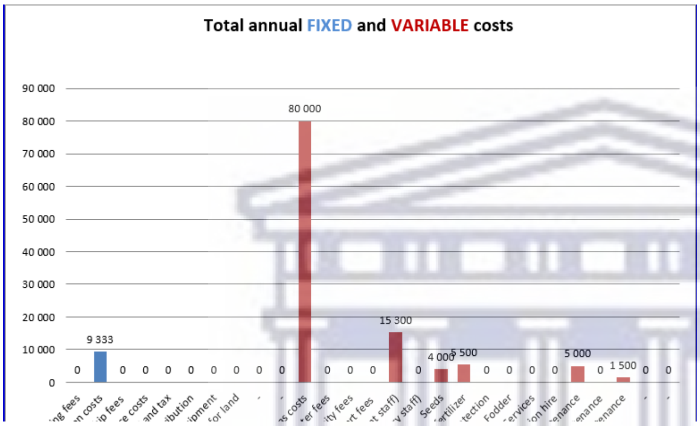
Figure 5. 2 Results from the farm analysis tool for JDN farm

Farm 2 Aritirheni Mqekwa results

The results for the farm analysis for the second farm (Aritirheni Mqekwa) are discussed below.

The farm's income comprised mostly of the sales of seasonal crops which amounted to R325,000, the other income was from hiring out of the farmer's tractor to the community or other farmers which was R3,150. The farm's gross income was R328,150 which was a total of the two incomes received. The costs/expenses of the farm were split into two categories: fixed and variable costs. The fixed costs for the farm were R9,333 and the variable costs were R111,300 giving a total of R120 633 for expenses. The gross farm profit (income-expenses) was calculated as R207,517. The graphs in figure 5.3 show how the fixed and variable costs were spread out.

The R9,333 for fixed costs was from depreciation costs of the equipment/assets owned by the farmer e.g. truck, tractor, plough etc. The variable costs included fuel and gas costs which were the highest with a total cost of R80,000 as seen on the graph. Following to that was the cost for paying workers on the farm (salaries) which had a total of R15,300 for the months they worked. The other variable costs were for buying seeds for which a total of R4,000 was spent for the seasonal crops planted. There was also cost incurred for buying fertilizer and manure for the crops which were R5,500 and lastly were the costs for repairs and maintenance of machinery and the irrigation systems which costed R5,000 and R1,500 respectively.



INVEST – Farm Analysis Tool

8 FARM INCOME STATEMENT

Farm code: Feasibility Farm 1

+	Gross value of seasonal crop production	325 000	ZAR	+	99%
+	Gross value of seasonal crop by-product production	0	ZAR	+	0%
+	Gross value of perennial crop production	0	ZAR	+	0%
+	Gross value of perennial crop by-product production	0	ZAR	+	0%
+	Gross value of livestock production:	0	ZAR	+	0%
+	Gross value of livestock by-product production:	0	ZAR	+	0%
+	Gross value of other income:	3 150	ZAR	+	1%
-	Anticipated losses of total sales (reduction factor)		%		
=	**GROSS FARM INCOME**	**328 150**	**ZAR**	=	100%
-	Total fixed costs	9 333	ZAR	+	8%
-	Total variable costs	111 300	ZAR	+	92%
=	**TOTAL COST**	**120 633**	**ZAR**	=	**100%**

=	**GROSS FARM PROFIT for period 2021 to 2022**	**207 516,67**	***ZAR***
	Farm Profit Margin	**63%**	
	average profit per ha of seasonal crops:	**50 000**	*ZAR per ha*
	average profit per ha of perennial crops:	**no crops**	*ZAR per ha*
	average profit per head of livestock:	**no livestock**	*ZAR per head*
	total crop area under cultivation:	**6,50**	*ha*

Figure 5. 3 Results obtained from the farm analysis tool for the Aritirheni Mqekwa farm scenario

5.3 PAYBACK TOOL

The payback tool of the SPIS Toolbox was used for analysis of the scenarios made for the small farm (JDN Trading) and the big farm (Aritirheni Mqekwa Farm) as well as the two villages (Loloka and Mbhedle). The results are presented below.

JDN Trading farm (smaller farm):

The tool estimated the payback time for the solar powered, diesel and grid powered pump. For all three systems, initial capital cost and operation/ running cost were estimated from the information provided by the suppliers. The output results derived from the inputs were in graphs and tabular form as shown in Figure 5.4.

The internal rate of return for 25 years was calculated to be 29% for the solar powered systems and 61% for grid powered systems. For the diesel system the internal rate of returns was not feasible, meaning the value was below 0.

For the net present value, the diesel system had a negative value which also indicated that the investment was not financially feasible. For both the grid and the solar system the values were positive meaning that the investment is financially feasible. The accumulated cash flow after 25 years for solar systems was calculated to be R4,699,727, R300,542 for grid powered systems and R-1,048,650 for diesel. From these results, it was evident that the solar systems yield a higher accumulated cash flow with diesel resulting in a negative accumulated cash flow over 25 years.

The life cycle cost of the systems was computed for a duration of 25 years. Among the three systems evaluated, the solar system exhibited the most economical value, amounting to R807,304. Following this, the grid system displayed a higher cost of R1,132,641, while the diesel system demonstrated the highest cost of R2,561,834. The findings demonstrated that solar systems exhibited a lower life cycle cost over a 25-year timeframe in comparison to both diesel and grid power. Consequently, solar systems emerge as a more cost-effective alternative among the three options due to their reduced operational and running expenses.

INVEST – Payback Tool

This INPUT sheet requires entry of values, which then serve the results displayed in the next OUTPUT sheet.

Basic assumptions

Currency used for calculation:	ZAR	use any currency
Inflation	4,5%	the national percentage rate for the devaluation of money per year (provided by national statistics)
Discount rate	4,0%	the annual rate used to determine the present value of future cash flows (Tip: simplified discount rate is often equal to **interest rate earned** from bank savings or treasury bonds)
Annual profit margin increase	3%	the rate at which the farmer will increase prices every year (calculated as per own records)
Annual fuel price increase	9%	the rate at which the fuel (Diesel, petrol or LPG) will increase every year (as provided by national regulator or from national energy statistics)
Annual electricity price increase	9%	the rate at which the grid electricity prices will increase every year (provided by national electricity regulator or utility)
Water levy (surcharge for water utilisation rig	–	**ZAR per m^3** the water price per m^3 as determined by government, local authority for utilising shared water resources with own pumping systems
Total maximum water pumped per day	29	**m^3 per day** as calculated in SAFEGUARD WATER-Water Requirement Tool or provided by pump supplier
Income: Gross Farm Profit per year	207 517	**ZAR per ye:** as calculated in INVEST-Farm Analysis Tool or from own records
Proportion of Profit to invest	20%	% of profit made available for investment into water pumping system

INVEST – Payback Tool

This OUTPUT sheet summarizes the results as per the entries in the afore completed INPUT sheet.

Click to remove from /add to analysis:

- Capital Investment
- Solar powered irrigation system costs
- Grid powered irrigation system costs
- Diesel powered irrigation system costs

Basic assumptions

Total water need per day	29 m^3 per day	
Total income per year	207.517 ZAR	(in Year 1)
Total investment amount per year	#VALUE!	(in Year 1)
Inflation	4%	
Discount rate	4%	
Annual profit margin increase	3%	
Annual fuel price increase	9%	

Note:

If "not feasible" is displayed for the Internal Rate of Return (IRR) then the IRR value is below 0%.

If a negative (-) Net Present Value (NPV) is displayed then the investment is not feasible.

If "no payback" is displayed for Years for Payback then system capital and/or operating expenses exceed income within 25 years

Analysis for Solar powered irrigation system

Internal Rate of Return (IRR) over 25 Y	29%
Net Present Value (NPV) over 25 years	4699.727 ZAR
Accumulated Cash Flow after Year 25	705.879 ZAR
System Life Cycle Costs (25 years)	807.304 ZAR
Years for Payback	4
Lending Bank:	Bank
Yearly Loan Repayment:	.0 ZAR

Analysis for Grid powered irrigation system

Internal Rate of Return (IRR)	61%
Net Present Value (NPV)	2993.203 ZAR
Accumulated Cash Flow after Year 2	380.542 ZAR
System Life Cycle Costs (25 years)	1132.641 ZAR
Years for Payback	2
Lending Bank:	Bank
Yearly Loan Repayment:	.0 ZAR
CO^2 Emmissions per year:	830 kg/year

Analysis for Diesel powered irrigation system

Internal Rate of Return (IRR)	not feasible
Net Present Value (NPV)	-3507.003 ZAR
Accumulated Cash Flow after Year	-1048.650 ZAR
System Life Cycle Costs (25years)	2561.834 ZAR
Years for Payback	no payback
Lending Bank:	Bank
Yearly Loan Repayment:	.0 ZAR
CO^2 Emmissions per year:	3 360 kg/year

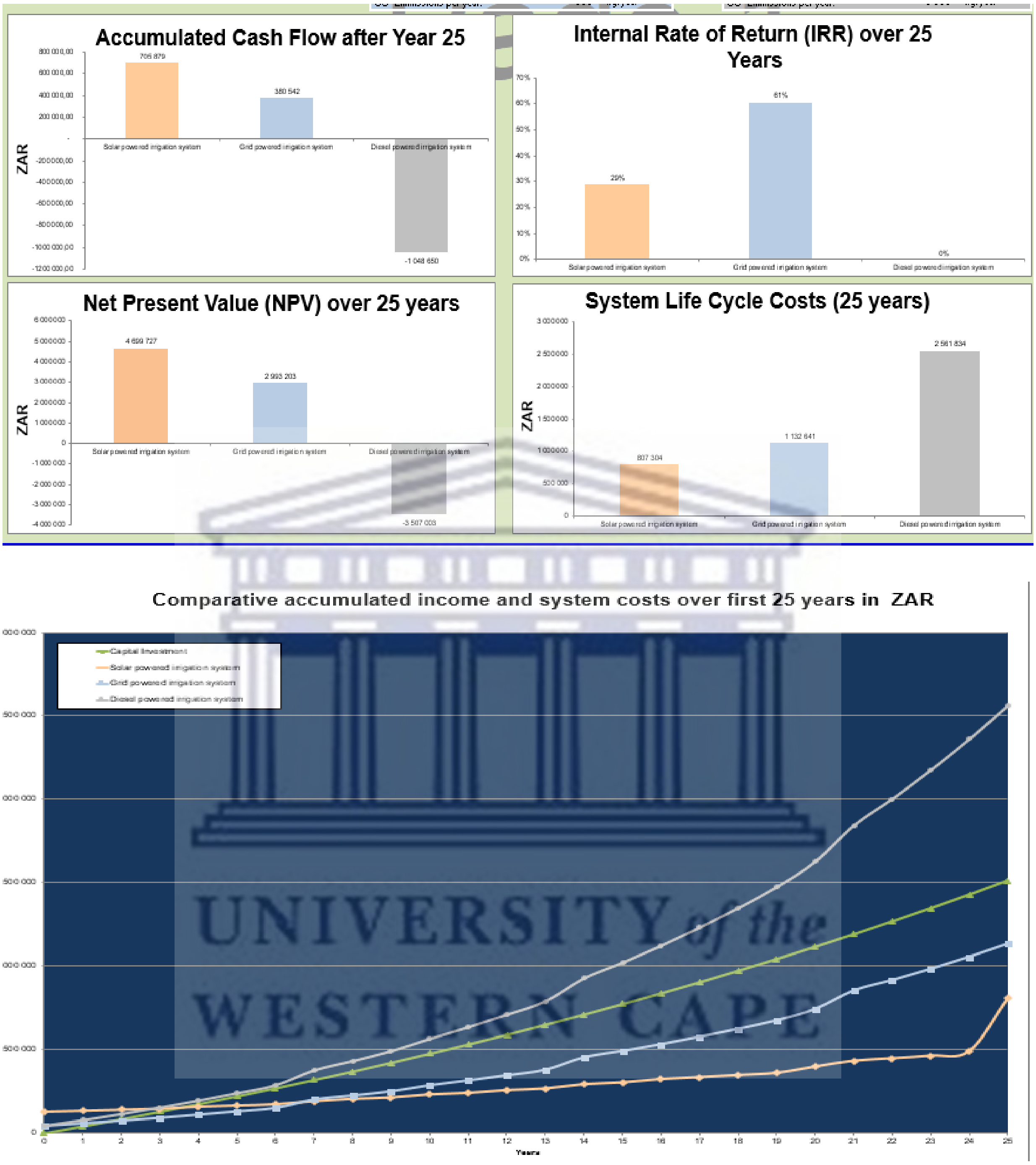


Figure 5. 4 Estimated costs for JDN Trading farm obtained from Payback tool

Aritirheni Mqekwa farm results

The second farm scenario was also evaluated with the same toolbox tools.

Some of the basic assumption values required by the Payback tool remained the same as these values are nationally shared such the inflation rate, fuel price increase percentage. As explained above the inflation rate was 4%, annual fuel price increased also at 9% and the discount rate was 4%.

The findings of the analysis conducted on solar powered irrigation systems are as follows. The 25-year internal rate of return was calculated to be 34%, accompanied by a net present value of R 5,856,852. The value of the accumulated cash flow after a period of 25 years was R901,177. The total life cycle costs of the systems over a period of 25 years amounted to R807,304, while the payback period for the initial investment was 4 years. The analysis results for grid powered systems showed an internal rate of 54% which was higher compared to that of solar systems. However, the net present value for grid systems was R3,224,085 which was lower compared to that of solar systems. Both these systems (solar and grid power) showed a positive present value which meant that investment in these systems was feasible. The accumulated cash flow after 25 years for grid systems was R410,764, with a system life cycle cost of R1,297,717 and a payback period of 2 years.

For diesel-powered irrigation systems, the results showed some variation for the internal rate of return as compared to the other two alternatives as the value was below 0 which means the option was not feasible. The system showed a negative Net Present Value of R-4,622,494 which meant investment in these systems was not feasible for the farmer unlike solar and grid systems which had positive values. The accumulated cash flow after 25 years also had a negative value of R-1,275,545. Since investment in these systems was not feasible there was also no payback period. The Figure 5.5 below represent the results discussed in a graphical and tabular form. The diesel system had no payback period, this was due to the systems capital and/or operating expenses exceeding the income within 25 years. There were no emissions for CO_2 for the solar system, only for the diesel and grid power. For diesel, the CO_2 emission was 3,823 kg/year and 945 kg/year for the grid system.

INVEST – Payback Tool

This INPUT sheet requires entry of values, which then serve the results displayed in the next OUTPUT sheet.

