Technical and Financial Feasibility of Alternative Renewable Energy Sources and Technologies in Irrigated Agriculture

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Background and Motivation

South Africa has been challenged with an energy crisis for some time. This has included the remoteness of electricity in rural areas, as well as the negative impact on the environment due to an overreliance on coal as a source of electricity. To address this challenge, framework policies have been adopted to enable increasing portions of renewable energy in the national mix.

Irrigation farming profitability is increasingly under pressure due to the rising cost of pumping irrigation water. The average tariff of electricity supplied by national parastatal ESKOM, has increased on average 11,3% per annum in the last 18 years. From 1998 until 2007 the increase in the tariff of electricity supplied by ESKOM was moving along with the inflation rate, sometimes as low as 2,5%, but in the year 2008 the average tariff of electricity increased rapidly. In one year it was 31,3% to maintain the company's sustainability and cover expenses associated with the expansion of infrastructure (Venter *et al.*, 2017).

The increase in the tariff of electricity has a significant effect on the cash flow, profitability and sustainability of irrigated agricultural production, and producers are employing various new technologies and improved managing methods to optimise water and electricity consumption (Dalton *et al.*, 2012). However, the above inflation increases in cost of the electricity supplied by ESKOM together with renewed interest in alternative energy sources, have made the option of alternative renewable energy more attractive and financially feasible (Lagrange *et al.*, 2016).

Alternative energy sources include solar, wind, water (hydro) and biomass schemes. Of most interest is solar energy as most areas in South Africa have an average of more than 2 500 hours of sunshine per year while average solar-radiation levels range between 4 to 5 and 6,5 kWh.m^{-2} in one day. Consequently, South Africa is ranked amongst the countries with the highest potential to generate electricity from solar radiation (Van Wyk, 2014).

Photovoltaic pumping dates back to more than 50 years in Europe, although mostly used to solve drinking water problems. A stable photovoltaic pumping market has since developed to supply water for developing countries and rural communities. The use of these relatively small systems, lower than 10 kW, had an economical explanation, as the use of variable flow and pressure is relatively easy, although they also require high reliability (Navarte, 2017).

In recent years, the photovoltaic pumping scenario has been deeply altered due to the drastic reduction in prices of photovoltaic modules, triggered by the Chinese industry. Furthermore, the rapid reduction of prices of frequency converters, supports the installation of relatively large photovoltaic systems, up to hundreds of kW, to replace either generator sets or the conventional electric grid for irrigation systems for large areas.

The potential market for these application in irrigation in South Africa is vast. According to the WWF, South Africa's wind energy potential alone is 6 700 GW (gigawatts), and the National Development Plan calls for the procurement of "at least 20 000 MW of renewable electricity by 2030" and the decommissioning of 11 000 MW of ageing coal-fired power stations (Creamer Media, 2018).

Problem Statement and objectives

Although a number of large commercial irrigated production enterprises has implemented solar and hydro schemes at farm level, there are still conceptions that alternative energy is expensive, vulnerable and not as reliable or sustainable as grid electricity, raising questions regarding the feasibility thereof at relatively small scale and in different parts of the country. There are still many questions regarding the feasibility of renewable energy in the irrigation sector, despite the success of currently implemented schemes. The need for a scoping research study regarding the technical and financial feasibility of alternative renewable energy sources and technologies in irrigated agriculture was therefore found necessary.

Outcomes and expected impacts from the study include research about improved energy security and transition to low-carbon economy and a reduction in dependency on expensive coal generated electricity. One of the outputs to be developed throughout the duration of the study include a database of technologies used with RE in irrigation with characteristics and conditions of use.

Subsequently this research can provide insight with regards to climatic aspects influencing feasibility of RE in the irrigated agriculture sector in different parts of the country and specifically at relatively small scale. Ultimately the scoping research study aims to address current outstanding issues contributing to the feasibility of using alternative energy sources and provide information on techno-economic factors affecting implementation.

The general objective of this research was to determine an overview of the technical and financial feasibility of alternative renewable energy sources and technologies in irrigated agriculture.

The following specific objectives were set to achieve the general objective of the research:

- To determine the extent of renewable energy application and the technologies currently used in South Africa's irrigated agricultural sector.
- To determine the factors affecting technical and financially feasible renewable energy supply solutions.
- To provide spatial guidelines in terms of maps showing the technical and financial opportunities of using alternative energy sources in irrigation and requirements for more research.

Approach and methodology

The initial approach of the study entailed a comprehensive literature review to identify the factors affecting the feasibility of alternative renewable energy sources for irrigation. Information was obtained with respect to what renewable energy source are, how it is harnessed and the adoption and use thereof worldwide. The different policies, procurement programmes and potential promotion in terms of the uptake of renewable energy as a source of electricity was investigated. The review further included research about the application of RE systems in irrigated agriculture with specific reference to existing systems, possible hindrances and viability solutions as well as how these systems operate. From the literature review it can be concluded that there is a need to verify the feasibility among different renewable energy sources for application in irrigated agriculture. It is important to evaluate the most viable irrigation system with renewable energy source combination.

Following the literature review, an overview was done of the potential and availability of renewable energy sources across South Africa and the ongoing or completed research in this regard. Next, the current implementation of renewable energy use in South Africa relating to irrigated agriculture was assessed. A process was undertaken to identify case studies in South Africa. Information about potential case studies was collected from meetings with specialists, literature, associations, webinars as well as suppliers of renewable energy sources identified during the course of the research study. Visits were arranged to some locations to establish the extent of the use of RE irrigation systems on the ground. Ample information was collected with the different approaches followed. In addition to the case studies identified, a database with various clients and suppliers, the type of RE system they installed was prepared.

As part of the spatial assessment of the technical and economic feasibility of renewable energy sources, a general framework to evaluate the planning and design of renewable energy systems was developed. The framework provides a means to conceptualise the different components and processes necessary to develop a renewable energy system in an integrated way. Various factors may drive the interest in renewable energy sources and it is important to understand these drivers since they provide the business case of the system. With the general framework as point of departure, the pre-feasibility process of applying renewable energy in irrigated agriculture was assessed. The general configuration of systems, the energy potential and the calculation of the output power was considered. An application of the framework and assessment was undertaken in the form of a case study relating to solar energy systems.

Lastly, solar feasibility maps were developed for daily energy requirements of 100 kWh, 500 kWh and 1 000 kWh which is also the technical feasibility if there is space on the user's property for the area and solar panels required. Solar panels with a standard performance of 0,325 kWp and solar panel area of 1,937 m^2 were selected for the feasibility maps. Different solar panel performance and area figures will result in different total number of panels and surface area required. The economic feasibility associated with these maps is indicated accordingly.

Results and conclusion

The techno-economic viability of PV systems and subsequently all alternative RE systems is influenced by numerous factors such as: the available space and design of the system, installation costs, operational and maintenance costs, financing options, electricity usage profile of the site, the generation profile of the plant, how often the system will be offline and the applicable electricity tariffs.

South Africa has some of the highest solar irradiance in the world and experiences some of the highest levels of yearly horizontal solar irradiation globally (WWF, 2017). Most regions receive an average of 8 to 10 hours of sunshine a day. The annual average hours of sunshine are 2 500 hours, with a 4,5 to 6,6 $kWh.m^{-2}$ level of radiation. Solar resource maps have been developed for the country and data from the Global Solar Atlas can be used to quantify the photovoltaic energy potential for a specific site. An initiative has also been implemented to avail high-resolution ground-based solar radiometric measurement data from stations located in the region of Southern Africa.

The potential of wind resources in South Africa is similar to that of solar resources. Adequate resources with the potential for high load factors can be found countrywide. As part of the WASA project, a high-resolution wind resource map for South Africa was developed. Mean annual wind speeds of 4 $m.s^{-1}$ are experienced at elevations of 100 m in most parts of the country. Although small-scale wind turbines operate effectively at this wind speed, they are normally mounted at elevations less than 50 m. Nineteen observation masts have been established to obtain metrological data concerning wind energy as part of the WASA project.

There is potential for 247 MW new small-scale hydro developments (PM and SANEDI, 2017). Rural areas of the Eastern Cape, Free State, Mpumalanga and KwaZulu-Natal are suitable locations especially for the development of small and micro hydropower plants. South Africa also has a lot of potential for embedded water transfer and gravity-fed systems (GIZ, 2015). Structures such as syphons, control gates, weirs, chutes and drops in the irrigation canals all across South Africa hold large unexploited hydro kinetic potential. There are flow measurement gauging stations in most of the major rivers, and canal networks, throughout South Africa.

The BioEnergy Atlas Project was initiated to assess the factors that determine the availability of the bioenergy feedstocks in South Africa. A newly developed web-based tool used for crop-based biomass and various maps for determining bioenergy potential have been developed. The implementation of biomass projects for the generation of electricity however still faces financial barriers in comparison to other mainstream renewable technologies such as wind and solar energy. Bio-digesters are generally not used for pumping water for irrigation.

Technological progression increases the viability of using RE as energy source for irrigation. The South African irrigated agriculture sector will benefit most from innovations with respect to PV systems and localised hydro energy schemes. Hydro power is definitely an option as renewable energy if there is a drop in elevation and security of water supply. The adoption of RE solely for irrigation purpose on a commercial scale is, however, still relatively low which raises the question whether potential users of RE are aware of recent technological developments and legislation.

In the irrigated agriculture sector, the technical feasibility of a renewable energy system is defined as the ability to design an energy system with existing technologies that will satisfy the electricity demand load EDL necessary to irrigate crops economically. The EDL is a function of the kilowatt (kW) required to drive the water through the irrigation system including the water distribution network and the total amount of hours (PH) the system is used to pump water. The evaluation of the factors influencing the required kW, is the output from the design process.

The second focus area, management, is concerned with operating the designed irrigation system with the overall objective of maximising profit. Economic feasibility is determined by calculating the present value of the Life Cycle Costs (LCC) that will result in a levelised cost of energy (LCOE) that is equal to the current cost of energy supplied by ESKOM under the Ruraflex electricity tariff. The LCC of a renewable energy system is an expression of how much it costs to purchase, install, operate, maintain and dispose of the system during its lifetime. The RES is deemed economically feasible if the LCOE is less than the known tariff currently paid for electricity. The breakeven life cycle cost of the renewable energy source can be determined since it is free from product specific data regarding the investment costs, maintenance and operation. Energy will be generated with an economically feasible investment if the LCC of the investment is less than BLCC.

The solar feasibility maps represent the technical feasibility if there is space on the user's property for the area and panels required. The attributes for the three different solar system sizes based on the max and min peak sunshine (kWh.kWp^{-1}) per day in South Africa were determined.

Attributes of a 100 kWh solar system based on peak sunshine per day in kWh.kWp^{-1}

ID	Peak sunshine per day	Energy required	kWp for 100 kWh required	Panels required	Area required	Technical feasibility	BLCC	Annually
Unit	**kWh.kWp^{-1}**	**kWh**	**kWp**	**-**	**m^2**	**kWh**	**R**	**R**
max	5,59	100	17,90	55	106,62	100	150	54 750
min	2,59	100	38,68	119	230,12	100	150	54 750

Attributes of a 500 kWh solar system based on peak sunshine per day in kWh.kWp^{-1}

ID	Peak sunshine per day	Energy required	kWp for 100 kWh required	Panels required	Area required	Technical feasibility	BLCC	Annually
Unit	**kWh.kWp^{-1}**	**kWh**	**kWp**	**-**	**m^2**	**kWh**	**R**	**R**
max	5,59	500	89,48	276	256,79	500	750	273 750
min	2,59	500	193,42	596	555,10	500	750	273 750

Attributes of a 1 000 kWh solar system based on peak sunshine per day in kWh.kWp^{-1}

ID	Peak sunshine per day	Energy required	kWp for 100 kWh required	Panels required	Area required	Technical feasibility	BLCC	Annually
Unit	**kWh.kWp^{-1}**	**kWh**	**kWp**	**-**	**m^2**	**kWh**	**R**	**R**
max	5,59	1 000	178,89	550	1066,19	1 000	1500	547 500
min	2,59	1 000	386,10	1188	2301,16	1 000	1500	547 500

It can be seen from the tables that for places where maximum peak sunshine occurs, less solar panels and surface area is required than for places where minimum peak sunshine occurs. Although the BLCC is the same for both maximum and minimum output, the latter is however considered less feasible since the cost impact will be bigger because of the number of solar panels required. The total number of panels required based on the energy requirement and solar irradiance at a specific location, is shown graphically on the maps.

A bigger impact on costing, is the size of battery and size of the pump. Not so much the size of the solar system and region. The production curve of a solar system is more important than the amount of energy the system yields. When water is pumped with solar energy, it is good practice to design the system larger than is required. A system design can be up to 2,5 times more than the pump/motor size. The cost of the production of water ($R.m^{-3}$) is an alternative method to determine if the installation of a solar system on a specific surface area will be viable.

From the available and derived feasibility maps, it can be seen that the application of renewable energy sources including solar, wind and hydro can be technically feasible in the irrigated agriculture sector. However, each application is site specific. This finding forms part of the new knowledge created by this project. The gaps filled or addressed by the new knowledge include the uncertainty and the lack of knowledge that used to exist about the feasibility of alternative renewable energy sources for irrigation.

New products produced from this research include:

- Scoping report summarising existing information and tools to determine feasibility of small-scale renewable energy application
- Map and list with currently installed renewable energy systems related to irrigation
- General framework to determine feasibility of renewable energy in irrigated agriculture
- Database with suppliers and technologies
- Solar feasibility maps for South Africa.

The scoping report gives a good summary of the different renewable energy systems and technologies, its potential and application related to irrigation. Some maps in terms of the availability of renewable resources already exist for utility level application. The innovation of the products lies in their applicability to small scale systems and irrigation.

The users and beneficiaries of the products and outputs from this study include suppliers, irrigation designers and farmers. Many users are not aware of the information sources available for assessing the feasibility of RES for irrigation. The number of currently implemented RES is small compared to the potential for RES in irrigated agriculture.

Recommendations and future research

Sustainable access to energy in future will require adjustments in both supply and demand design approaches. In the case of irrigation, utilising an alternative energy source will not only require new knowledge and skills in the industry on designing, installing and managing “on-farm” electricity generating infrastructure but also adapted approaches to planning and designing the irrigation system in terms of operating hours available per day and strategic placement of water storages.

An integrated approach to RE development is necessary to ensure that interrelation between the size of the system, energy demand and the rules governing banking and offset of electricity with ESKOM results in the most profitable system. A clear need exists for improved decision support with respect to the management and development of grid-tied systems as an energy security option. The development of a decision support system for irrigated agriculture will fill the gap in financial and economic assessment skills farmers may lack in determining risk and viability of RE projects.

There is scope for a follow up study where solar is definitely an option as alternative renewable energy for irrigation. The detail factors to be considered need to be identified in such a study and the different system configuration options such as elevated storage, grid-tied, not grid-tied, etc. need to be considered. All the intricacies and detailed analysis in terms of what the feasible alternatives are, should be evaluated. There is potential for developing a framework for evaluating different type of systems in more detail and develop a calculation procedure or model that will assist users to undertake a detail analysis in terms of feasibility.

The WRC should finance a new project perhaps in collaboration with local suppliers of alternative renewable energy sources to develop a framework for evaluating different type of systems in more detail and develop a calculation procedure or model that will assist users to take the detail into account.

ACKNOWLEDGEMENTS

The research presented in this report emanated from a project in response to a directed call, initiated, managed and funded by the Water Research Commission entitled:

"Scoping study regarding the technical and financial feasibility of alternative renewable energy sources and technologies in irrigated agriculture"

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
ARC-IAE	Agricultural Research Council – Institute for Agricultural Engineering
AREP	Association of Renewable Energy Practioners
BLCC	Breakeven Life Cycle Cost
CEO	Chief Executive Officer
CO_2	Carbon Dioxide
CRSES	Centre of Renewable and Sustainable Energy Studies
CSIR	Council for Scientific and Industrial Research
DBSA	Development Bank of Southern Africa
DC	Direct Current
DFFE	Department of Forestry, Fisheries and the Environment
DHI	Diffuse Horizontal Irradiance
DME	Department of Minerals and Energy
DNI	Direct Normal Irradiance
DoE	Department of Energy
DPMG	Department of Planning, Monitoring and Evaluation
DRDLR	Department of Rural Development and Land Reform
DWA	Department of Water Affairs
DWS	Department of Human Settlements, Water and Sanitation
EDL	Energy Demand Load
EECS	European Energy Certificate System
EIA	Environmental Impact Assessment
GEF	Global Environmental Facility
GHI	Global Horizontal Irradiance
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HAWT	Horizontal Axis Wind Turbine
HK	Hydro Kinetic
ICID	International Commission on Irrigation and Drainage
IEA	International Energy Association
IPPs	Independent Power Producers
IRENA	International Renewable Energy Agency
IRP	Integrated Resources Plan
LCC	Life Cycle Cost
LCOE	Levelised cost of energy
MoA	Memorandum of Agreement
MPPT	maximum power point tracker
MSEMs	Micro, Small and Medium Enterprises
NDP	National Development Plan
NERSA	National Energy Regulator of South Africa
NPC	Net Present Cost
NSDF	National Spatial Development Framework
NT	National Treasury