Basic assumptions

Currency used for calculation:	ZAR		use any currency
Inflation	4,5%		the national percentage rate for the devaluation of money per year (provided by national statistics)
Discount rate	4,0%		the annual rate used to determine the present value of future cash flows (Tip: simplified discount rate is often equal to **interest rate earned** from bank savings or treasury bonds)
Annual profit margin increase	3%		the rate at which the farmer will increase prices every year (calculated as per own records)
Annual fuel price increase	9%		the rate at which the fuel (Diesel, petrol or LPG) will increase every year (as provided by national regulator or from national energy statistics)
Annual electricity price increase	9%		the rate at which the grid electricity prices will increase every year (provided by national electricity regulator or utility)
Water levy (surcharge for water utilisation rig	-	ZAR per m³	the water price per m³ as determined by government, local authority for utilising shared water resources with own pumping systems
Total maximum water pumped per day	33	m³ per day	as calculated in SAFEGUARD WATER-Water Requirement Tool or provided by pump supplier
Income: Gross Farm Profit per year	234 300	ZAR per ye:	as calculated in INVEST-Farm Analysis Tool or from own records
Proportion of Profit to invest	20%		% of profit made available for investment into water pumping system


INVEST – Payback Tool
This OUTPUT sheet summarizes the results as per the entries in the afore completed INPUT sheet.
Click to remove from /add to analysis:
Capital Investment
Solar powered irrigation system costs
Grid powered irrigation system costs
Diesel powered irrigation system costs
Basic assumptions
Total water need per day 33 m³ per day
Total income per year 234.300 ZAR (in Year 1)
Total investment amount per year #VALUE! (in Year 1)
Inflation 4%
Discount rate 4%
Annual profit margin increase 3%
Annual fuel price increase 9%
Note:
If "not feasible" is displayed for the Internal Rate of Return (IRR) then the IRR value is below 0%.
If a negative (-) Net Present Value (NPV) is displayed then the investment is not feasible.
If "no payback" is displayed for Years for Payback then system capital and/or operating expenses exceed income within 25 years
Analysis for Solar powered irrigation system
Internal Rate of Return (IRR) over 25 Y 34%
Net Present Value (NPV) over 25 years 5856.852 ZAR
Accumulated Cash Flow after Year 25 901.177 ZAR
System Life Cycle Costs (25 years) 807.304 ZAR
Years for Payback 4
Lending Bank: Bank
Yearly Loan Repayment: .0 ZAR
Analysis for Grid powered irrigation system
Internal Rate of Return (IRR) 54%
Net Present Value (NPV) 3224.085 ZAR
Accumulated Cash Flow after Year 2 410.764 ZAR
System Life Cycle Costs (25 years) 1297.717 ZAR
Years for Payback 2
Lending Bank: Bank
Yearly Loan Repayment: .0 ZAR
CO² Emmissions per year: 945 kg/year
Analysis for Diesel powered irrigation system
Internal Rate of Return (IRR) not feasible
Net Present Value (NPV) -4622.494 ZAR
Accumulated Cash Flow after Year -1275.545 ZAR
System Life Cycle Costs (25years) 2984.027 ZAR
Years for Payback no payback
Lending Bank: Bank
Yearly Loan Repayment: .0 ZAR
CO² Emmissions per year: 3 823 kg/year
Accumulated Cash Flow after Year 25
ZAR
901 177
410 764
-1 275 545
Solar powered irrigation system
Grid powered irrigation system
Diesel powered irrigation system
Internal Rate of Return (IRR) over 25 Years
34%
54%
0%
Net Present Value (NPV) over 25 years
5 856 852
3 224 085
-4 622 494
System Life Cycle Costs (25 years)
807 304
1 297 717
2 984 027

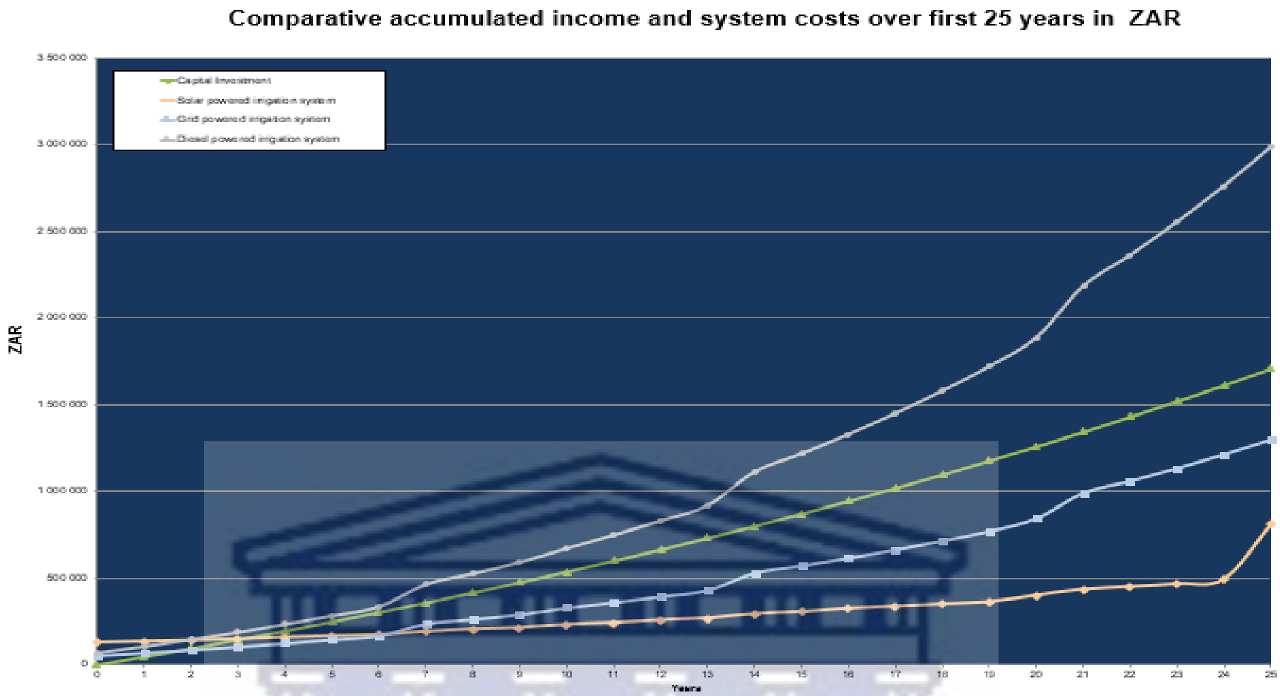


Figure 5. 5 Estimated costs for JDN Trading farm obtained from Payback tool

The same basic assumptions were kept constant for the villages such as the inflation rate, fuel percentage increase and discount rate. The water pumped as per the minimum water requirements (25 litres/person/day) was multiplied by the population size and the income (estimated values based on the village size) were the values that changed.

The results for the villages were as follows.

Loloka Village results

Loloka's analysis of the solar system yielded a noteworthy Internal Rate of Return (IRR) of 25% (figure 5.6). Additionally, the Net Present Value (NPV) was calculated to be R3,744,800, while the Accumulated Cash Flow (ACF) amounted to R538,311 over a period of 25 years. The total life cycle cost of the system over a period of 25 years amounted to R 744,223, accompanied by a payback period of 4 years. The grid system exhibited an Internal Rate of Return (IRR) of 46% and a Net Present Value (NPV) of R 1,519,743, which was comparatively lower than that of the solar system. The Accumulated Cash Flow after a period of 25 years amounted to R106,202, indicating a lower level of cash accumulation for these systems in comparison to solar systems over the same time frame. This could be accounted for by the operational and running costs that grid systems have which are higher than solar systems.

The system life cost was R1,206,331 with a payback period of 3 years. The diesel system had no payback period. This was due to the systems capital and or operating expenses exceeding the income within 25 years and it showed a negative value for Net Present Value meaning the investment was not feasible. There were no emissions for CO_2 for the solar system, only for the diesel and grid power. For diesel, the CO_2 emission was 3,823 kg/year and 945 kg/year for the grid system.

INVEST – Payback Tool

This INPUT sheet requires entry of values, which then serve the results displayed in the next OUTPUT sheet.

Basic assumptions

Currency used for calculation:	ZAR		use any currency
Inflation	4,5%		the national percentage rate for the devaluation of money per year (provided by national statistics)
Discount rate	4,0%		the annual rate used to determine the present value of future cash flows (Tip: simplified discount rate is often equal to **interest rate earned** from bank savings or treasury bonds)
Annual profit margin increase	3%		the rate at which the farmer will increase prices every year (calculated as per own records)
Annual fuel price increase	9%		the rate at which the fuel (Diesel, petrol or LPG) will increase every year (as provided by national regulator or from national energy statistics)
Annual electricity price increase	9%		the rate at which the grid electricity prices will increase every year (provided by national electricity regulator or utility)
Water levy (surcharge for water utilisation rig	-	**ZAR per m³**	the water price per m³ as determined by government, local authority for utilising shared water resources with own pumping systems
Total maximum water pumped per day	33	**m³ per day**	as calculated in SAFEGUARD WATER-Water Requirement Tool or provided by pump supplier
Income: Gross Farm Profit per year	180 000	**ZAR per ye:**	as calculated in INVEST-Farm Analysis Tool or from own records
Proportion of Profit to invest	20%		% of profit made available for investment into water pumping system

INVEST – Payback Tool

This OUTPUT sheet summarizes the results as per the entries in the afore completed INPUT sheet.

Click to remove from /add to analysis:

- Capital Investment
- Solar powered irrigation system costs
- Grid powered irrigation system costs
- Diesel powered irrigation system costs

Basic assumptions

Total water need per day	33 m³ per day	
Total income per year	180.000 ZAR	(in Year 1)
Total investment amount per year	#VALUE!	(in Year 1)
Inflation	4%	
Discount rate	4%	
Annual profit margin increase	3%	
Annual fuel price increase	9%	

Note:

If "not feasible" is displayed for the Internal Rate of Return (IRR) then the IRR value is below 0%.

If a negative (-) Net Present Value (NPV) is displayed then the investment is not feasible.

If "no payback" is displayed for Years for Payback then system capital and/or operating expenses exceed income within 25 years

Analysis for Solar powered irrigation system

Internal Rate of Return (IRR) over 25 Y	26%
Net Present Value (NPV) over 25 years	3744.800 ZAR
Accumulated Cash Flow after Year 25	538.311 ZAR
System Life Cycle Costs (25 years)	774.223 ZAR
Years for Payback	4
Lending Bank:	Bank
Yearly Loan Repayment:	.0 ZAR

Analysis for Grid powered irrigation system

Internal Rate of Return (IRR)	46%
Net Present Value (NPV)	1519.743 ZAR
Accumulated Cash Flow after Year :	106.202 ZAR
System Life Cycle Costs (25 years)	1206.331 ZAR
Years for Payback	3
Lending Bank:	Bank
Yearly Loan Repayment:	.0 ZAR
CO² Emmissions per year:	945 kg/year

Analysis for Diesel powered irrigation system

Internal Rate of Return (IRR)	not feasible
Net Present Value (NPV)	-5792.651 ZAR
Accumulated Cash Flow after Year	-1496.907 ZAR
System Life Cycle Costs (25years)	2809.440 ZAR
Years for Payback	no payback
Lending Bank:	Bank
Yearly Loan Repayment:	.0 ZAR
CO² Emmissions per year:	3 823 kg/year

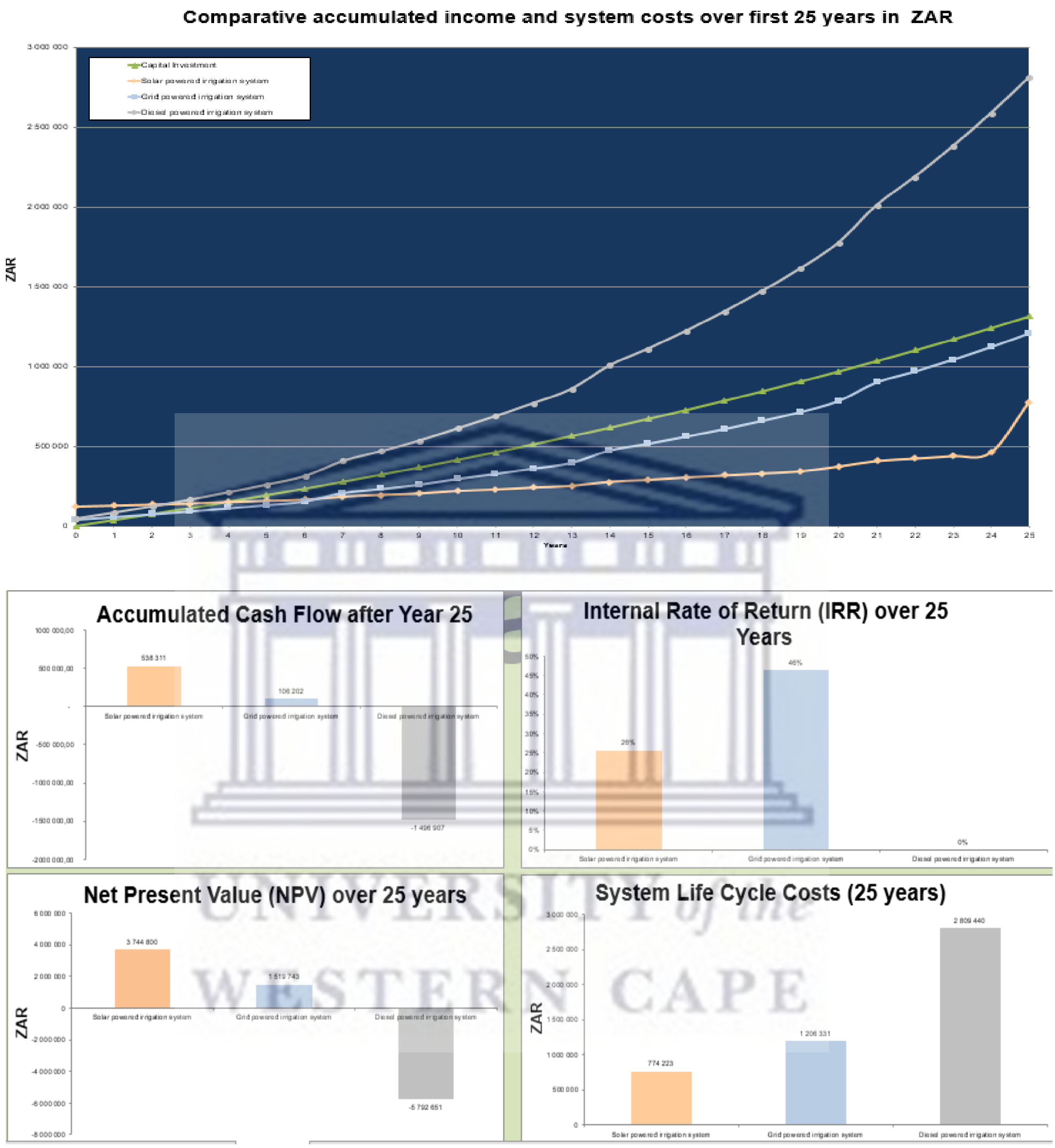


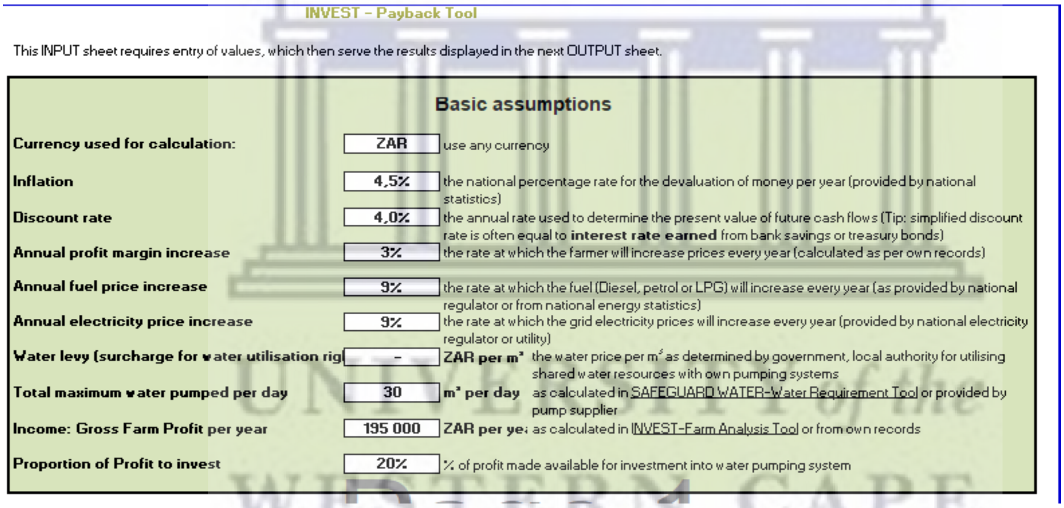
Figure 5. 6 Estimated costs for Loloka village from payback tool

Mbhendle Village results

For the second village (Mbhedle) the internal rate of return for 25 years was calculated to be 27% for the solar powered systems and 53% for grid powered systems. For the diesel system the internal rate of return was not feasible, meaning the value was below 0 (Figure 5.7).