PET	Potential Evapotranspiration
PV	Photo Voltaic
PVOUT	Photo Voltaic Output
RDE	Royal Danish Embassy
RE	Renewable Energy
RECSA	Renewable Energy Certificates market participants association – Southern Africa
REEEP	Renewable Energy and Energy Efficiency Partnership
REFIT	Renewable Energy Feed-In Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RES	Renewable Energy System
SADC	Southern Africa Development Countries
SAEON	South African Environment Observation Network
SANEDI	South African National Energy Development Institute
SAIAE	South African Institute of Agricultural Engineers
SAURAN	Southern African Universities Radiometric Network
SAW	Super Armature Winding
SDGs	Sustainable Development Goals
SECP	Sustainable Energy Consumption and Production
SETRM	Solar Energy Technology Roadmap
SPIS	Solar Powered Irrigation Systems
SVPWPS	Solar Photovoltaic Water Pumping System
UN	United Nations
VAT	Value Added Tax
VAWT	Vertical Axis Wind Turbine
VSD	Variable Speed Drive
WASA	Wind Atlas for South Africa
WEPS	Wholesale Electricity Pricing System
WWF	World Wide Fund for nature

LIST OF UNITS

°C	Degrees Celsius
GW	Gigawatt
GWh	Gigawatt hour
$gC.sq.m^{-1}.yr^{-1}$	Grams of Carbon per metre squared per year
ha	hectare
Hz	Hertz
$J.m^{-2}$	Joule per metre squared
$kg.m^{-3}$	Kilogram per metre cubed
km	Kilometre
kW	Kilowatt
kWe	Kilowatt-electric
kWh	Kilowatt hour
$kWh.m^{-2}$	Kilowatt hour per metre squared
$kWh.kWp^{-1}$	Kilowatt hour per kilowatt peak
$kWh.year^{-1}$	Kilowatt hour per year
$kW.m^{-2}$	Kilowatt per metre squared
kWp	Kilowatt peak
$kWp.m^{-2}$	Kilowatt peak per metre squared
$\ell.day^{-1}$	Litre per day
$\ell.hour^{-1}$	Litre per hour
m	Metre
m^2	Metre squared
$m^3.h^{-1}$	Metre cubed per hour
$m^3.s^{-1}$	Metre cubed per second
$m.s^{-1}$	Metre per second
$m.s^{-2}$	Metre per second squared
mm	Millimetre
MW	Megawatt
MWh	Megawatt hour
$R.kWh^{-1}$	Rand per kilowatt hour
$R.m^{-3}$	Rand per metre cubed
TWh	Terawatt hour
V	Volt
W	Watt
$Wh.m^{-2}$	Watt hour per metre squared

1 INTRODUCTION

1.1 Background

Irrigation farming profitability is increasingly under pressure due to the rising cost of pumping irrigation water. The average tariff of electricity supplied by national parastatal ESKOM, has increased on average 11,3% per annum in the last 18 years. From 1998 until 2007 the increase in the tariff of electricity supplied by ESKOM was moving along with the inflation rate, sometimes as low as 2,5%, but in the year 2008 the average tariff of electricity increased rapidly. In one year it was 31,3% to maintain the company's sustainability and cover expenses associated with the expansion of infrastructure (Venter *et al.*, 2017).

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Renewable energy (RE) can be harnessed from solar, wind, water (hydro), geothermal and biomass sources. Of most interest is solar energy as most areas in South Africa have an average of more than 2 500 hours of sunshine per year while average solar-radiation levels range between 4 to 5 and 6,5 $kWh.m^{-2}$ in one day. Consequently, South Africa is ranked amongst the countries with the highest potential to generate electricity from solar radiation (Van Wyk, 2014).

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The potential market for the application of alternative renewable energy systems in irrigated agriculture in South Africa is vast. According to the WWF, the South Africa's wind energy potential alone is 6 700 GW (gigawatts), and the National Development Plan calls for the procurement of "at least 20 000 MW of renewable electricity by 2030" and the decommissioning of 11 000 MW of ageing coal-fired power stations (Creamer Media, 2018).

1.2 Problem statement

Although a number of large commercial irrigated production enterprises has implemented solar and hydro schemes at farm level, there are still conceptions that alternative energy is expensive, vulnerable and not as reliable or sustainable as grid electricity, raising questions regarding the feasibility thereof at relatively small scale and in different parts of the country. There are still many questions regarding the feasibility of renewable energy in the irrigation sector, despite the success of currently implemented schemes. The need for a scoping research study regarding the technical and financial feasibility of alternative renewable energy sources and technologies in irrigated agriculture was therefore found necessary.

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Subsequently this research can provide insight with regards to climatic aspects influencing feasibility of RE in the irrigated agriculture sector in different parts of the country and specifically at relatively small scale. Ultimately the scoping research study aims to address current outstanding issues contributing to the feasibility of using alternative energy sources and provide information on techno-economic factors affecting implementation.

1.3 Scope of project

The project has an exploratory approach which specifically focuses on the available literature on the subject of renewable energy application in the irrigated agriculture sector in South Africa and the factors influencing its feasibility. Information to be obtained include important principles pertaining to the different renewable energy systems, the availability of renewable energy sources, existing system implementation, the development of feasibility maps and the need for further research. The approach entails a literature review and collecting existing information especially in terms of the spatial distribution of the application of renewable energy systems at utility level. Additionally, the factors influencing feasibility need to be identified as well as a general framework to perform a feasibility study. The project does not include the development of a model as such. Each of the renewable energy sources will be examined in terms of its availability, information regarding its implementation and the existing technologies and suppliers.

1.4 Aims and objectives

1.4.1 *Main aim*

- To determine an overview of the technical and financial feasibility of alternative renewable energy sources and technologies in irrigated agriculture.

1.4.2 *Specific objectives*

- To determine the extent of renewable energy application and the technologies currently used in South Africa's irrigated agricultural sector.
- To determine the factors affecting technical and financially feasible renewable energy supply solutions.
- To provide spatial guidelines in terms of maps showing the technical and financial opportunities of using alternative energy sources in irrigation and requirements for more research.

1.5 Research question

- How does the financial and technical feasibility of alternative renewable energy sources and technologies affect their application in irrigated agriculture?
- What information, methods and tools are available to assess the feasibility of the application of renewable energy sources in irrigated agriculture?

1.6 Significance of the study

The scoping study will aim to address current outstanding issues contributing to the feasibility of using alternative renewable energy sources such as:

- Available technologies, their characteristics, capital costs, current degree of use and service providers.
- Operational aspects over the life cycle of the technologies to determine advantage, disadvantages, and life cycle costs.
- The potential application of the different technologies in different regions of the country.
- The condition for and scale of successful implantation of renewable energy sources in irrigation.
- The requirement for more detail investigations.

1.7 Structure of report

This section consists of all elements being discussed in this report. Chapter 1 entails a brief introduction on the importance, challenges, and necessity of this study regarding the technical and financial feasibility of alternative renewable energy sources and technologies in irrigated agriculture. Chapter 2 focuses on the review of literature about available alternative energy sources and technologies, suppliers and service providers for irrigation. Chapter 3 gives an overview of the potential renewable energy sources identified in different parts of South Africa and Chapter 4 looks into the existing renewable energy systems relating to irrigated agriculture. Certain methods and procedures were adopted to spatially assess the feasibility of the application of alternative renewable energy sources in irrigated agriculture. This is discussed in Chapter 5. In Chapter 6 the study is concluded and Chapter 7 entails a recommendation for future research.

The main headings and sections in this report include:

- Chapter 1: Introduction
- Chapter 2: Literature review
- Chapter 3: Potential renewable energy sources in South Africa

- Chapter 4: Assessing renewable energy use in South Africa related to irrigation
- Chapter 5: Spatial assessment of technical and economic feasibility of renewable energy sources
- Chapter 6: Conclusion
- Chapter 7: Recommendations for future research

The following appendices are included:

- Appendix A: Database of suppliers and technologies
- Appendix B: Case studies – current implementation
- Appendix C: Workshop Report
- Appendix D: Knowledge dissemination
- Appendix E: Capacity building
- Appendix F: Solar energy feasibility maps

2 LITERATURE REVIEW

2.1 Overview

Agriculture provides employment to 40% of the world's population, many of whom continue to live in poverty (United Nations, 2015). Irrigation is increasing in demand due to a rising world population demanding higher food production. A changing climate is also adding to the decrease in freshwater supply (Hartung and Pluschke, 2018). Irrigation is a measure that can improve crop yields, reduce the risk associated with fluctuating rainfall patterns and also enable multiple cropping practices (FAO, 2011). It is seen as the engine to help ensure income generation, security in food supply, job creation and rural development. In all these advantages of irrigation, Hartung and Pluschke (2018) states that energy supply is still key to provide this service.

The major source of power for smallholder irrigation is currently either petrol or diesel fuel. Not only do these contribute to CO_2 (carbon dioxide) emission and air pollution, but spillage thereof adds to the pollution of the soil and groundwater. The energy sector is developing many innovations for the use of sustainable sources that are less harmful to the environment (Nederstigt and Bom, 2014). Renewable energy is widely used in a range of different applications, including the power supply for rural irrigation all over the world, as stated in a study by Kaya and Köse (2015).

Renewable energy contributes to approximately 20% of global energy use. Countries such as USA, Germany, China, Japan and India are major investors in renewable energy – 60% of these being in solar energy and 30% in wind energy. Other renewable energy alternatives include hydram pumps, biomass, biofuel and hybrid systems (Nederstigt and Bom, 2014).

The 2030 Agenda for Sustainable Development with the Sustainable Development Goals (SDGs) was adopted by the UN (United Nations) General Assembly in 2015. Among the SDGs is a specific goal on energy with the aim to "ensure access to affordable, reliable, sustainable and modern energy for all". The dedicated goal on energy is also in line with the Paris Agreement on Climate Change (UN, n.d.).

South Africa's National Development Plan (NDP) for 2030 has a long-term perspective to reach a defined desired goal with identified roles for the different sectors of society to achieve it, as mentioned in a Media Briefing by Trevor Manuel in 2013. The NDP seeks to prioritise the procurement of 20 000 MW of renewable electricity by 2030, decommission 11 000 MW of ageing coal-fired power stations, hydro-imports from the region, and increase energy-efficiency investments. With its aim to build environmental sustainability and resilience, the reduction of greenhouse gas emissions and improvement of energy efficiency is highlighted (South African Government, 2019).

Aligned with the 2030-NDP, The National Spatial Development Framework (NSDF) was developed as a strategic long-term spatial plan towards 2050 which will serve as South Africa's primary national spatial development policy. The NSDF identified national spatial action areas, i.e. 1) National Transformation Corridors, 2) Central Innovation Belt, 3) National Resource

Risk Areas, 4) National Urban Regions and 5) Arid-Innovation Region. Each of these action areas correlate with different NSDF sub-frames. Under the national resource production sub-frame, the strengthening of small-scale agriculture is to be performed in action area 1; mineral beneficiation and alternative energy production is to be supported in action area 2; pocket of productive agricultural land and generation of alternative energy generation needs to be supported in action area 5 (Department of Rural Development and Land Reform (DRDLR) and Department of Planning, Monitoring and Evaluation (DPMG), 2019).

2.2 Energy sources

2.2.1 *Non-renewable energy sources*

2.2.1.1 ***Coal***

Coal is used to produce 36% of the world's electricity and provides 77% of South Africa's primary energy needs. Twenty five percent of the coal produced in South Africa is exported internationally, while the remaining production is used in various local industries. The process of producing electricity from coal starts with coal being pulverized in mills into a fine powder. This powder is blown into boilers and the particles are heated up to the point of combustion. This process generates heat which turns water into steam, rotating the blades of a turbine and producing an electric current inside the generator. Power lines are used to transport this electric current to consumers (ESKOM, n.d.).

2.2.1.2 ***Nuclear***

Similar to coal-fired electricity generated from a turbine driven with steam, a Nuclear Power station also requires a source of energy to drive the turbines. Nuclear energy is generated by the nuclear reaction of splitting the atoms of uranium, the natural element with the highest atomic mass. This process is called fission. The heat generated by this process is used to boil water to steam and rotate the station's turbines. This process does not produce any carbon dioxide emissions or greenhouse gases. However, there are various negative perceptions about the nuclear waste produced due to its association with nuclear weapons and the safety thereof (ESKOM, n.d.).

2.2.1.3 ***Natural Gas***

According to International Energy Association (IEA) (2019), approximately 25% of electricity is generated with natural gas which also supplies 22% of the energy used worldwide. Compared to other fossil fuels, natural gas is versatile and considered more environmentally friendly with reference to air quality and greenhouse gas emissions. The use of natural gas for the generation of electricity has become more favourable since 1990. The process for generating electricity, as with coal, entails the burning of fossil fuel to heat water which produces steam that rotates a turbine (IEA, 2019).

2.2.2 *Renewable energy sources*

2.2.2.1 ***Solar energy***

The use of solar energy is usually divided into two main areas: solar thermal and solar electricity. The first uses the sun as a direct source of heat energy and is most commonly used for supplying hot water to houses and swimming pool. The solar electricity seeks to convert light from the sun directly into electricity through a process known as photovoltaic (Kaushik, 2011).

Solar thermal heating

The water heater market in South Africa is showing signs of success and further development. The current implementation of thermal heating includes solar cookers, space heating systems, process heaters and water heaters (Banks and Schäffler, 2006). These systems can be categorised either as passive or active. The latter are typically seen in large-scale applications where a pump circulates the fluid heated by the sun. Passive systems are typically seen in small-scale residential applications know as thermo-syphon systems where the fluid is circulated through natural means (Schmidt, 2019).

Solar photovoltaic (PV)

Solar PV refers to the direct conversion of solar energy to electric power (Nederstigt and Bom, 2014). Solar radiation is the emission of electromagnetic energy from the sun. This energy is measured and reported as the solar irradiance. The units for solar irradiance can be expressed as $J.m^{-2}$ or $Wh.m^{-2}$. The factors that influence the value of the incident energy on the earth's surface include location, air, pollution and cloud cover (Jain and Jain, 2017). Energy from the sun's radiation is utilised by PV, by means of semiconductors exhibiting a photovoltaic effect to capture sunlight and convert it into direct current (DC) electricity. On cloudy days, electricity can still be generated to some extent since direct sunlight is not required for PV panels to work. For PV technologies to constantly supply electric power, inverters and storage batteries are required to store the excess energy. Up to 20% of the industrial or commercial facilities' electricity requirements obtained from the national grid can be replaced by the electricity provided through solar PV systems (PM and SANEDI, 2018).

Data regarding solar radiation is gained from Satellite irradiation measurements, ground station measurements pyranometers and round station measurements of sunshine hours (PM and SANEDI, 2017). The total amount of shortwave radiation received on a horizontal surface from above, is termed the Global Horizontal Irradiance (GHI). This value is of importance to photovoltaic installations. It includes both Direct Normal Irradiance (DNI) as well as Diffuse Horizontal Irradiance (DHI) (Vashishtha, 2012).

Photovoltaic systems may be categorized as either stand-alone, for vehicle applications (solar vehicles), grid-connected and building systems. Electric power is not supplied to the grid with stand-alone systems. The size of these systems varies widely ranging from applications as large as spacecraft to as small as wristwatches (Wikipedia, 2019).

For remotely situated applications such as communication satellites, terrestrial communication sites, remote homes and villages, and water pumps, with small power requirements and where the installation of distribution lines is not feasible, photovoltaic power generation has been an ideal solution. When solar energy at these locations is not sufficient, the configuration of these systems can be hybridised including an engine-driven generator to charge batteries. Even though the utility-provided power has generally been cheaper than the PV power, the latter is becoming more affordable allowing the use of photovoltaics for grid-connected applications to increase. Grid-connected systems have the advantage of supplying emergency electric power when natural disasters occur and utility electric power is interrupted. For these systems inverters are required to convert the DC power from solar cells to Alternating Current (AC) power and feed it back into the distribution system. The large area required for PV modules and its high cost, are however still hindrances to the implementation of PV power to supplement existing electrical utilities (Penick and Louk, 1998).

A basic photovoltaic system integrated with utility grid is shown in Figure 2-1 as adopted from Singh, (2013).

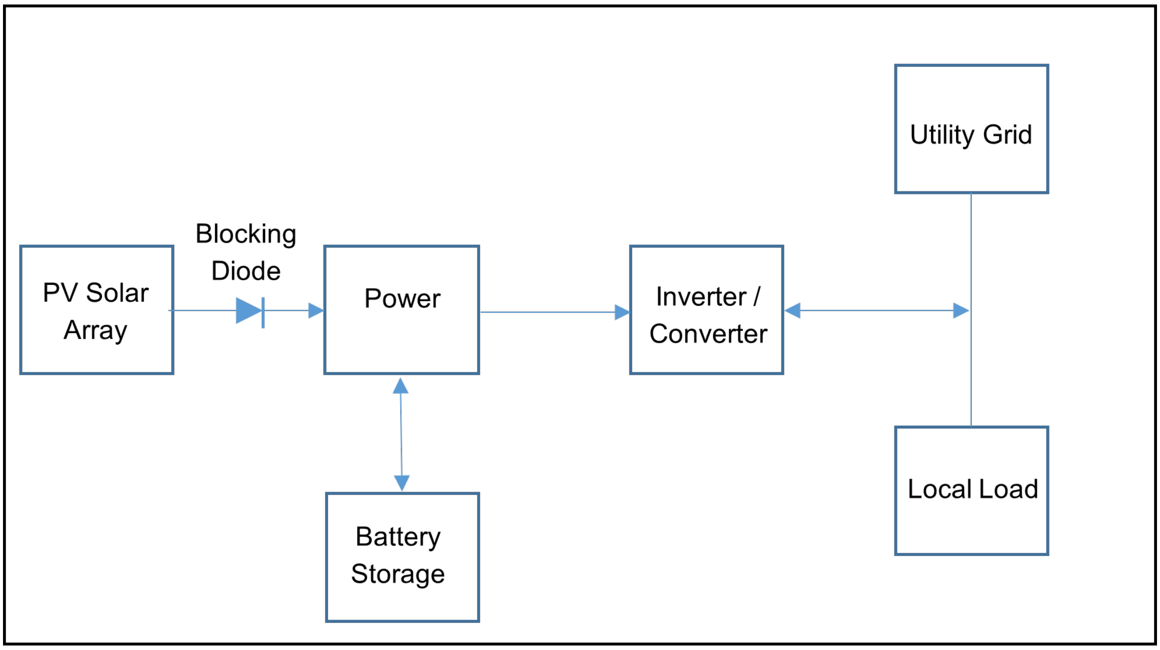


Figure 2-1: Block diagram of photovoltaic system (Singh, 2013)

Solar radiation is converted into electricity by means of the interconnected silicon cells which PV modules (solar panels) are composed of. A flow of electrons, commonly referred to as DC electricity, is created when photons (light) are absorbed by these cells. An interconnected system of PV modules is referred to as a PV array which functions as a single electricity producing unit.