For the net present value, the diesel system had a negative value which also indicated that the investment was not financially feasible. For both the grid (R2,359,478) and the solar system (R4,158,946) the values were positive meaning that the investment is financially feasible. The accumulated cash flow after 25 for solar systems was calculated to be R614,607, R268,124 for grid powered systems and R-1,203,547 for diesel. From these results, it was evident that the solar systems yield a higher accumulated cash flow with diesel resulting in a negative accumulated cash flow over 25 years.

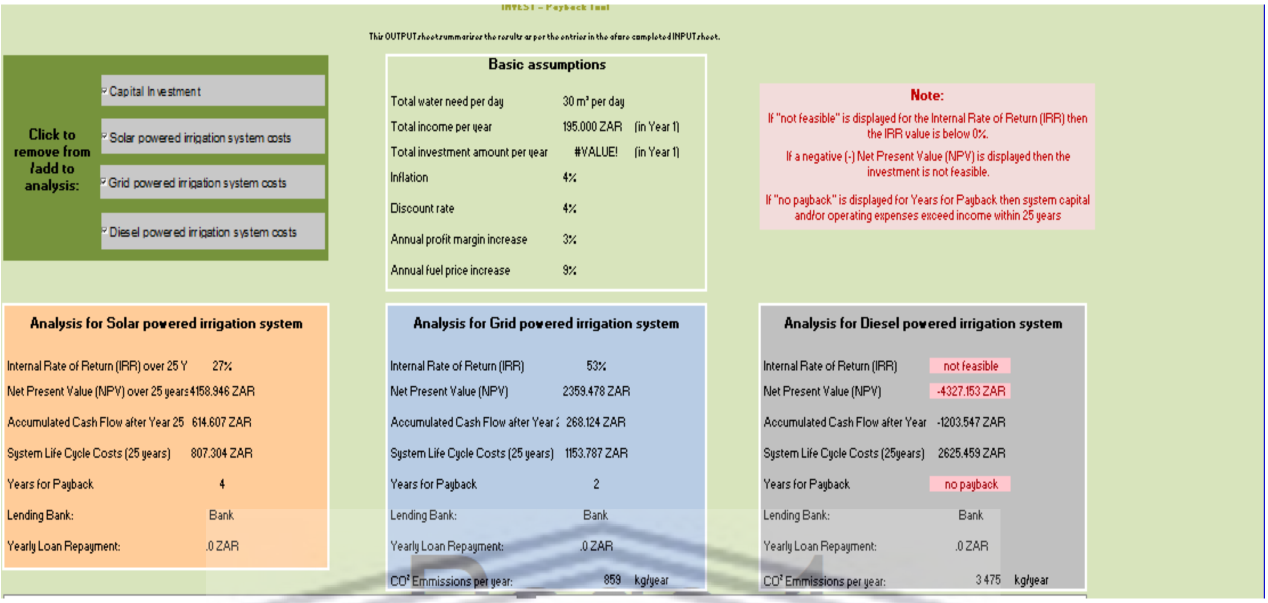
The life cycle cost of the systems was calculated for a duration of 25 years. Among the three systems evaluated, the solar system exhibited the lowest cost, amounting to R807,304. The grid system followed with a cost of R1,153,787, while the diesel system displayed the highest cost of R2,625,459. The solar system exhibited a payback period of 4 years, while the grid system demonstrated a payback period of 2 years. The consideration of CO_2 emissions was limited to diesel and grid powered systems exclusively. The carbon dioxide (CO_2) emissions associated with diesel fuel were measured at a rate of 3,475 kilograms per year, while the grid system exhibited emissions of 859 kilograms per year.

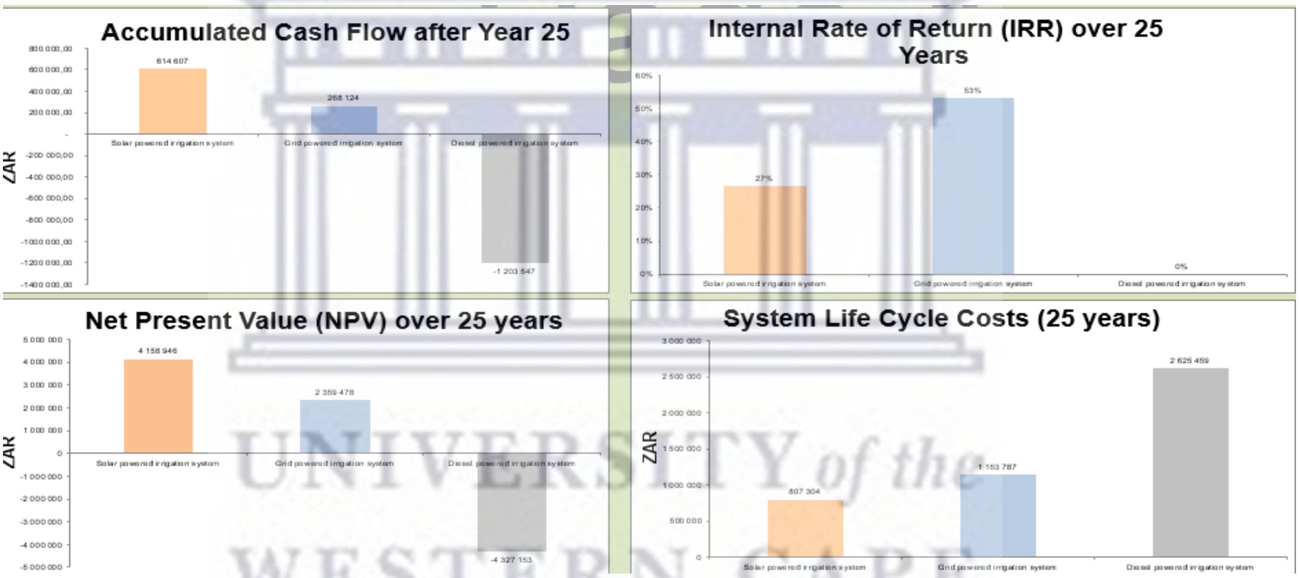

INVEST – Payback Tool

This INPUT sheet requires entry of values, which then serve the results displayed in the next OUTPUT sheet.

Basic assumptions

Currency used for calculation:	ZAR	use any currency	
Inflation	4,5%	the national percentage rate for the devaluation of money per year (provided by national statistics)	
Discount rate	4,0%	the annual rate used to determine the present value of future cash flows (Tip: simplified discount rate is often equal to **interest rate earned** from bank savings or treasury bonds)	
Annual profit margin increase	3%	the rate at which the farmer will increase prices every year (calculated as per own records)	
Annual fuel price increase	9%	the rate at which the fuel (Diesel, petrol or LPG) will increase every year (as provided by national regulator or from national energy statistics)	
Annual electricity price increase	9%	the rate at which the grid electricity prices will increase every year (provided by national electricity regulator or utility)	
Water levy (surcharge for water utilisation rig	-	ZAR per m³	the water price per m³ as determined by government, local authority for utilising shared water resources with own pumping systems
Total maximum water pumped per day	30	m³ per day	as calculated in SAFEGUARD WATER-Water Requirement Tool or provided by pump supplier
Income: Gross Farm Profit per year	195 000	ZAR per ye	as calculated in INVEST-Farm Analysis Tool or from own records
Proportion of Profit to invest	20%	% of profit made available for investment into water pumping system	


INVEST – Payback Tool
This OUTPUT sheet summarises the results as per the entries in the afore completed INPUT sheet.
Click to remove from /add to analysis:
Capital Investment
Solar powered irrigation system costs
Grid powered irrigation system costs
Diesel powered irrigation system costs
Basic assumptions
Total water need per day 30 m³ per day
Total income per year 195.000 ZAR (in Year 1)
Total investment amount per year #VALUE! (in Year 1)
Inflation 4%
Discount rate 4%
Annual profit margin increase 3%
Annual fuel price increase 9%
Note:
If "not feasible" is displayed for the Internal Rate of Return (IRR) then the IRR value is below 0%.
If a negative (-) Net Present Value (NPV) is displayed then the investment is not feasible.
If "no payback" is displayed for Years for Payback then system capital and/or operating expenses exceed income within 25 years
Analysis for Solar powered irrigation system
Internal Rate of Return (IRR) over 25 Y 27%
Net Present Value (NPV) over 25 years 4158.946 ZAR
Accumulated Cash Flow after Year 25 614.607 ZAR
System Life Cycle Costs (25 years) 807.304 ZAR
Years for Payback 4
Lending Bank: Bank
Yearly Loan Repayment: 0 ZAR
Analysis for Grid powered irrigation system
Internal Rate of Return (IRR) 53%
Net Present Value (NPV) 2359.478 ZAR
Accumulated Cash Flow after Year 268.124 ZAR
System Life Cycle Costs (25 years) 1153.787 ZAR
Years for Payback 2
Lending Bank: Bank
Yearly Loan Repayment: 0 ZAR
CO² Emmissions per year: 859 kg/year
Analysis for Diesel powered irrigation system
Internal Rate of Return (IRR) not feasible
Net Present Value (NPV) -4327.153 ZAR
Accumulated Cash Flow after Year -1203.547 ZAR
System Life Cycle Costs (25years) 2625.459 ZAR
Years for Payback no payback
Lending Bank: Bank
Yearly Loan Repayment: 0 ZAR
CO² Emmissions per year: 3 475 kg/year


Accumulated Cash Flow after Year 25
ZAR
614 607
268 124
-1 203 547
Solar powered irrigation system
Grid powered irrigation system
Diesel powered irrigation system
Internal Rate of Return (IRR) over 25 Years
27%
53%
0%
Net Present Value (NPV) over 25 years
4 158 946
2 359 478
-4 327 153
System Life Cycle Costs (25 years)
807 304
1 153 787
2 625 459

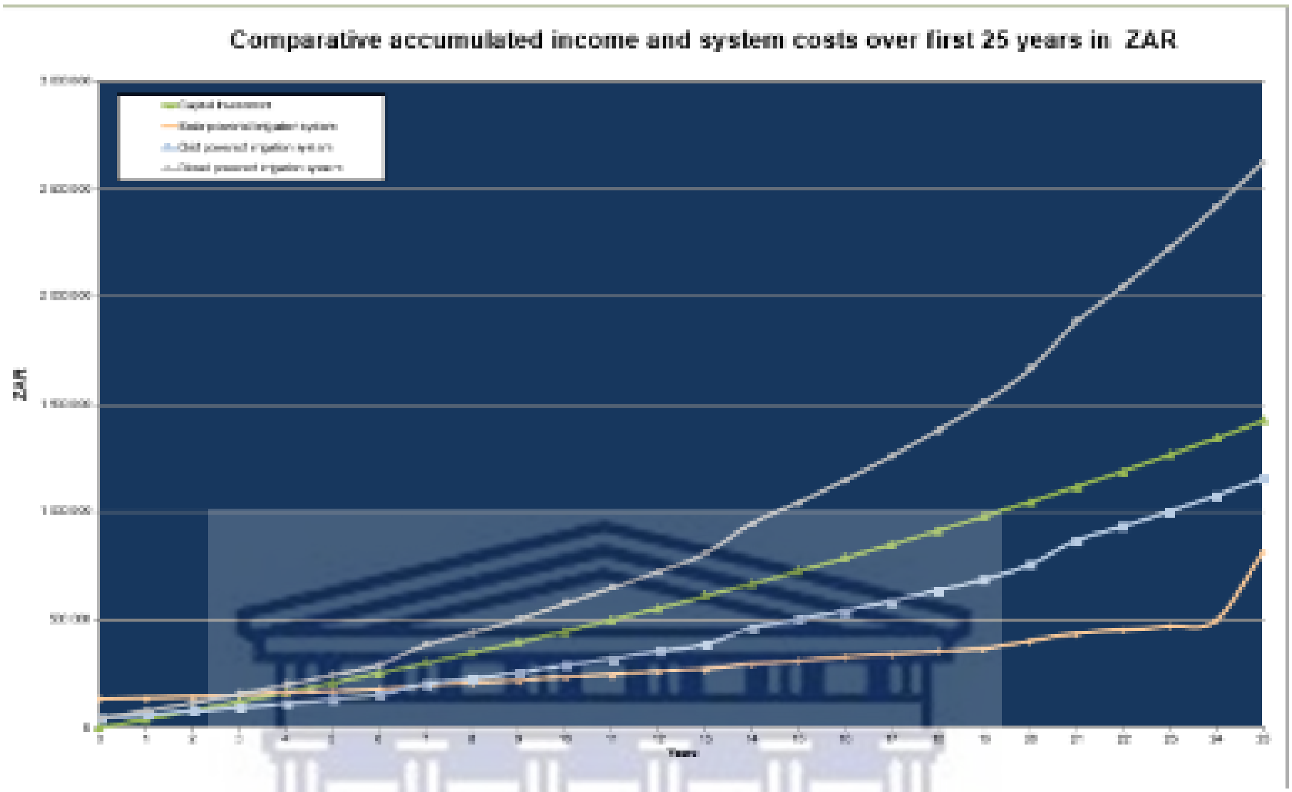


Figure 5. 7 Estimated costs for Mbhedle village obtained from Payback tool

5.4 FINANCE DEPLOYMENT ANALYSIS TOOL

The tool was used to evaluate the financing options for the farmers and the two villages.

Firstly, for the farmers (Figure 5.8) the results showed that four financial options are available to them. These were the options in which they could get capital for their farms for investment in the proposed solar groundwater pumping systems. Both farmers' economic status was more or less the same; both were not receiving any form of financial assistance from the government. They were still waiting for an outcome/response on applications they had put in over years. The farmers operate their farms based on the profits made from crop sales. Sometimes, they have to supplement from their own personal accounts. The results showed similar financing options available to them as they did not have any other sources of income and did not possess any collateral in the banks. The options were leasing, cooperative, informal saving and pay per use. The leasing option is a financial alternative that enables farmers to utilize equipment without the requirement of outright ownership. On the other hand, the cooperatives option allows farmers to become members of an institution that facilitates collective collaboration among farmers, thereby providing them with various financial and economic benefits. One type of informal financing option involves a collective group of individuals who pool their savings into a shared fund, from which they can then borrow funds. Another option is the pay-per-use model, which is a business strategy provided by water service providers.

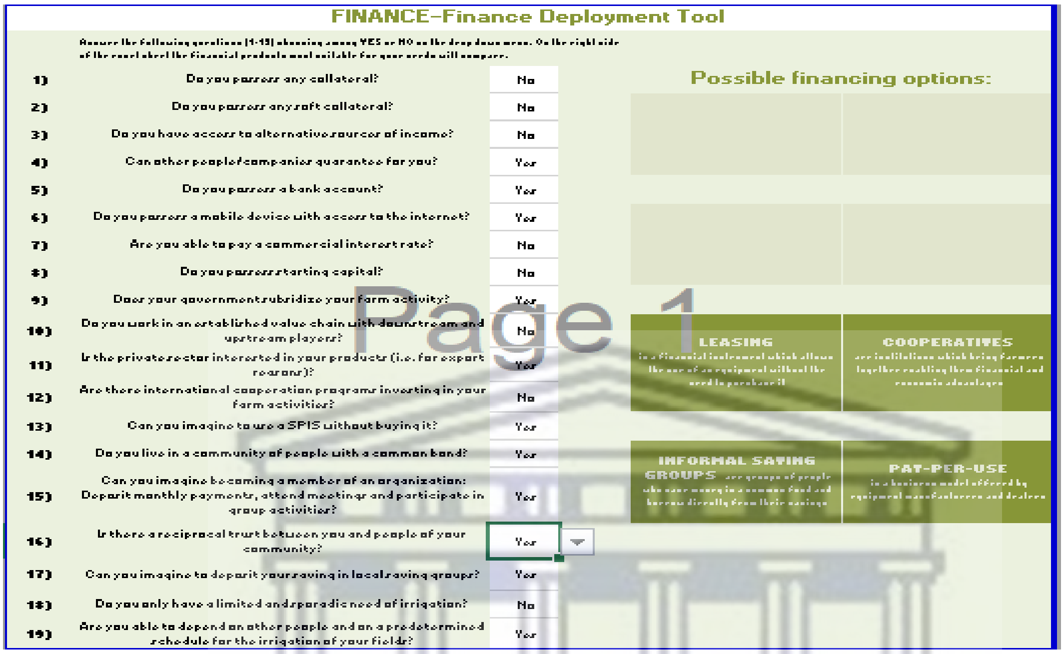


Figure 5. 8 Results of the finance deployment tool for the farms

For the two villages (Figure 5.9) the financing options were similar to those of the farms, just with an additional two financing options which were not available for the farmers. These options were Micro Finance Institutions (MFIs) and mobile money. MFIs are entities that facilitate financial inclusion for individuals in low-income segments of society. Mobile money, on the other hand, is a financial service that leverages mobile telecommunications to extend credit to individuals, regardless of whether they possess traditional bank accounts or not.

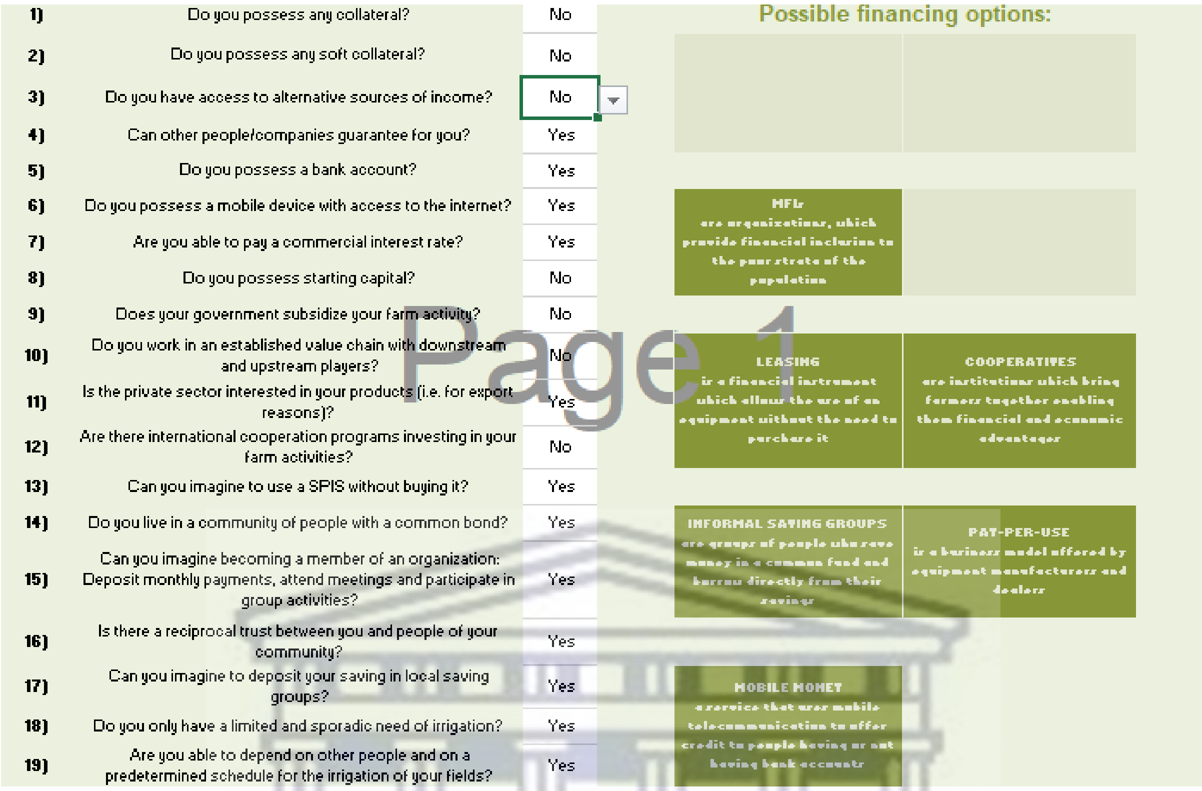


Figure 5. 9 Results of the finance deployment tool for the villages

5.5 MARKET ASSESSMENT TOOL

The market assessment tool takes into account fundamental geophysical parameters and offers guidelines and weights for users to select from. This aids in the evaluation of parameters that contribute to the creation of a conducive business environment for solar powered water pumps.

The geophysical attributes encompassed several parameters, including land cover/land use, solar radiation, water availability, topography, crop and livestock, and ambient temperature. The groundwater table depth was estimated to be from 7 to 25 m in the toolbox geophysical parameters and it had a critical relevance as the solar pumps will be used for pumping groundwater. The minimum ambient temperature was estimated to be from 1°C to 30°C and it was rated as very important in terms of relevance. The slope of the area was determined to be flat and it was inconsequential as it had no effect on the systems. The main agricultural production in the area was seasonal and perennial crops which was determined to be critical in terms of relevance as the solar powered water pumps will also be used for irrigation purposes. The land cover of the area was determined to be predominantly shrub lands and in terms of suitability it was under the moderately suitable rating as the solar systems can still be installed in such land. In terms of solar irradiation, the average solar irradiation was estimated above 1460 m^2 which was the highest value in the options given in the toolbox and it scored as highly suitable as the water pumps will be powered through solar energy, therefore there needs to be enough solar radiation. For determining the aridity of the area, the average monthly temperature and precipitation was used. The data were obtained from nearby weather stations (Gravelotte and ZZ2). The area was determined to be highly suitable as it has several months with high temperatures and low rainfall.

The factors influencing the business environment encompassed various aspects such as governmental and non-governmental interventions, financing, the cost and accessibility of alternative power sources, the level of technical capacity related to Solar Photovoltaic Irrigation Systems (SPIS), the awareness levels regarding solar photovoltaics and irrigation technologies, the importance of agriculture to the economy, land use rights and tenure, as well as transportation and communication infrastructure. These are presented in the tool in a question format and answers to the questions were obtained through the links provided in the toolbox. For each answer chosen, there was a specific percentage weighting allocated to it and the parameters mentioned above that affect the business environment were either rated as critical, inconsequential or slightly important. The government and non-governmental interventions were rated as critical. This is because the parameter is about evaluating the role of the government and other organisations in promoting renewable energy, solar energy to be exact, by looking at the laws, regulations that enhance the adoption of solar energy. The financing aspect was also rated critical as this encompasses the financial support available for end users as the systems have high capital costs. The availability and cost of alternative sources had an important rating as this evaluates the costs of other energy supplies. This helps in determining if there is a market for these systems and how competitive they are financially as compared to other alternatives.

The results from the toolbox are shown in Figure 5.10. Financing had a major market potential. This was due to potential subsidies for the capital cost of the systems so there is financial support available. A moderate market strength was depicted for land use rights, ownership and tenure because the farms are in rural areas and the land they occupy is state-owned so they get permission to occupy and not full ownership of the land. The significance of agriculture to the local economy showed a minor market potential; this is due to the Province thriving in the mining sector for platinum. The total score for the market potential of SPIS in the area was 62.62% which indicates a good market potential.

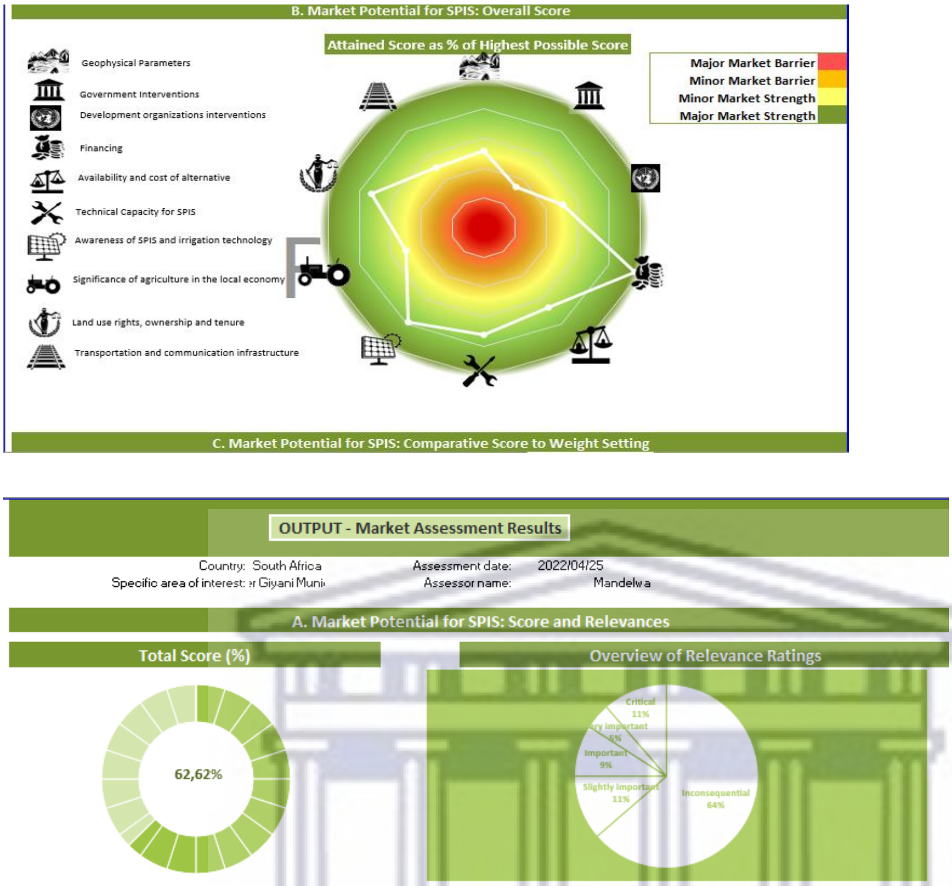


Figure 5. 10 Results from the market analysis tool box

The market analysis tool was used to test all four scenarios. However, due to the nature of the data required to populate the toolbox, being mostly geographical features and the scenario case studies being located in the same geographical area, the input data and results were the same. For example, the weather data needed in the market analysis tool for all scenarios was obtained from the two weather stations closest to Giyani that are recording (ZZ2 and Gravelotte primary school). Also, the links available in the tool that provide data for a parameter consider the broader location; maps provide data at coarse resolution for South Africa as whole. Although the user can zoom into a specific region, it is not possible to obtain the slope for each individual farm, so the categorization is generic for the area. The socio-economic and governance inputs were the same for the broader area.

5.6 LIFE CYCLE ASSESSMENT

Figure 5.11 presented below depicts a comprehensive compilation of input and output data pertaining to the life cycle analysis. The input dataset comprises a comprehensive inventory of the primary constituents employed in the fabrication process of solar panels, including cadmium. The category column represents the database list in which the raw materials were chosen from. Once the raw material has been selected and entered, the software generated a sub-category based on the category the material was chosen from. The last column is the amount column which represented the quantity of each raw material used and the units are chosen based on how the raw material is measured or quantified e.g. kg/g/MJ.

The output table consisted of the list of what was to be analysed as outputs, which were carbon dioxide, nitrogen oxide and sulphur dioxide emissions for environmental impact. The recipe midpoint(H) obtained from the eco-invent database was used for the analysis as it is highly recommended for use in environmental impact life cycle analysis amongst the other methods (ecological footprint, eco-indicator).

In his study, Sørensen (1994) highlights the significance of conducting a life cycle assessment in order to make informed energy choices between renewable energy systems and conventional fuel-based systems. It is further noted in the study that besides the economic benefits a number of other impacts such as low CO_2 emissions strongly favour the choice of renewable energy. These advantages contributed to the selection of using the LCA software for this study in conducting a life cycle assessment for solar powered irrigations systems, the results obtained from the analysis are presented and explained below.