Solar energy is therefore converted to DC power (directly dependent on insolation) by the PV array. The PV system also contains a power conditioner which consists of a maximum power point tracker (MPPT), a battery charge and a discharge controller. The battery bank is required to store excess generated electricity on cloudy days or at night-time. The purpose of the charge discharge controller is to prevent overcharging or too much discharging of the battery bank. To ensure that the maximum power generated by the solar PV array is extracted at all times, the MPPT is needed. The use of MPPT technology is regarded unnecessary in simple PV systems where the battery voltage and the PV module voltage match. Near-maximum power collection from the PV module is possible if the battery voltage is stable enough. To facilitate the array generated power to flow only towards the power conditioner, a blocking diode is used. If this component is not present during low insolation, the battery will discharge back through the solar array (Singh, 2013).

Solar thermal energy

Solar thermal systems use solar energy to heat a medium (either liquid or gas) and transfers the thermal energy to an engine, which can be a turbine, steam engine or Stirling engine. The thermal energy is then converted into mechanical power which can be used to drive a water pump. This pump can also be used manually, thus also giving the option of using it for domestic or irrigational use outside of sunlight hours to get additional water supply. Benefits of these systems include their low cost, simple operation and easy maintenance. They can be repaired locally, which saves the cost of travelling or expensive labour (Nederstigt and Bom, 2014).

Solar thermal electric

The sun's heat is used to drive conventional steam turbine drive power plants with the application of solar thermal electric technologies. An advantage of these technologies is that single plants can be built on a multi-megawatt to gigawatt scale. The potential for energy storage in thermal energy stores, such as molten salt, allows some of these plants to continue operating after sunset. Another practical option is gas hybridisation. Solar thermal electricity generation is likely to be cheaper than photovoltaics and play a larger role in the medium term. This is however still an uncertain comparison (Banks and Schäffler, 2006). Figure 2-2 shows an example of a Parabolic-trough solar thermal power plant (PTSTPP) scheme.

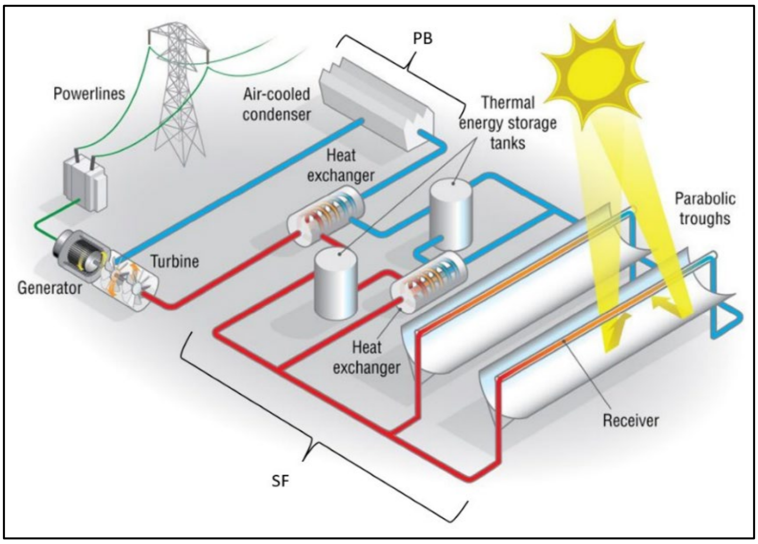


Figure 2-2: Parabolic-trough solar thermal power plant (Arias *et al.*, 2021)

2.2.2.2 ***Wind energy***

Wind is moving air containing kinetic energy. This energy can be extracted by means of wind turbines. The wind causes the rotor blades of the turbine to turn and then rotates the rotor and drive shaft within the turbine producing mechanical energy. Electrical energy is then generated with the turbine's generator. Not all wind turbines require gearboxes (Schmidt, 2019) since small-scale wind turbines have direct-drive generators and can either be induction generators or alternators. Induction generators are basically the same as induction motors. A negative aspect of this system is that the rotor can become so heavy causing the generator to be inefficient at low rotor speeds. The application of this type of generator is usually in larger turbines. Small scale turbines make use of the alternator type generator which is also used in vehicles. In this case the rotor is lighter enabling power generation at much lower rotor speeds (Brosius, 2009).

Small-scale wind turbines can be one of two types, i.e. vertical-axis wind turbines (VAWT) or horizontal-axis wind turbines (HAWT) (Schmidt, 2019). The main wind turbine types are the propeller-type HAWT, drag-based Savonius design, lift-based Darrieus and H-rotor, also known as Giromil, VAWTs. Examples are shown in Figure 2-3 (Kozak, 2014).

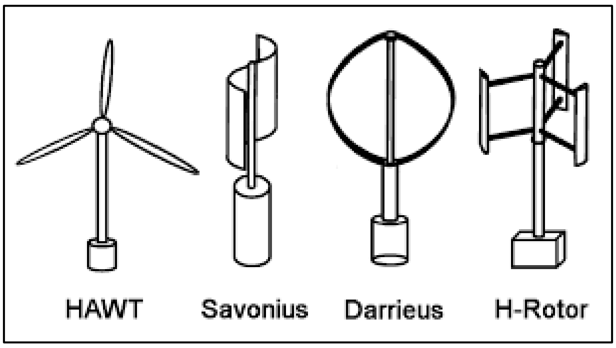


Figure 2-3: Wind turbine types (Kozak, 2014)

Horizontal-Axis Wind Turbines are well suited for farms where there are open areas, allowing wind to blow with ease and minimal obstruction. Vertical Axis Wind Turbines are more suitable in commercial and residential areas since the performance of HAWTs would be negatively affected by the surrounding buildings, etc. in urban areas (Schmidt, 2019)**.**

VAWTs have the following advantages (Brosius, 2009; Schmidt, 2019):

- the turbine doesn't need to point into the wind
- extract energy from any direction
- can operate in places with more variation in wind direction
- operate effectively with turbulent and gusty winds due to less moving parts
- can be installed in close proximity to one another
- efficient

One of the major disadvantages of VAWTs however is that they can be unreliable due to cyclic stress on the tower caused by large torque ripples. Additional rotors or an external power source is often required to initiate turning. This is due to their low starting torque (Brosius, 2009).

In the case of HAWTs it is important that the turbine points into the wind. The direction in which the rotor faces therefore needs to change with the variation in wind direction. The rotor diameters of small-scale HAWTs, range from 1,5 m to 3,5 m. They normally operate at a height of 10 m or higher and require a minimum wind speed of 2,5 $m.s^{-1}$ to start generating electricity. For effective operation an average windspeed of 4 $m.s^{-1}$ is required. The power rating of small-scale HAWTs is 1 kW to 10 kW (Schmidt, 2019). In Table 2-1 the typical sizes of wind turbines and its components are given.

Table 2-1: Sizes and components of wind turbines (Van Dam *et al.*, 2008)

	Utility-Scale	**Small / Distributed**
Capacity	1 MW - 3 MW	300 W - 50 kW
Rotor diameter	60 m - 110 m	1 m - 15 m
Total height	90 m - 170 m	< 50 m
Application	Utility electricity generation (supplying the grid)	Powering nearby (onsite) electrical loads

2.2.2.3 ***Water (Hydro) energy***

Hydropower systems can either be installed at dam walls or downhill thereof (impound system) or in channels diverted from rivers (runoff-river systems). Modern technology allows for up to 95% of the energy available from water to be harnessed and converted into electrical energy (PM and SANEDI, 2018). The purpose with impoundment of water is to create enough head/pressure when releasing the water to turn a turbine downstream of the impoundment. These turbines are referred to as reaction turbines where pressure energy is converted into mechanical or electrical energy. Figure 2-4 shows an example of the installation of a reaction turbine.