The OpenLCA generated results which showed a broader category of impacts even though it had no category that was specifically analysing CO_2 emission impacts. There were 18 environmental impact categories generated of which there were zero traces for some of the impact categories as seen in Figure 5.12. For the purpose of the study we assumed the mass of the solar panel was around 18 kg, which was obtained from an online solar panel store as common mass for a solar panel (Jackery supplier, available at: https://jackery.co.za/contact/accessed 13 November 2023). The solar panels were assumed to be made of cadmium as it is one of the materials used to manufacture solar panels (Wild-Scholten et al., 2004). The outputs were all the same for all phases which were carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide.

During the manufacturing phase, cadmium was utilized as the input material due to its application in the production of solar panels. In the results below, an equivalent (Eq) refers to the quantity of a material that undergoes a reaction with, or is equal to, a certain amount (usually one mole) of the other substance in a particular chemical reaction.

The outcome of the manufacturing process revealed traces under the following categories:

- Climate change with an amount of 6 kg CO_2-Eq (assesses global warming potential associated with greenhouse gases)

- Freshwater eco-toxicity :8.73420 kg, 1.4- dichlorobenzene (DCB)-Eq (determines the chance, exposure, and impact of toxic substances over an indefinite time span)
- Human toxicity :6.66110E5 kg 1.4-DCB-Eq
- Marine eco-toxicity :519.38826 kg 1.4-DCB-Eq
- Marine eutrophication: 2.33400 kg N-Eq (calculates the potential of enrichment of nutrients in soil or water from polluting emissions)
- Particulate matter formation: 2.52000 kg Particulate Matter formation (PM10)-Eq (determines the potential for emissions and secondary formation of particulate matter)
- Photochemical oxidant formation: 6.48649 kg nitrogen oxide and volatile organic compounds (NMVOC) (measures the potential formation of tropospheric ozone)
- Terrestrial acidification :9.36000 6 kg SO_2-Eq (determines potential of acidification of water and soils due to acid rain)
- Terrestrial eco-toxicity 210.27070 kg 1.4-DCB-Eq

For the transportation phase the inputs were oil used in vehicles transporting these to warehouses or retailers as well as the energy used. These were the results:

- Climate change: 240 kg CO_2-Eq
- Fossil depletion: 10.90000 kg oil-Eq
- Marine eutrophication: 93.36000 kg N-Eq
- Particulate matter formation: 100.80000 kg PM10-Eq
- Photochemical oxidant formation: 259.45946 kg (NMVOC)
- Terrestrial acidification: 374.40000 kg SO_2-Eq

For the usage phase, the input material used was ammonia which is used to clean the solar panels, and these were the results:

- Climate change: 1.00 kg CO_2-Eq
- Marine eutrophication: 0.66500 kg N-Eq
- Particulate matter formation: 1.38000 kg PM10-Eq
- Photochemical oxidant formation: 1.08108 kg (NMVOC)
- Terrestrial acidification: 8.91000 kg SO_2-Eq

And lastly for end of life stage, the input material was energy which is used in the discarding or recycling of these solar panels at the end of their 25 years' life time. The results obtained as output traces were:

- Climate change: 1.00 kg CO_2-Eq

- Marine eutrophication: 0.38900 kg N-Eq
- Particulate matter formation: 0.42000 kg PM10-Eq
- Photochemical oxidant formation: 1.08108 kg (NMVOC)
- Terrestrial acidification: 1.56000 kg SO_2-Eq

Photochemical oxidation impact occurs under certain atmospheric conditions; pollutant-forming oxidants occur when there is sunlight and low humidity and in the presence of nitrogen oxide and volatile organic compounds (NMVOC) such as ethane. Photochemical oxidation can cause breathing problems and eye irritation (Madronich and Flocke, 1999). Terrestrial acidification is an occurrence characterized by alterations in soil chemical properties resulting from the deposition of nitrogen oxides, ammonia, and sulphur dioxide (Azevedo et al., 2013). This study primarily focused on the characterization of sulphur dioxide (SO_2). The acidification can lead to a decline in soil fertility which may cause reduced rates for photosynthesis and plant biomass (Falkengren-Grerup, 1986).

Particulate Matter formation (PM10) refers to inhalable particles with a diameter of 10 micrometres and smaller (Humbert et al., 2011). The formation of atmospheric particles occurs through complex chemical reactions involving pollutants such as sulphur dioxide and nitrogen oxide, which are emitted from power plants and industrial facilities. Particulate matter contains very tiny droplets that can be inhaled. Once inhaled, these can cause serious health problems leading to lung or cardiopulmonary cancer (Gronlund et al., 2015). The climate change category was traced by carbon emissions as they form part of greenhouse gas emissions. Intarapong et al. (2016) defines eco-toxicity as the environmental impact that is measured by the release of toxic compounds such as benzene and di-chlorobenzene. The software distinguishes between terrestrial eco toxicity and marine eco toxicity. Terrestrial eco toxicity primarily arises from pesticide emissions on agricultural soil, as well as the utilization of sulphuric acid and steam during the conversion process. The latter is primarily characterized by the release of heavy metals and sulphuric acid, predominantly into the atmosphere. These were traced in this study and worth noting as they are harmful to humans once inhaled (Raugei and Frankl, 2009). Solar powered systems will be installed or implemented in high population villages where exposure can happen. There was also an impact on fuel depletion as these panels will have to be transported over some distance to where they will be implemented and this will require fuel, which will place a higher demand on fuel.

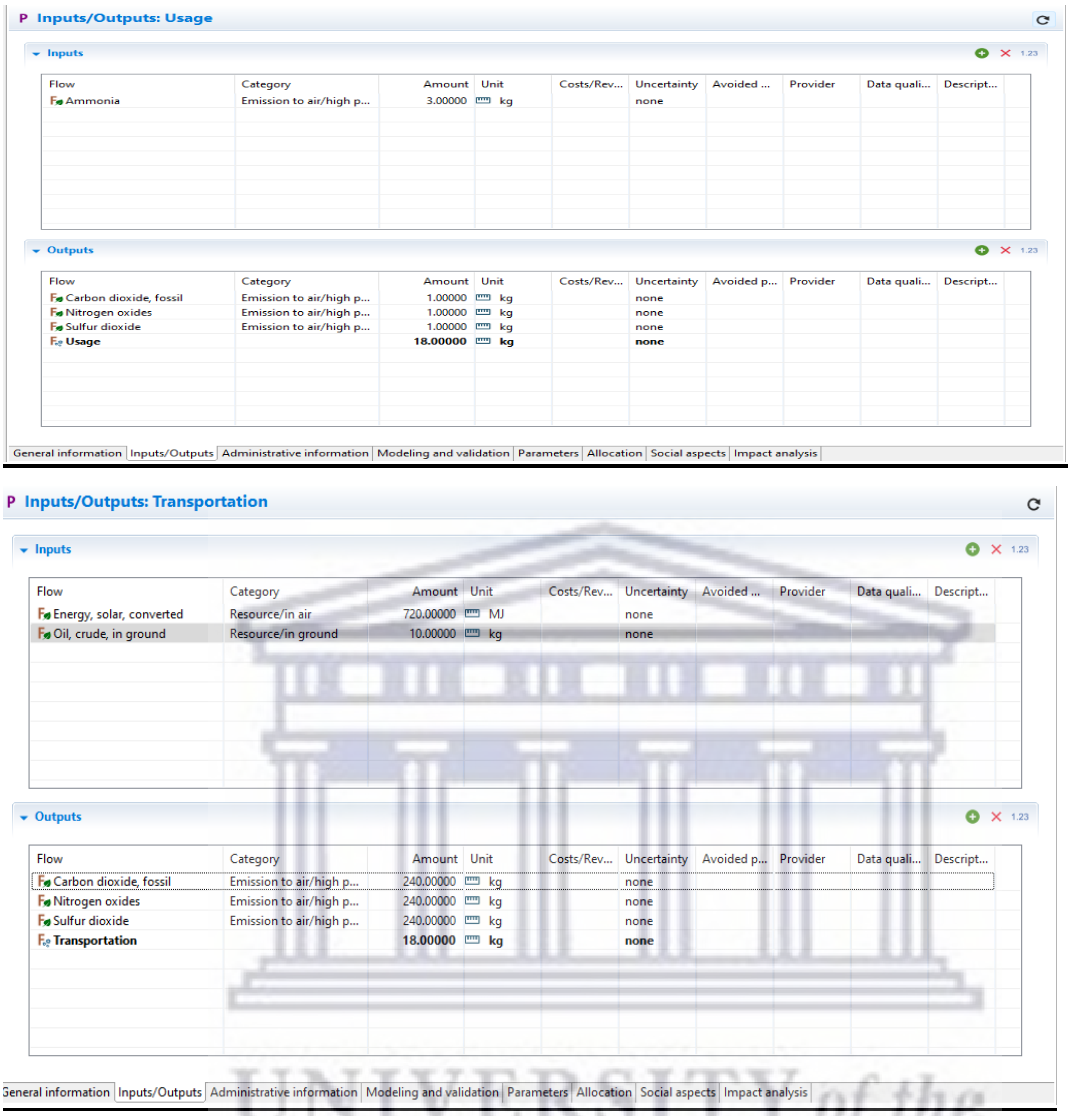
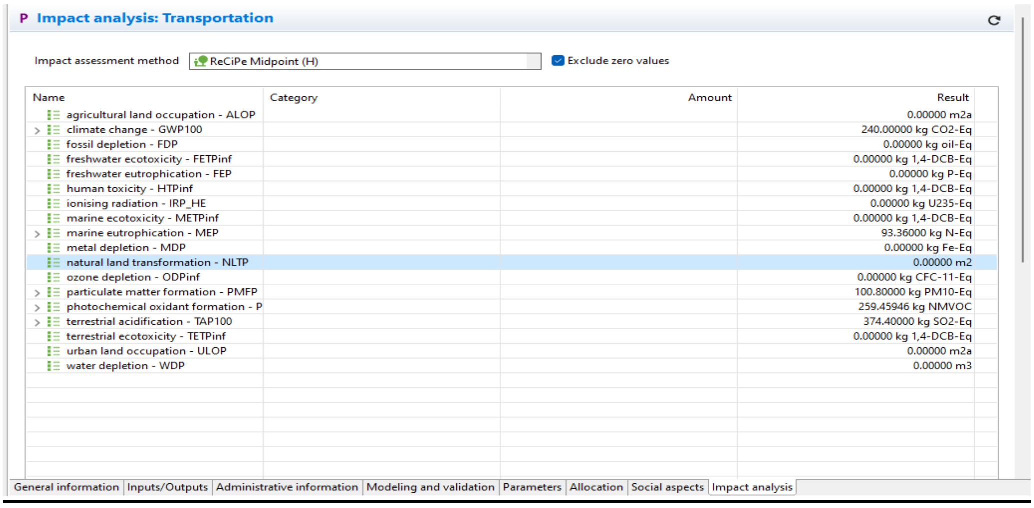


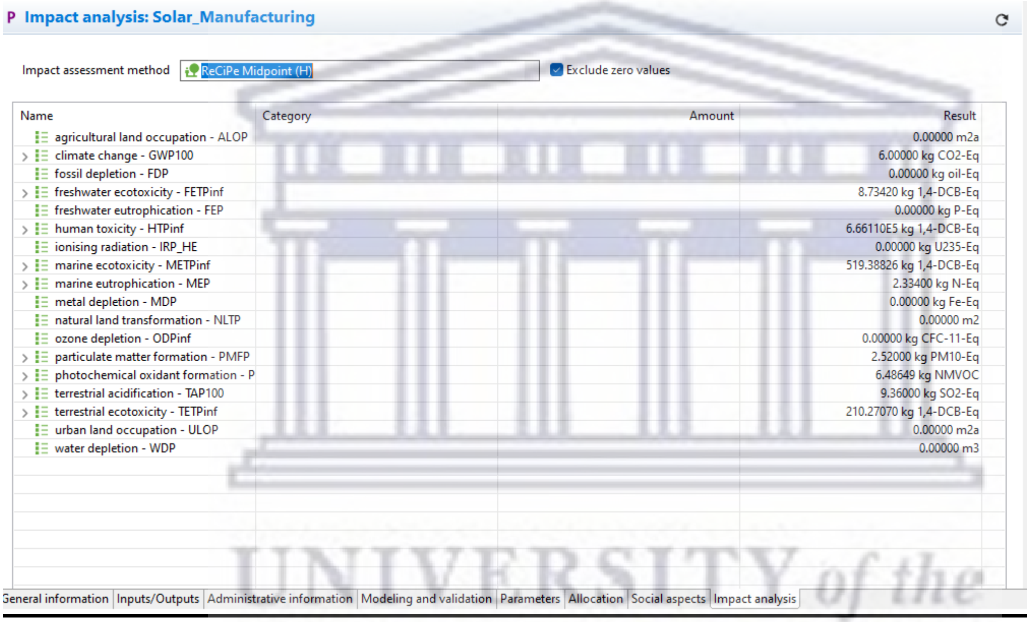
Figure 5. 11 Input and output data for the OpenLCA life cycle analysis



Impact analysis: Transportation

Impact assessment method: ReCiPe Midpoint (H) — Exclude zero values

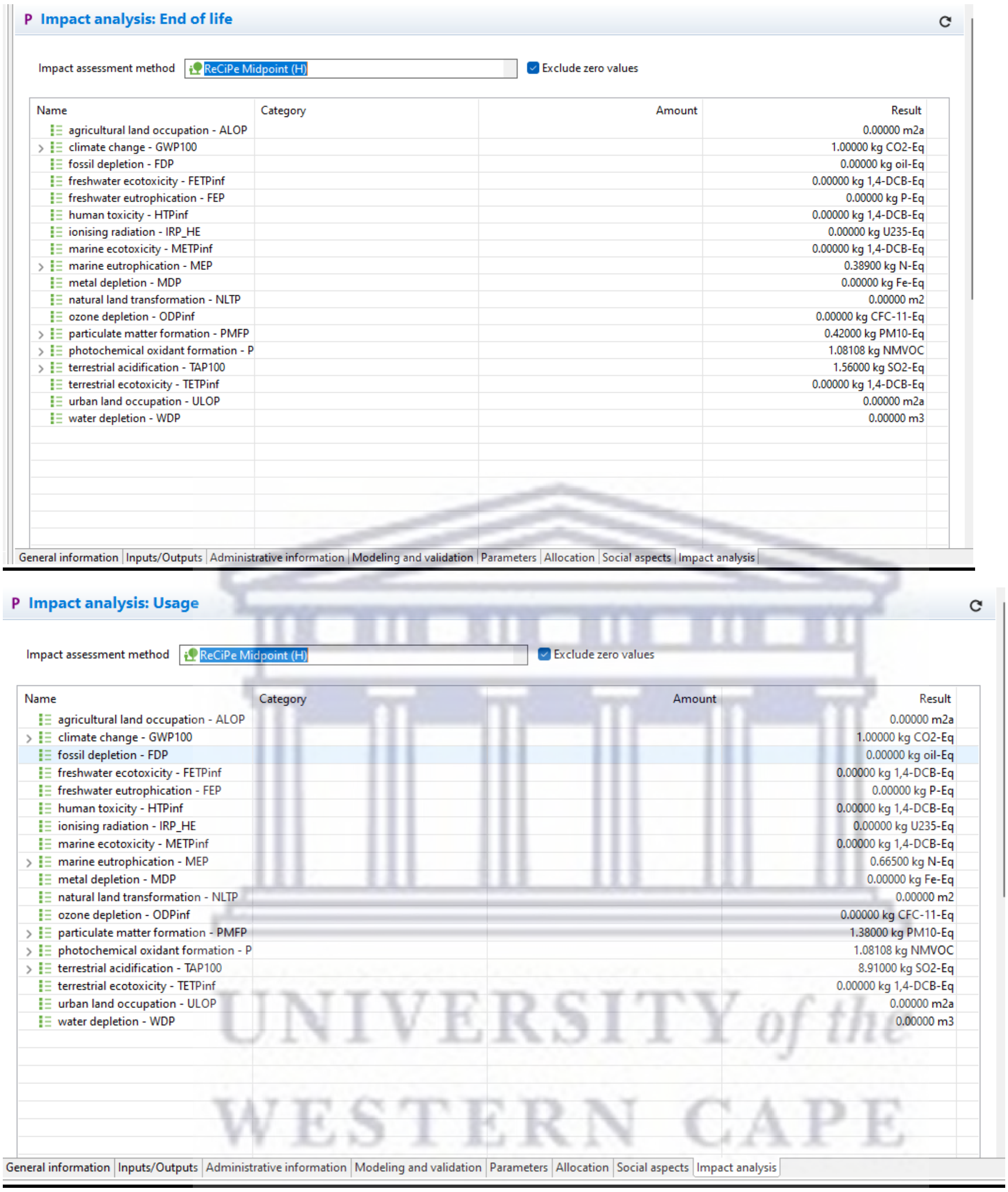
Name	Category	Amount	Result
agricultural land occupation - ALOP			0.00000 m2a
climate change - GWP100			240.00000 kg CO2-Eq
fossil depletion - FDP			0.00000 kg oil-Eq
freshwater ecotoxicity - FETPinf			0.00000 kg 1,4-DCB-Eq
freshwater eutrophication - FEP			0.00000 kg P-Eq
human toxicity - HTPinf			0.00000 kg 1,4-DCB-Eq
ionising radiation - IRP_HE			0.00000 kg U235-Eq
marine ecotoxicity - METPinf			0.00000 kg 1,4-DCB-Eq
marine eutrophication - MEP			93.36000 kg N-Eq
metal depletion - MDP			0.00000 kg Fe-Eq
natural land transformation - NLTP			0.00000 m2
ozone depletion - ODPinf			0.00000 kg CFC-11-Eq
particulate matter formation - PMFP			100.80000 kg PM10-Eq
photochemical oxidant formation - P			259.45946 kg NMVOC
terrestrial acidification - TAP100			374.40000 kg SO2-Eq
terrestrial ecotoxicity - TETPinf			0.00000 kg 1,4-DCB-Eq
urban land occupation - ULOP			0.00000 m2a
water depletion - WDP			0.00000 m3



Impact analysis: Solar_Manufacturing

Impact assessment method: ReCiPe Midpoint (H) — Exclude zero values

Name	Category	Amount	Result
agricultural land occupation - ALOP			0.00000 m2a
climate change - GWP100			6.00000 kg CO2-Eq
fossil depletion - FDP			0.00000 kg oil-Eq
freshwater ecotoxicity - FETPinf			8.73420 kg 1,4-DCB-Eq
freshwater eutrophication - FEP			0.00000 kg P-Eq
human toxicity - HTPinf			6.66110E5 kg 1,4-DCB-Eq
ionising radiation - IRP_HE			0.00000 kg U235-Eq
marine ecotoxicity - METPinf			519.38826 kg 1,4-DCB-Eq
marine eutrophication - MEP			2.33400 kg N-Eq
metal depletion - MDP			0.00000 kg Fe-Eq
natural land transformation - NLTP			0.00000 m2
ozone depletion - ODPinf			0.00000 kg CFC-11-Eq
particulate matter formation - PMFP			2.52000 kg PM10-Eq
photochemical oxidant formation - P			6.48649 kg NMVOC
terrestrial acidification - TAP100			9.36000 kg SO2-Eq
terrestrial ecotoxicity - TETPinf			210.27070 kg 1,4-DCB-Eq
urban land occupation - ULOP			0.00000 m2a
water depletion - WDP			0.00000 m3



Impact analysis: End of life

Impact assessment method: ReCiPe Midpoint (H) — Exclude zero values

Name	Category	Amount	Result
agricultural land occupation - ALOP			0.00000 m2a
climate change - GWP100			1.00000 kg CO2-Eq
fossil depletion - FDP			0.00000 kg oil-Eq
freshwater ecotoxicity - FETPinf			0.00000 kg 1,4-DCB-Eq
freshwater eutrophication - FEP			0.00000 kg P-Eq
human toxicity - HTPinf			0.00000 kg 1,4-DCB-Eq
ionising radiation - IRP_HE			0.00000 kg U235-Eq
marine ecotoxicity - METPinf			0.00000 kg 1,4-DCB-Eq
marine eutrophication - MEP			0.38900 kg N-Eq
metal depletion - MDP			0.00000 kg Fe-Eq
natural land transformation - NLTP			0.00000 m2
ozone depletion - ODPinf			0.00000 kg CFC-11-Eq
particulate matter formation - PMFP			0.42000 kg PM10-Eq
photochemical oxidant formation - P			1.08108 kg NMVOC
terrestrial acidification - TAP100			1.56000 kg SO2-Eq
terrestrial ecotoxicity - TETPinf			0.00000 kg 1,4-DCB-Eq
urban land occupation - ULOP			0.00000 m2a
water depletion - WDP			0.00000 m3

General information | Inputs/Outputs | Administrative information | Modeling and validation | Parameters | Allocation | Social aspects | Impact analysis

Impact analysis: Usage

Impact assessment method: ReCiPe Midpoint (H) — Exclude zero values

Name	Category	Amount	Result
agricultural land occupation - ALOP			0.00000 m2a
climate change - GWP100			1.00000 kg CO2-Eq
fossil depletion - FDP			0.00000 kg oil-Eq
freshwater ecotoxicity - FETPinf			0.00000 kg 1,4-DCB-Eq
freshwater eutrophication - FEP			0.00000 kg P-Eq
human toxicity - HTPinf			0.00000 kg 1,4-DCB-Eq
ionising radiation - IRP_HE			0.00000 kg U235-Eq
marine ecotoxicity - METPinf			0.00000 kg 1,4-DCB-Eq
marine eutrophication - MEP			0.66500 kg N-Eq
metal depletion - MDP			0.00000 kg Fe-Eq
natural land transformation - NLTP			0.00000 m2
ozone depletion - ODPinf			0.00000 kg CFC-11-Eq
particulate matter formation - PMFP			1.38000 kg PM10-Eq
photochemical oxidant formation - P			1.08108 kg NMVOC
terrestrial acidification - TAP100			8.91000 kg SO2-Eq
terrestrial ecotoxicity - TETPinf			0.00000 kg 1,4-DCB-Eq
urban land occupation - ULOP			0.00000 m2a
water depletion - WDP			0.00000 m3

General information | Inputs/Outputs | Administrative information | Modeling and validation | Parameters | Allocation | Social aspects | Impact analysis

Figure 5. 12 Environmental impacts results populated from the OpenLCA life cycle analysis cradle to grave.

5.7 WATER QUALITY RESULTS

End of winter results

The water quality results presented in Table 4.1 below show that Mbhedle village in May 2022 had values higher than South African National Standards (SANS) 241 for EC, TDS, Cl, NO_3, Na, TOC and Mn while the rest of the contaminants were within the acceptable standards. For JDN trading farm (Matsambo Ngamba) the contaminants that were above the SANS 241 standard were EC, Cl, Na, TOC and Mn. And lastly for Aritirheni Mqekwa farm the results showed high values for EC, Cl, NO_3, Na and TOC. For agricultural purposes, the water is marginally fit for irrigation due to EC>2000 µS/cm. Elevated NO_3^- could be a source of N replacing some of the fertilization requirements.

Table 4. 1 Results of the laboratory analyses of groundwater samples collected from the study around winter.

Analysis	**Mbhedle**	**Ngamba farm**	**Ahitirheni Mqekwa farm H14-1700**	**SANS 241**	**Water quality fitness for irrigation (DWAF, 1996)**
EC (µS/cm) (25°C)	2500	2691	2672	≤ 1700	2000
pH (25°C)	7.286	6.857	7.16	≥ 5 and ≤ 9.7	6.5-8.4
TDS (ppm) @ 25°C	1336	643	971	≤ 1200	Up to 40
Colour (Hazen)	1.7	1.7	0	< 15	-
					-
F (mg/L)	0.592	0.547	0.596	≤ 1.5	Up to 2.0
Cl (mg/L)	475.706	678.633	632.826	≤ 300	Up to 100
SO_4 (mg/L)	44.819	36.347	46.188	≤ 500 (health)	-
				≤ 250 (aesthetic)	-
PO_4 (mg/L)	n.d	n.d	n.d	-	-
NO_2 (mg/L)	n.d	.	n.d	≤ 2.96	-
Br (mg/L)	1.303	1.408	1.506	-	-
NO_3 (mg/L)	73.867	31.269	68.950	≤ 48.7	-
					-
Na (mg/L)	357.126	240.526	217.145	≤ 200	Up to 70

Analysis	Mbhedle	Ngamba farm	Ahitirheni Mqekwa farm H14-1700	SANS 241	Water quality fitness for irrigation (DWAF, 1996)
NH_4 (mg/L)	n.d.	n.d.	n.d.	≤ 1.5	-
K (mg/L)	12.138	6.909	6.048	-	-
Mg (mg/L)	93.167	133.473	137.232	-	-
Ca (mg/L)	85.097	161.796	174.406	-	-
					-
TOC [mg/l]	16.519	16.181	15.674	≤ 10	-
					-
Al (µg/L)	<LOQ	15.54	0.94	≤ 300	Up to 5
Mn (µg/L)	121.84	155.37	6.25	≤ 400 (health) ≤ 100 (aesthetic)	Up to 0.02
Fe (µg/L)	68.25	35.07	4.29	≤ 2000 (health) ≤ 300 (aesthetic)	Up to 5.0
Cu (µg/L)	2.07	2.88	0.89	≤ 2000	Up to 0.2
Zn (µg/L)	847.94	4.86	4.27	≤ 5000	Up to 1.0

LOC: Limit of quantification, LCS: Laboratory control sample, ND: No detection

<u>End of summer results</u>

As shown in Table 4.2 below in November 2022 for Mbhedle village the water quality results showed high values for EC, TDS, CL, NO_2, NO_3, Na and Mn and the other contaminants were within the acceptable range. The Ngamba farm only had Mn as a value higher than the SANS

241 standard while Aritirheni Mqekwa farm had exceeding values for EC, Cl, TDS, NO_3 and Na.

The pH was mostly good for all the sites, however, the other contaminants are important as they can pose a risk to the population drinking the water. The water would need to be purified before it is used for drinking purposes to remove all the contaminants and ensure it is safe to drink.

Water is marginally suitable for irrigation purposes at Mbhedle and Ahitirheni Mqekwa, and suitable at Ngamba farm in terms of EC.

Table 4. 2 Results of the laboratory analyses of groundwater samples collected from the study sites around summer

Analysis	Mbhedle	Ngamba farm	Ahitirheni Mqekwa farm H14-1700	SANS 241	Water quality fitness for irrigation (DWAF, 1996)
EC (µS/cm) (25°C)	2455	1533	2683	≤ 1700	2000
pH (25°C)	7.53	7.01	7.21	≥ 5 and ≤ 9.7	6.5-8.4
TDS (ppm) @ 25°C	1228	767	1342	≤ 1200	Up to 40
Colour (Hazen)	0.3	0.0	0.0	< 15	-
F (mg/L)	0.439	0.452	0.443	≤ 1.5	Up to 2.0
Cl (mg/L)	472.705	277.122	668.842	≤ 300	Up to 100
SO_4 (mg/L)	44.114	28.093	46.311	≤ 500 (health) ≤ 250 (aesthetic)	-
PO_4 (mg/L)	n.d	Below	n.d	-	

Analysis	Mbhedle	Ngamba farm	Ahitirheni Mqekwa farm H14-1700	SANS 241	Water quality fitness for irrigation (DWAF, 1996)
		calibration standard			
NO_2 (mg/L)	6.698	n.d	n.d	≤ 2.96	-
Br (mg/L)	1.264	0.609	1.387	-	-
NO_3 (mg/L)	62.825	24.799	73.812	≤ 48.7	-
					-
Li (mg/L)	0.025	0.009	0.026	-	-
Na (mg/L)	359.952	153.405	242.848	≤ 200	Up to 70
NH_4 (mg/L)	n.d.	n.d.	n.d.	≤ 1.5	-
K (mg/L)	11.663	2.393	2.771	-	-
Mg (mg/L)	90.863	74.068	129.812	-	-
Ca (mg/L)	81.935	87.14	164.636	-	-
					-
TOC [mg/l]	6.079	9.804	6.522	≤ 10	-
Al (µg/L)	<LOQ	<LOQ	<LOQ	≤ 300	Up to 5
Mn (µg/L)	114.013	120.563	9.604	≤ 400 (health) ≤ 100 (aesthetic)	Up to 0.02

Analysis	Mbhedle	Ngamba farm	Ahitirheni Mqekwa farm H14-1700	SANS 241	Water quality fitness for irrigation (DWAF, 1996)
Fe (µg/L)	<LOQ	<LOQ	<LOQ	≤ 2000 (health)	Up to 5.0
				≤ 300 (aesthetic)	
Cu (µg/L)	0.895	<LOQ	12.800	≤ 2000	Up to 0.2
Cd (µg/L)	0.034	0.020	0.139	≤ 3	Up to 0.01
Zn (µg/L)	1403.012	0.814	377.931	≤ 5000	Up to 1.0

LOC: Limit of quantification, LCS: Laboratory control sample, ND: No detection

5.8 DISCUSSION OF RESULTS

5.8.1 SOCIO-ECONOMIC FEASIBILITY

Payback tool.