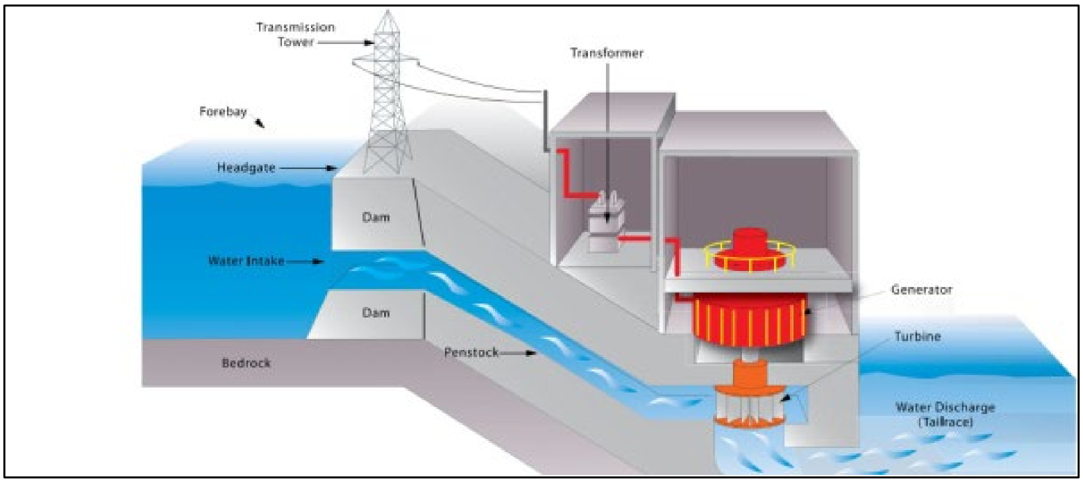


Figure 2-4: Diagram of a hydroelectric generating station (Earth Science Australia, 2021)

Reaction turbines should be constructed to withstand the operating pressure and their turbine blades must be fully submersed (PM and SANEDI, 2018). This type of hydropower systems is either storage-hydropower or pumped-storage hydropower systems. The latter entails continuously harnessing energy from the same water by recycling it between a lower and upper reservoir with pumps (Niebuhr, 2018).

Where water is diverted from a river or installed within existing infrastructure, water flows through an impulse turbine at a high flowrate and by striking the buckets converts the kinetic energy of the moving water into electricity (PM and SANEDI, 2018). Run-off river installations are normally referred to as low-head hydropower systems. These installations don’t require storage facilities and are able to supply electricity on a continuous basis (Niebuhr, 2018).

In Table 2-2 different turbine types and the typical head height at which they are installed are given. In Figure 2-5 different hydropower turbines are shown.

Table 2-2: Turbine types and typical head height (Earth Science Australia, 2021)

Turbine	Head height		
	High > 50 m	**Medium 10-50 m**	**Low < 10 m**
Impulse	Pelton	Crossflow	Crossflow
	Turgo	Turgo	
	Multi-jet Pelton	Multi-jet Pelton	
Reaction		Francis (spiral case)	Francis (open flume)
			Propeller
			Kaplan

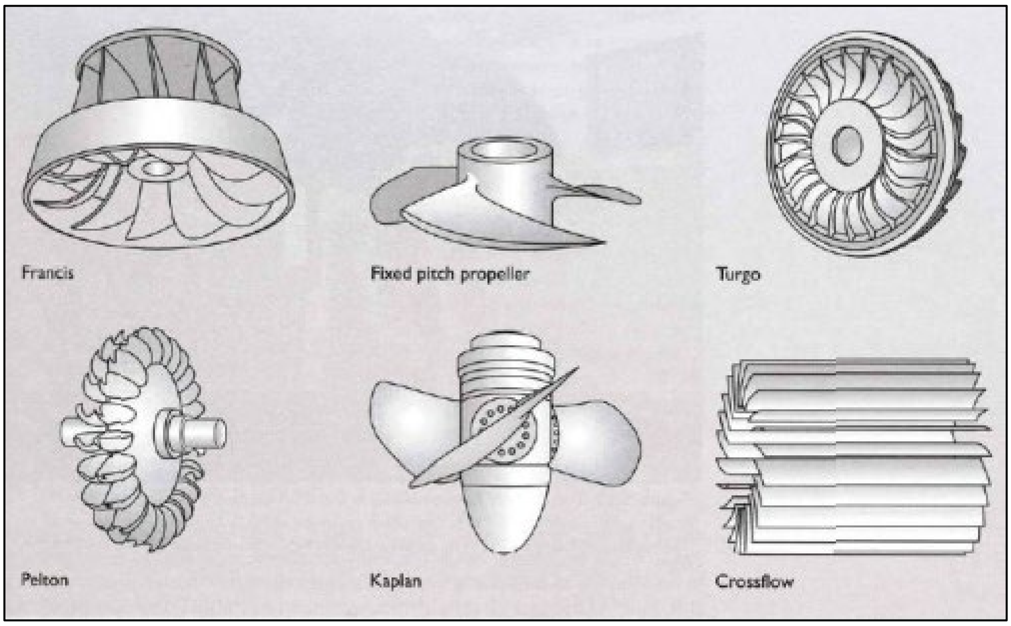


Figure 2-5: Hydropower turbine types (Earth Science Australia, 2021)

Most micro-hydropower plants are installed in a runoff-river system. Micro-hydropower installations at dam walls are limited due to the financial constraints it entails. Small and micro hydro plants have the advantage of being hybridised with other renewable energy sources or standalone systems. Where there are dams on commercial farms there are hydro energy potential (PM and SANEDI, 2018). With reference to the National Water Act, every hydropower plant needs to be authorised regardless of the installation size (DME, 2003).

Energy can also be harnessed from existing water supply infrastructure such as irrigation distribution canals and between reservoirs (PM and SANEDI, 2018). Power at these plants will typically be generated with hydrokinetic (HK) turbines which depends on the velocity of the water rather than the pressure head and flow (Niebuhr, 2018). The HK system components typically include the turbine itself, the support structures (flotation device in some cases), the electric power converter (control systems and generator), the transmission systems and remote communication and control link. Figure 2-6 shows the components.

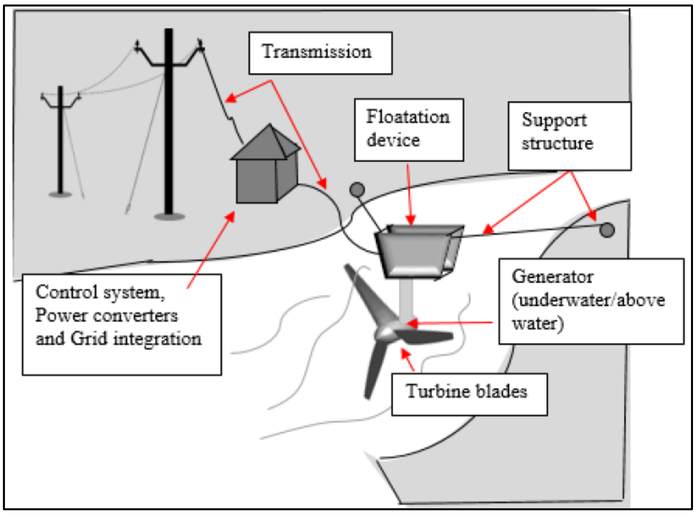


Figure 2-6: Components of HK energy systems (Niebuhr, 2018)

The four important factors to take into consideration when determining the electricity potential and project costs for a hydropower system are the head, flow and the length of the penstock (pipeline) and electricity transmission line. The classification of hydropower systems is based on the head/pressure, i.e. high (>100 m), medium (30-100 m) and low (<30 m) (SEA, 2017). Table 2-3 summarises the classification of hydropower sizes.

Table 2-3: Classification of hydropower size (SEA, 2017)

Category	**Capacity**
Pico	< 20 kW
Micro	20 - 100 kW
Mini	100 kW - 1 MW
Small	1 - 10 MW
Macro / Large	> 10 MW

With good maintenance, the technologies related to hydropower plants can operate effectively for more than 50 years. However, a design life of 25 years is quoted by most hardware manufacturers of hydro-turbines (Schmidt, 2019).

*2.2.2.4 **Bioenergy***

The availability of onsite bioenergy is one of the most important factors influencing its feasibility as a renewable energy source. Electricity production from bioenergy can be used for applications requiring a high power output at a constant supply. These applications typically include electric steam systems, furnaces and reactors. Hybridisation with this renewable energy type is therefore also site specific and only appropriate where the feed stock is sustainably available at a low cost (PM and SANEDI, 2018). Figure 2-7 shows the conversion options of biomass into useful energy.