In terms of the socio-economic feasibility for implementing solar powered groundwater pumps, the payback tool results showed that the costs associated with the use of diesel are not feasible for the farms. This further alludes to the financial struggles that were brought forth by the farmers as a result of having to use diesel-powered pumps. The tool considered all the income a farmer receives as well as their expenses and, given the profits made, the results indicated that investment in diesel pumps was not feasible for the farmers. The results also showed that in terms of financing options, the farmers do not qualify for loans as they do not have any collateral assets or even other income that can be used by a bank as guarantee for granting a loan. This further puts the farmers at a disadvantage and attests to the need for an alternative source of power supply that will enable them to cut down on fuel costs while still delivering water efficiently. Solar powered pumps were shown to be a feasible and affordable option by the toolbox results, as these systems use the energy from the sun.

The Payback tool results for the villages also indicated that the use of diesel for power supply was not feasible as this has high costs. This further alludes to the socio-economic status of both the villages and the farms. The current grid and diesel-powered systems used in the villages were installed by the government, however their functionality and maintenance was left to be a responsibility of the villagers. The villages do not have any funds available that were given by the government to use for operating these systems and because the population is mostly poor and unemployed, no one has money that they can spare/ donate for buying fuel. The results favoured the solar powered pumps as they had less costs associated with their operation. The results for the villages had some differences due to the water requirements not being the same as the population also differs, so the implementation of the solar powered pumps would also differ as it would need to be suitable for the populations and their water requirements. This was the same with the farmers as well, the farms had different sizes and irrigation demands based on the crop grown in the specific farms. The smaller farm had less area to be irrigated and thus less water required, therefore the costs associated with implementing the solar powered water pumps was proportional to the water needs they would need to supply. A large farm has a large area of crops to irrigate and a higher demand of water thus there were more costs for the bigger farm.

Market analysis tool.

From the Market analysis tool, the results showed that the area has enough solar radiation, therefore solar powered systems can be installed. The market analysis tool also showed that there is a great market for solar powered water pumps as most areas/ villages around Giyani rely on groundwater supply for daily living and irrigation. However, most pumps are powered through diesel which has become an issue as the fuel prices keep increasing, making it difficult for water to be pumped as farmers and villagers do not afford buying fuel frequently. The members of the community as well as farmers showed willingness to adopt the use of solar systems as an alternative. Most of the villages and farms already have existing water infrastructure that can be used to connect to the solar powered water pumps. Most of the replacements that need to happen were mostly for pipes and fittings. The use of solar powered irrigation systems showed as the favourable option as some boreholes within the villages were powered through grid electricity, however this was left as an expense for the community as the municipality was not consistent in supplying electricity units. The villagers raised financial concerns with the high electricity costs as well. In their study, Mahmoud and Natherb (2003) employed the Life Cycle Cost (LCC) methodology to examine the economic considerations associated with solar photovoltaic pumps in comparison to diesel systems. Their findings indicate that, from a cost perspective, Photovoltaic systems outperform diesel systems. In a similar study, the economic feasibility of remote photovoltaic water systems in a desert region of Tunisia was examined by Mahjoubi et al. (2013). The intended purpose of the solar-powered pump was to facilitate the pumping of an average daily volume of 45 m^3 over the course of a year, in contrast to a pump that relies on a diesel generator for power. The findings derived from the Life Cycle Cost (LCC) analysis demonstrated that photovoltaic pumping exhibits economic viability for deployment in arid regions.

The results showed that the financing options available to the farmers were less than those available for the two villages. This puts the villages at more advantage in terms of acquiring financial support for the implementation of these systems. This would have a greater benefit for the community as it possesses a chance of ending their water scarcity problems. The farmers are at a disadvantage as it is only an individual (owner of farm) that does the application for financial support as opposed to an application for community benefit which banks/financers tend to favour as it benefits a larger group of people than just one individual and their business. Even investors or donors are most likely to show interest in community beneficial projects. Even though the financing options available to farmers were few, their income profile still placed them at an advantage to receive financial aid, as them being profitable would indicate good financial status for banks to consider. The results from this study confirm the claims of a study by Meah et al. (2008) which found solar photovoltaics as the most suitable alternative source for use in water pumping for rural areas as it has less carbon footprint and is cost competitive. The study also found that out of the 3 energy systems which were investigated for feasibility (solar, diesel, grid), the solar systems are also best suited to be used in the rural areas where there are dry and hot climatic conditions. The findings align with the research conducted by Mahjoubi et al. (2013) which examined the economic feasibility of remote photovoltaic water systems in a desert region of Tunisia. The objective of the study was to compare the performance of a solar-powered pump, designed to deliver an average daily volume of 45 m^3 year-round, with that of a pump powered by a diesel generator. The findings derived from the Life Cycle Cost (LCC) analysis demonstrated the economic feasibility of utilizing photovoltaic pumping systems in arid regions.

Rapid assessment tool

The results from the Rapid assessment tool indicated that renewable energy is becoming more popular even in the South African context, as it is becoming more regulated through creation of policies and laws that will govern and enhance the use and development renewable energy such as solar energy. The results also showed that there are organisations/ institutions targeted at supporting solar energy adoption and scaling. These show the commitment and effort from the government in solving the current energy crisis. Renewable energy technologies continue to be in demand especially in current times where there are prevalent power cuts. These may be a threat to food security as farmers' form part of the food supply, however with solar powered water pumps the issue of power cuts/costs can be prevented as the energy is freely available.

Impact analysis tool

Concerning the impacts on natural resources and environment (Figure 5.1), the effects of increased evapotranspiration has been considered in a previous study (Lebea et al., 2021) emanating from the research funded by the Water Research Commission (Jovanovic et al., 2018). It was estimated that the seasonal evapotranspiration of tomato, a common vegetable in the area, is about 450 mm/a. This figure could be representative for other vegetables commonly grown in the area. Given the climatic and soil conditions, it would be possible to grow three vegetable crops per year in the area. This would amount to a water consumption through evapotranspiration of about 1350 mm/ or 13500 m^3/ha. Comparatively, a village with a population of about 1500 would consume a similar volume of water per year at a provision rate of 25 L per person per day (minimum water demand according to accepted international and national standards). Sustainable water abstraction limits can be set for each specific site (borehole, well), for example by switching off the pump automatically when a certain groundwater level has been reached (this was the case of a farm borehole described by Jovanovic et al., 2018). Although groundwater base flow has not been assessed, it is inevitable that some impacts on downstream users would manifest with increased groundwater abstraction. This would particularly impact downstream communities and the Kruger National Park. It should be noted that a disconnect was observed between the regional groundwater table and the sand river bed aquifer in the Molototsi River (Jovanovic et al., 2018), with surface-groundwater interactions occurring at very localized sites. Conceptually, the sand river bed aquifers appear to be recharged mainly through surface runoff and occasional flow events that occur on average a few times per year.

Groundwater quality as a result of irrigation return flow is not deemed to be a problem mainly because the farms are spaced apart. Salinization and other impacts on the soil (acidification, alkalinisation, waterlogging) are not expected in the short-term, however this should be monitored in the long-term. However, land degradation through soil erosion represents a big problem in the area and it manifests through sheet and especially gulley erosion. Soil compaction was also observed to occur below the ploughing layer.

Groundwater quality is generally fit for drinking and especially agriculture. The quality of water in the sand bed river aquifers is excellent because recharge occurs directly from rainfall

(Jovanovic et al., 2018). However, water quality needs to be monitored according to standards and protocols, especially for drinking water purposes, to determine any potential risks from all non-point and point pollution sources. Although formal waste collection sites do not exist in the area, including e-waste, batteries, plastics etc., the volume of waste generated by the solar-powered pump systems is sufficiently small to be stored at localized sites and it will not represent a problem. However, the increased use of fertilizers and pesticides will have to be monitored for adherence to protocols.

The employment rate within a given society is of paramount importance in facilitating economic growth and development. Furthermore, the respondents' level of adaptation in terms of their response and recovery to emergencies is also impacted. The coping strategies and adaptation methods employed by individuals who are employed and unemployed may differ due to the varying access to economic resources, which can enhance the employed individual's ability to cope.

5.8.2 ENVIRONMENTAL FEASIBILITY: LIFE CYCLE ASSESSMENT

The environmental feasibility is discussed in terms of the life cycle impacts of solar-powered groundwater pumps and the potential impacts on groundwater depletion, quality and land use. It served to address specific objective 1 of the study (To evaluate the environmental feasibility of using solar panel-powered pumps for abstraction of shallow groundwater, section 1.3.2).

In a previous study conducted by Pama et al. (2021), the authors employed a life cycle analysis (LCA) to assess the environmental consequences associated with the construction of a residential building. The writer of this text makes a pertinent reference to a crucial consideration that is equally applicable to the present study: the necessity of conducting a life cycle analysis before initiating any construction activities. The opportunity is provided to the contractor for assessing the environmental consequences resulting from the construction process, specifically in relation to the materials employed in the construction of the building. By adopting this approach, it enables the reduction of identified impacts through the exploration and utilization of alternative construction materials that possess lower environmental footprints. The study concludes with providing a list of materials and components that have the highest environmental impact in construction. This list was made available to contractors so as to try to minimise environmental impacts. Similarly, the current study evaluated the feasibility of using solar powered groundwater pumps in the rural areas of Giyani by looking at the environmental impacts from these systems to aid and provide awareness to the broader project that this study is a part of, which seeks to be implementing these solar powered irrigation systems in the rural areas.

The findings obtained from the utilization of the OPENLCA software indicate that the implementation of solar photovoltaic systems entails certain environmental consequences. Several substances were detected in limited amounts, but they remain significant due to their potential implications for the specific scenario examined in this research. These impacts present a risk to both human health and soil fertility, which holds great importance in the agricultural domain, given that farmers will also utilize the solar panels. The software utilized a database to perform calculations on the environmental impacts associated with the utilization of solar photovoltaic systems. These calculations were conducted by considering the materials employed throughout the entire lifecycle of these systems. The focal point which was to test out if there are any environmental impacts from these systems during their lifetime, and the impacts identified if any, would be valuable to note prior to the implementation of these systems in the villages and by the farmers pumping water. The results gave insight to what can be expected and allow for any mitigation plan or strategies as the impacts have been identified. In line with the study by Alsema and Nieuwlaar (2000), this study shows that even though solar photovoltaics do present a positive shift for power generation and for lowering carbon footprint, there are still some environmental impacts linked to some phases in their lifetime such as the manufacturing and disposal of photovoltaic modules which can never be ignored. The results showed that the manufacturing phase has the most impacts on the environment based on the resulting traces while the usage and end of life had the least traces. These impacts emanate from the various processes involved in the manufacturing of solar panels such as extraction of raw materials, solar panel module acquisition, production of contaminates, pollution of water resources and air emissions as well as their impact on the land. During this phase there is also a great need for water for the cooling process, which can be an environmental strain in areas that are arid and where water is scarce.

The water extracted from boreholes would need to be monitored, to prevent over-extraction which will occur if the groundwater is constantly pumped without allowing recovery time. Groundwater over-extraction has impacts on the water table, ecosystem depending on it, and it can also become expensive to pump as equipment that can reach deeper will need to be used. Members of the community showed willingness in training on how to monitor the water extracted. The farmers were already doing so using their own methods which can be polished to ensure accuracy and reliability. Over-abstraction can also be minimised by alternating the water from the borehole with water from the river when it is available.

Parameters such as rainfall frequency, water quality and weather data must be monitored as well in order to know which periods have rain and which are dry; as there will be more demand on groundwater during the dry seasons. Groundwater can be contaminated through activities happening around the source such as waste disposal, urban activities etc., therefore the quality of water must be tested, to ensure it remains within acceptable standard for drinking at all times and avoid any health hazards to the users and ecosystems dependent on it. The farms need to also monitor their expenditure versus their income and their crop yield. This will help to understand the impact these solar powered pumps have had, whether it still resulted in a good crop yield while decreasing fuel expenditure and any costs associated with lack of water for a farmer. The solar panels can be installed on the rooftops of buildings already existing in the farms and villages to prevent them taking up space or land that can be used for something more beneficial, and in a case where more land space is needed, these solar systems can also be installed marginal land.

CHAPTER 6: CONCLUSION

The study found the implementation of solar powered water pumps to be both economically and environmentally feasible for the selected sites. These findings addressed both objectives of the study. There is a great market potential for the systems, and the geophysical parameters of the sites are suitable for installation of these water systems. The findings also indicated there are laws, legislations and strategies put in place already by the government and other organisations to enhance the use of renewable energy such as solar, of which the use of these solar powered systems would support and fall under.

The weather pattern analysis showed the warmest month is December with high rainfall from November to March. The coldest temperatures were experienced around June. These results assisted in understanding when will there be a great demand for pumping water (periods of no rain). The farmers are making enough profit to allow for investment in these systems, however the initial costs associated with the solar panel systems are high compared to diesel and grid systems. However, the running costs are low for the solar powered systems which would allow for savings in the long term. There are more financing opportunities for drinking water supply than for agriculture, however water quality requirements for drinking water are more stringent. The water quality at the sites was tested and the results indicated a good pH balance however there were other constituents found in the water e.g. especially NO_3 that had exceeding values above the SANS 241 standards. Therefore, the water would need to be purified prior to drinking to eliminate health risks. The water quality is generally good for agricultural utilization.

The study also found that solar powered systems have some environmental impacts especially in the manufacturing phase such as impact on climate change, freshwater eco-toxicity, particulate matter formation however these were lower during usage and end of life phases. Therefore, these must be addressed or mitigated before implementation can occur.

This study recommends the following:

- Implement solar powered groundwater pumping systems to improve water, food and energy security in rural areas of Limpopo.
- Groundwater abstraction, groundwater levels and groundwater quality should be monitored regularly upon implementation.
- Efficiency and durability of the systems should also be monitored.
- Small water treatment plants should be installed for drinking water supply.
- Communities and borehole operators need to be trained in the operation and maintenance of solar powered groundwater pumps.
- Environmental feasibility should be done using at least two life cycle analysis software and compare the results obtained for better accuracy on environmental impacts.
- Monitoring impacts from different types of solar panels, to evaluate which has most impacts on the environment.
- Analysing the manufacturing phase to find ways to decrease the high environmental impacts emanating from this phase.

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Appendix A

Descriptions of other villages visited but not used in the scenarios of this study

Mphangani and Zava

The village of Mphangani has seven boreholes that exist and of the seven, only two are working/operational. The other boreholes are dry and have poor water quality, and the water is not safe for drinking. All the boreholes were drilled by the Department of Water and Sanitation and their details can be obtained from the Mopani District Municipality (the water services authority in the area). The boreholes are also centred in one place with no reticulation and they experience problems with diesel pumps. The village has one big reservoir and two 10 m^3 JoJo tanks which are currently not in use. These problems have forced the villagers to have illegal water connections. One other major concern was that the municipality does not maintain the existing infrastructure and the villagers do not know who exactly is responsible for maintaining the infrastructure between the local government, contractors or the community itself.

Members from the farmers' committee raised an issue about the poor support from the Department of Agriculture and the representative from the Department informed the farmers about budget constraints that have been implemented, which affected their travelling allowances for traveling to the villages during the Covid-19 pandemic. The Department further advised farmers to take initiative and visit the offices of the Department of Agriculture on an annual basis to find out about available funding schemes. The ward councillor was very supportive of the proposed project and was eager to take the research team to visit three sites.

The first site visited was borehole MPA.21.001, which was connected to a reservoir situated about 1 km away and was not functional. The second site was also a borehole which was not numbered and groundwater from this borehole was for domestic use by the adjacent suburb. The boreholes and infrastructure are maintained by the community users. The third site was the VVV farm, which cultivates a variety of vegetables (peppers, cabbage, tomato, chillies, watermelons and maize) and uses drip irrigation. The drip-irrigation system makes use of water pumped from the Greater Letaba River, situated 1.4 km away, and two power generators. The farm spends about R200 of diesel per day to irrigate 4 hours per day with drip-irrigation. The farms produce is sold at the market.

Khaxani and Xitlakati

The villages are situated near the confluence of the Molototsi River into the Greater Letaba River. This is an area that collects drainage water in the catchment and it is relatively rich in water. Water is collected into a large earth dam and groundwater is consistently found about 10 m deep. These communities use boreholes as a back-up since the dam in the village runs dry and the boreholes do not run dry. The community has a water committee and the majority of the challenges in these villages were of technical nature. There are two operational boreholes from where water was pumped from, however the pumps in these boreholes were stolen so there is a need for new pumps. The boreholes pump water to a storage tank that is elevated above ground level. There is a reticulation system in place for distributing water from the tank but it needs a booster pump to increase the water pressure so that water can reach all parts of the villages. The main bulk water pipelines are not connected to the storage reservoir.

The farmers in the villages complained about farming equipment being expensive and also the costs for getting/renewing a PTO (Permission to Occupy), they requested for help with the PTO process. The villagers indicated that fencing and the cost associated to it was also a challenge. The village had no pipes or a dam that supplied water from the river to the farms, therefore farmers were forced to drill their own boreholes independently. However, the water from these boreholes was not sufficient for farming purposes. The farmers use furrow irrigation and they indicated that they were not aware about the water rights requirements.

The two operating boreholes with pumps were visited which were established by the Department of Water and Sanitation and numbered H14-0121 and H14-0771. In addition, an abandoned, previous cooperative farming site was visited. The equipment and assets were stolen and vandalized.

Matsotsosela, Mzilela and Mayephu

In Matsotsosela, water is supplied through the bulk water supply system from Xitlakati once per week. There were four boreholes in the village and of the four one was dry with no water. Two of the four boreholes are meant to be powered by electricity as they are connected to the electric grid power line. Households within the village practice subsistence farming with the willingness to move to large scale farming once conditions allow. There is one borehole that is close to the reservoir but it is old and therefore not functional. There is one operating borehole, however water cannot reach all areas and it does not supply the entire village, the cost of electricity is very high. Boreholes H14-0026 and H14-0025 were visited, both established by the Department of Water and Sanitation. Borehole H14-0026 is not functional whilst borehole H14-0025 is operational. It is located 1 km from the reservoir and it supports various villages, but it needs a stronger pump because the pressure head is too low.

Mzilela has three boreholes which are not electrified, water can only be accessed once a month through the bulk water system supply. Only one borehole is operational with a booster pump that fills the reservoir tanks. There was a new borehole which was drilled by Mopani District Municipality but fuel supply for pumping is a problem. The community has a poultry project which they are struggling to operate due to high electricity costs. The Mzilela cooperative farm, is not operating any more due to a court case on PTO between the women's cooperative and new younger aspiring farmers. The borehole, pump and water storage tank for the project are still in place.

In Mayephu, there are 21 boreholes in total and out of these, two were newly drilled and have not been connected to the grid power. The boreholes are H14-1815 and H14-1818 established by the Department of Water and Sanitation. One of the two boreholes (H14-1818) is situated at a location in the village that may cause contamination, it is not connected to the electricity grid and not functional. There is one functional borehole (H14-1815) which is located at about 1 km from the village's reservoir and has sufficient water. In this village, water has to be pumped five times a week in order to refill the tanks for only one day of water supply. There are fuel limitations due to costs. The community members viewed the installation of solar energy equipment as an economic benefit at this site to adjust and increase the pumping hours. The local government does not monitor the system and it is operated by the water committee member on a voluntary basis. The water committee member and operator of the system felt that the local government should recognize his work and give him some compensation since he volunteers to provide services for them.

The fuel consumption is about 210 L per 10 days. The municipality often sends a truck to supply water to the community but the water is never enough to supply the whole village, it's a first-come first-serve arrangement and each household is allocated 60 L. The Mayephu village does not have any agricultural activities due to the lack of water.

Mghonghoma, Guwela

There are eight boreholes that were drilled in the village and only one is operational. Some of the boreholes were drilled by Mopani District Municipality but were left unequipped. The community does not have a storage facility for the pumped water and water does not reach all households. Villagers have to carry the pumps in and out, preventing them from being stolen. The watering points require travelling long distances. The villagers raised the need of a small earth dam that could be used for livestock watering, as borehole water is used for domestic purposes at this point in time.

Guwela had five boreholes and out of the five, two are not working. One is powered by diesel and the other through electricity. The boreholes are situated/located in such a manner that they cover the whole community. Guwela has five zones and only one (Zone 1) has more water as compared to the rest, it receives water twice a week from the trucks that supply water.

Dzumeri

Dzumeri has seven sections and only three sections have boreholes that are operational. In the remaining four sections, community members have to buy water from those that have drilled boreholes in their back yards. The village has 6 boreholes in total and only two are working, yielding enough water. The other four boreholes in the village either have no water at all, have collapsed or have a low yield. One of the two functional boreholes was located at a distance from the community, meaning villagers have to travel far in order to access water since there is no reticulation system. The community indicated a need for water to be brought closer to the village, they also believed that their farming can flourish if they were to have access to adequate water. Some farms have stopped operating due to lack of water supply.

Dzumeri village spreads along the Molototsi River and a lot of water can be found along the riparian area. There were three boreholes along this river which could be good sites for a water supply system. The community alluded to the need of pumping water closer to the village to prevent the long distance travelling to get water. They also proposed building a small dam on the Molototsi River that could capture high flows.

During the consultative discussion, community members indicated that villagers are in dare need of water and they need interventions to start as soon as possible. They also asked whether the intervention would include people that intend to start farming or only people that are already farming. In addition, they were also interested whether the study will benefit the whole community or only farmers. The representative of the Limpopo Department of Agriculture and Rural Development informed the community that PTOs can be obtained via the Municipality upon approval from the traditional leader (the approval is part of the documentation submitted to the Municipality).

Three boreholes along the Molototsi River were visited. They are between 150 and 200 m deep and very good yielding (about 6 L/s). They operate on electricity. However, the community needs to drive to the site to fetch water because of steep slopes. There is need to uplift the water to the village. The boreholes were drilled by Mopani District Municipality and they are marked with the Department of Water and Sanitation markers. Additional boreholes are located in the village and they were also visited. One borehole pumps water to the community on street taps, but it doesn't have a reservoir, which makes it inconvenient to operate. Another borehole is in the village, and it is accompanied with 5 Jojo tanks mounted on an elevated structure that is easily visible from the main road.

There were three farms that were visited in Dzumeri and adjacent suburbs. The first farm (JDN Trading) was a vegetable farm with two boreholes. According to the farmer, a former school principal, it is not clear whether the borehole yield is sufficient and the pressure head appears to be low. The boreholes in the farm are operated with electricity. The second farm was Aritirheni Mqekwa farm located in Daniel Ravalela village. It is a mixed family farm with a mango orchard and vegetables that was used as study site in previous research (Jovanovic et al, 2018). There were 9 boreholes on the farm, 4 of which are fairly new and they were drilled by the Department of Water and Sanitation in 2016. Borehole logs and characteristics are available from previous WRC research (Jovanovic et al, 2018). The farm is adjacent to a dam. The farmer used diesel pumps and an electricity line was connected on the farm a few years ago. However, the electricity costs are extremely high (R5000 per month). The third farm was Nhlambeto farm and it is located in Dzumeri village on the Molototsi River banks. The emerging farmer was growing vegetables until last year abstracting water from the river bed for irrigation. He was recently asked by the community to stop abstracting water because this lowers the groundwater level and other water users cannot dig deep in the river bed to collect water for household consumption. As a result, the farmer stopped farming. However, the problem could be resolved by installing a deeper abstraction point. Based on previous geophysical measurements, the river sand alluvium is between 4 and 6 m deep (Jovanovic et al, 2018).

Muyexe

The Muyexe village has 12 boreholes in total and only four are working. The community receives water from the bulk water system from the Nsami dam, however this supply is often cut off for periods of about 1-2 months. During those periods, the village depends on borehole water and uses it for domestic and livestock supply. One borehole is connected to the main bulk water supply system; the other boreholes can be accessed by the community but they are at a great distance. A reverse osmosis water purification system exists but was only functional for the first six months after which it broke down, electric cables supplying power to the system were stolen. There were two boreholes which were visited that were operational and delivering water through a reticulation system to the street taps, however the pressure was low, and the purification system (reverse osmosis) of these boreholes was not functional. Both these boreholes are powered by electricity and the bill is paid by the Municipality.

The village of Khakhala did not have any boreholes, except for the two boreholes that are currently not operating since they are not connected to the electricity grid. Water is needed for domestic use and livestock. Bulk water is supplied only once in a month.

A farming site was visited where the Muyexe community project was developed in 2013 -14 through the Rural Development Program, the site is currently being rehabilitated by the Limpopo Department of Agriculture and Rural Development. The farm has drip-irrigation laterals, a main conveyance pipe system and fertigation tanks already installed. One new borehole has a low yield and the older borehole drilled by the Department of Water and Sanitation had a very good yield, but its pump needed to be repaired. The pack house built on the premises consists of offices and storage space. The site has also a storage building and a nursery.

The figures below are pictures taken during site visits

Figure 5. 13 Showing community workshop held in Mbhedle

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Figure 5. 14 Mayephu village reservoir about 1 km from borehole; cost of fuel to pump water into the reservoir is very high.

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Figure 5. 15 Village reservoir; a booster pump is sufficient to fill tanks; however, no diesel is supplied by Municipality to operate it.

Figure 5. 16 A hi tirheni Mqekwa farm in Daniel Ravalela (Dzumeri)

Appendix B.

The following is information obtained from farmers about their income vs expenses, these data were used in the Farm Analysis tool.

<u>JDN farm expenditure type</u>

Seasonal crop expenses: R434 for 1000 seeds; buys 5000 seeds for cabbage

Perennial crop expenses: R370 per 1000 mangoes for harvesting

Livestock: N/A

Operation& maintenance(infrastructure): R3500 per month

Operation& maintenance (fixed equipment): N/A

Fuel cost: R600 per hire for a tractor; R1500 tires replacement

Labour:

Sales and distribution: R360 per day (packing) per person

Management and administration: R12.50 market fee, for selling at the market.

<u>Income</u>

Seasonal crop sales: R1600 for 68 tomatoes boxes

By products from seasonal crop: N/A

Perennial crop sales: R9800 sales for a month

<u>Equipment</u>

Tractor: R275 000 (second hand)

Water pump: R3500

Workers

6 temporary workers, female (5) male (1)

Salaries: 1500 p/m

Aritirheni Mqekwa Agricultural Primary Cooperative.

Farm size 10 ha, but 6.5 used for seasonal crop, 3.5 perennial crops

Expenses Type:

Seasonal crop expenses: 12 kg delicate fertiliser R5500 per season

Perennial crop expenses: N/A

Livestock: N/A

Operation & Maintenance: R30000 pipes for irrigating per year

Operation &maintenance: R20000 motors & pumps per year

Fuel: 2 trucks fuel R100 000 per year

Labour: R10 000 per month

Sales & distribution: R30 000 per season

Management & distribution: packaging R5 000 per year

Income

Seasonal crop sales: R300 000 per year

Electricity: R3500 p/m

Equipment & asset

2 tractors: R590 000 each

Ripper plough: R70 000

Disc offset plough: R45 000

Disc plough: R33 000

Furrow plough: R8000

Slasher: R16 000

Trainer: R65 000

Borehole costs: R30 000 for maintenance/ repairs

3 JoJo tanks: R34 000

Main pipes: R30 000

Farmshed value: R15 000

Tractor hiring: R1050 per hectare

Staff consisted of 4 males and 5 females, 9 in total

PTO for land occupation

Salaries: R1700 per month

Solar Panels Quotes for use in payback tool

AF SOLAR INSTALLER
VAT NO:
Reg:
30646 Maluleka street Mamelodi Easte

BILL TO
DR Eugene Sagwati
Custom VAT NO:
Telephone:+27679088755
Mobile:
Email Adress

Number: Quo113
Date: 20/09/2021
Page: 1

OFF GRID QUOTE

Description	Quantity	Price
LP5K - Luxpower 5KW Off-Grid	1	R 11,250.00
CNBN-330W Polycrystalline Solar Panel	6	R10500
4 SH5.12 - Shoto 5.12kwh Lithium Ion Battery	1	R 23,500.00
FD160-Fuse switch disconnector Size 160A	1	R650
100DF-100A 500V DIN Fuse 100NHG	2	R85
4 Strings low voltage combine box	1	R2400
W6B-6mm Black solar cable wire	15m	R250
W6R-6mm Red solar cable wire	15m	R250
GR1-6mm Galvanized Rail-0.8mm(25x11mm	2	R626
PS1S-Power snap 9B Clip	24	R720
Double power transfer switch	1	R900
MC4 Connector	4	R 173.92

Only material TOTAL: R50404.92
LABOR: R11000
Labor incl material; R61404.92

OFF GRID QUOTT

AF SOLAR INSTALLER
VAT NO:
Reg:
30646 Maluleka street Mamelodi Easte

BILL TO
DR Eugene Sagwati
Custom VAT NO:
Telephone:+27679088755
Mobile:
Email Adress

Number: Quo113
Date: 20/09/2021
Page: 1

OFF GRID QUOTE

Description	Quantity	Price
LP5K - Luxpower 5KW Off-Grid	1	R 11,250.00
CNBN-330W Polycrystalline Solar Panel	6	R10500
DYN3 - 3.6kWh Dyness Li-Ion Battery	1	R 14,686.96
FD160-Fuse switch disconnector Size 160A	1	R650
100DF-100A 500V DIN Fuse 100NHG	2	R85
4 Strings low voltage combine box	1	R2400
W6B-6mm Black solar cable wire	15m	R250
W6R-6mm Red solar cable wire	15m	R250
GR1-6mm Galvanized Rail-0.8mm(25x11mm	2	R626
PS1S-Power snap 9B Clip	24	R720
Double power transfer switc	1	R900
MC4 Connector	4	R 173.92
DYN4 - Dyness Power Cable	1	R 313.04

Only material TOTAL: R42804.96
LABOR: R10000
Labor incl material; R52804.96