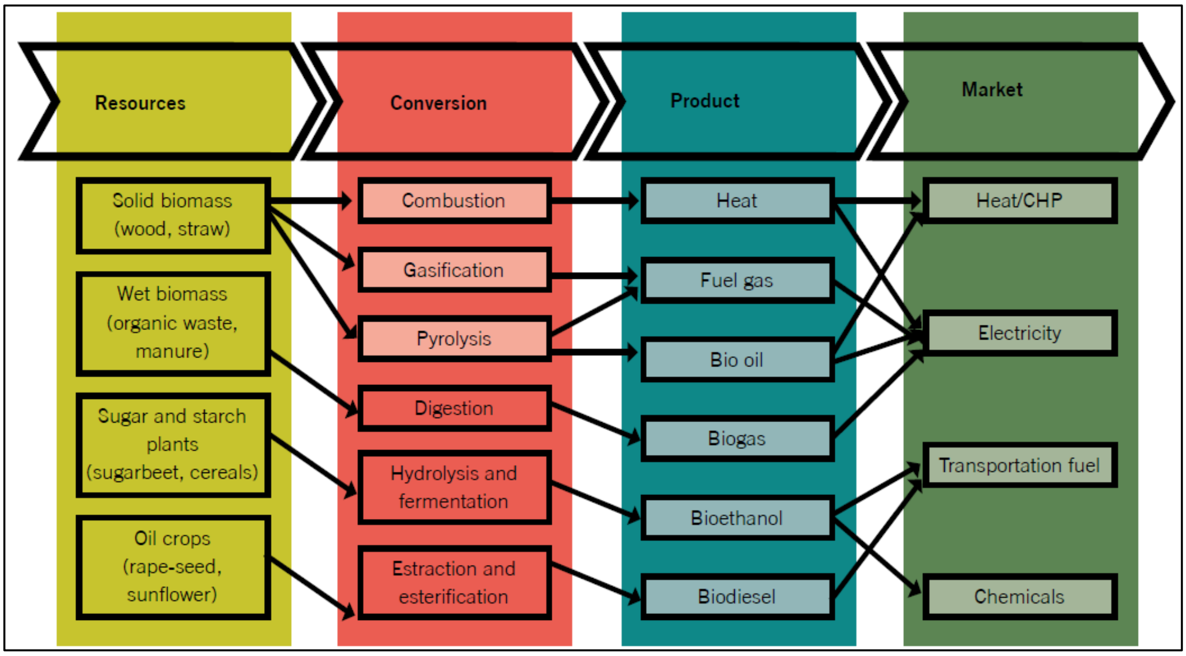


Figure 2-7: Conversion of biomass into useful energy (REEEP and SANEDI, 2016)

Biomass is physical biological material that comes from plants or animals which has the capacity to produce electricity, heat or liquid fuels used in various industrial processes as raw material for a range of products (Hakeem *et al.*, 2015). The use of bioenergy can be classified as 'traditional' or 'modern'. The combustion of biomass such as wood, charcoal and animal waste are referred to as 'traditional' bioenergy. This accounts for more than half of the world's bioenergy use. 'Modern' technologies include liquid biofuels, biogas, bio-refineries, wood pellet systems as well as other technologies (International Renewable Energy Agency (IRENA), 2018).

Banks and Schäffler (2006) explores the direct and indirect use of biomass which can either be directly burned for heating or power generation or it can be converted into oil or gas substitutes. The transport sector uses liquid biofuels as a substitute to gasoline. In densely populated countries, biomass has great potential to boost energy supplies (IRENA, 2018).

2.2.2.5 ***Geothermal energy***

Geothermal is known as the type of thermal energy generated and stored within the earth and is available worldwide (Abolhosseini *et al.*, 2014). Geothermal energy is carried from within the sub-surface to the surface of the earth by means of water and/or steam. Medium to high temperature sources are needed in order to generate electricity. These are mainly found in tectonically active areas (IRENA, 2018). Fischer *et al.* (2006) names the three types of geothermal power plants that are operating today: dry steam plants, flash steam plants, and binary-cycle plants. This form of energy is not dependant on weather conditions and has high capacity factors. These reasons make it possible for geothermal power plants to supply baseload electricity. A schematic showing how geothermal energy works is shown in Figure 2-8.

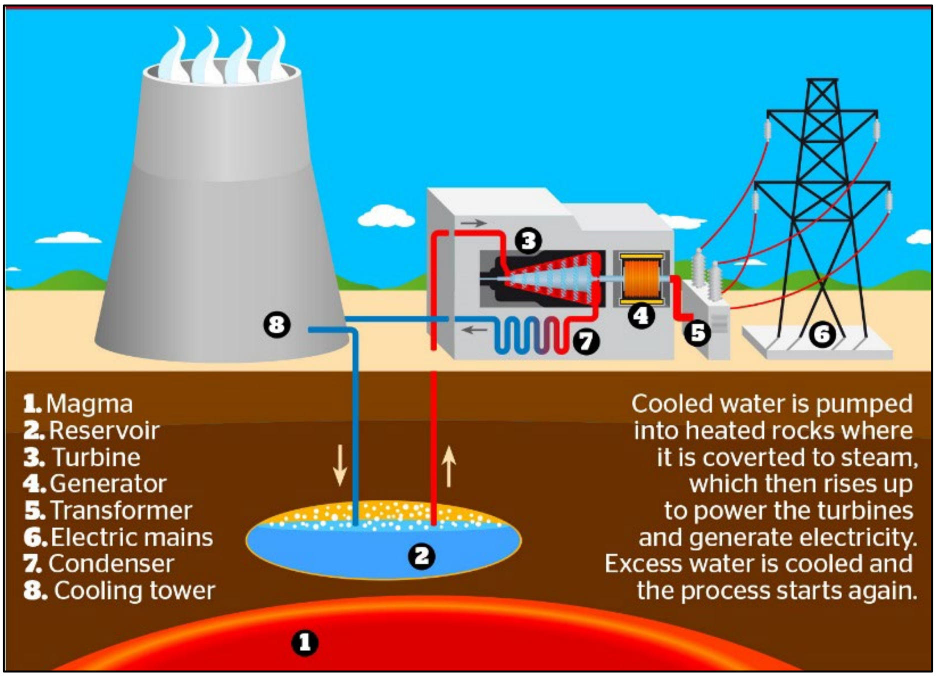


Figure 2-8: How geothermal energy works (Technogineer, 2020)

2.2.2.6 ***Ocean (Wave) energy***

Although not yet in use, the ocean's tides and waves can also be used to generate electricity. Research and development are being done on this promising technology. Wave energy captures the energy in waves to generate electricity, while tidal energy is produced by means of tidal range, tidal current or hybrid technologies. Other sources include salinity gradient energy, derived from differing salt concentrations, as well as ocean thermal energy conversion, which uses the temperature difference between warm surface and deep seawater to generate power (IRENA, 2018).

2.3 The adoption and use of renewable energy

2.3.1 *Globally*

The IEA focuses on energy security, economic development and environmental awareness. They ensure reliable, affordable and clean energy among their 30 member countries and worldwide. They host a free statistics database which allows them to produce timely and consistent monthly data for oil, oil price, natural gas and electricity. In Figure 2-9 the world electricity generation from different sources is shown from 1990 until 2016 in GWh clearly indicating coal as the predominant source.

The adoption and sustainable use of all forms of renewable energy is promoted by the intergovernmental organisation IRENA and they support countries in their transition to a sustainable energy future. This organisation has a statistics department responsible for data collection with regards to renewable power generation capacity, renewable power generation and renewable energy balances. Data is collected from IRENA members on an annual basis by means of a questionnaire and supplemented "desk research".

The global installed Renewable Energy capacity from 2010 until 2018 is shown in Figure 2-10 in hundred thousand MW. Figure 2-11 shows the global renewable energy electricity generated from 2010 until 2016 in 1 000 GWh. Hydropower is the RE source with the most installed capacity and electricity generated (IRENA, 2018).

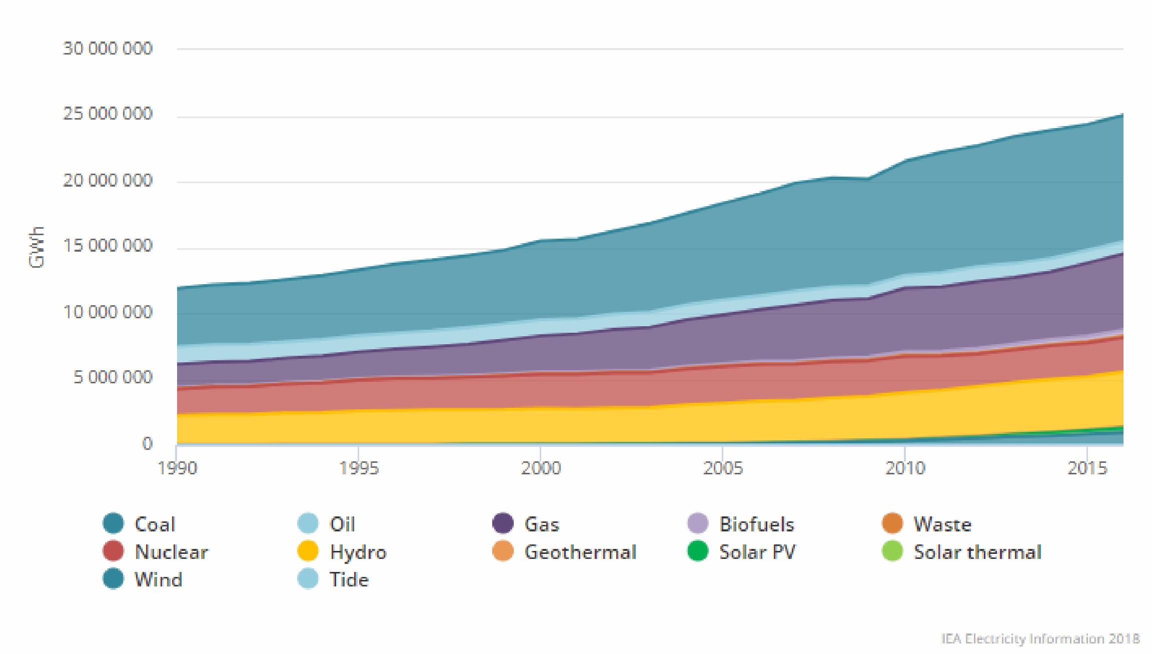


Figure 2-9: World Electricity generation 1990-2016 (IEA, 2019)

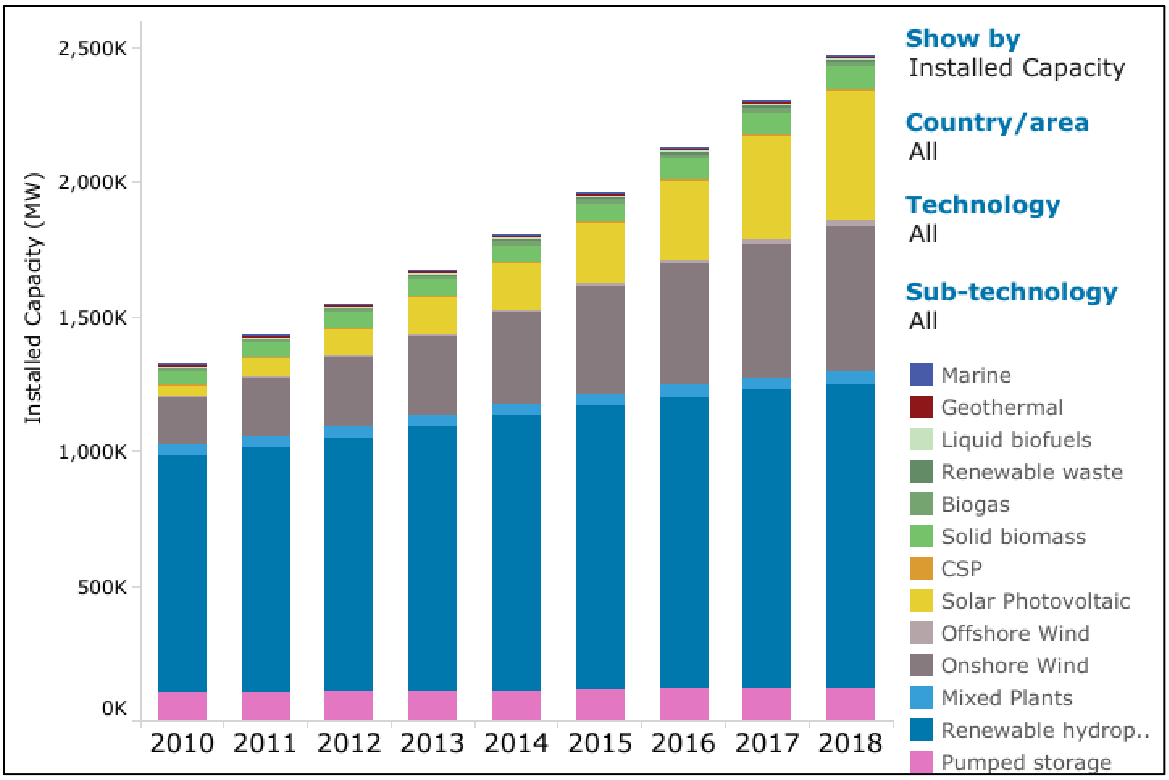


Figure 2-10: Global renewable energy installed capacity (IRENA, 2018)

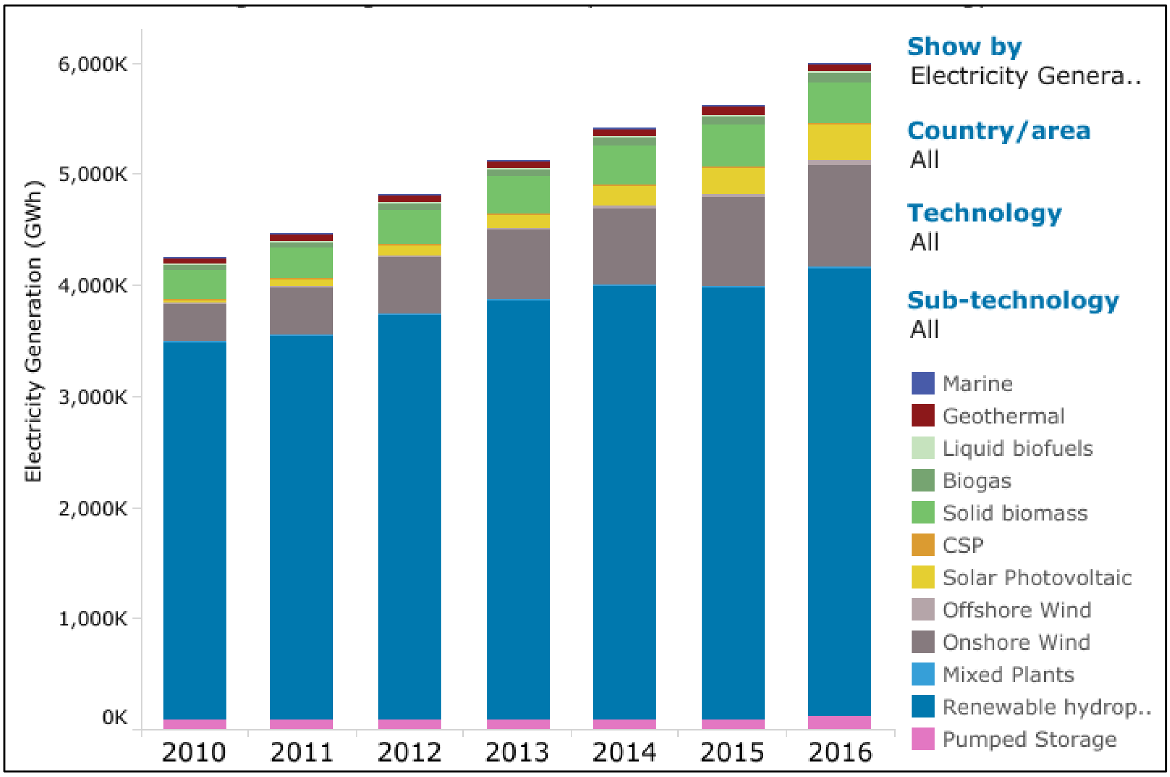


Figure 2-11: Global renewable energy electricity generated (IRENA, 2018)

Humans have harnessed biomass-derived energy, with wood being the largest producer of biomass fuel. Historically, wood has always been a primary source of energy for mankind and is presently estimated by McKendry (2002) to contribute to 10% to 14% of the world's energy supply. In Africa energy is mainly produced from biomass (47%), oil (24,8%), coal (16,5%), gas (10,4%), and other renewable sources, such as large and small hydro, solar, and geothermal sources (1,3%) (Benoit, 2006). Except for South Africa, biomass as a source of generating electricity has not been extensively explored in the African region.

Solar PV systems' share in renewable energy is growing annually. This is due to the result of increased demand and mass production, decreasing the unit price of solar panels. Costs have reduced with approximately 80% between 2012 and 2015. The International Renewable Energy Agency projects a further cost reduction of 59% for electricity generated by solar PV by 2025 compared to 2015 prices (Hartung and Pluschke, 2018). Improvement in technology over the years, resulting in an increase in performance, also makes this a popular choice as an alternative to conservative energy sources. These panels can be placed in any area where there is enough sunlight, at any scale. The installation process as well as operation of the system is relatively simple for small and large systems. Different to petrol or diesel pumps, frequent trips to the nearest town for fuel is eliminated (Nederstigt and Bom, 2014).

Although considered a costly source of energy to harness, prices of solar can soon rival that of traditional coal. In Chile the Northern grid generated more electricity from solar energy than could be consumed locally resulting in very low electricity cost for the consumers. Elon Musk, CEO of the electrical vehicle company Tesla, says that: "Solar will be the single largest producer of energy in the UK in the long term", and claims that 80% to 90% of solar energy through clouds still reach the earth. Germany aims to be 35% solar powered by 2020 while

China and Sydney, Australia aims for 20% and 100% respectively by 2030. Solar panel technology is excelling to enable the production of energy from rain as well (The Truth about Solar, 2016).

Wind energy has been used for thousands of years to produce mechanical energy for grinding, milling, and water pumping. In 1887, Charles F. Brush built the first automatically operated wind turbine in Cleveland. The turbine had a generating capacity of 12 kW, weighed four tonnes and was eighteen metres high. Eighty countries around the world have been using wind power commercially since 2009, with China taking the lead (DMRE, n.d.1). According to REN21 (2016) wind technologies supply approximately 3,7% of world electricity production. In contrast to the rest of the world, Africa possesses incredible unexploited wind energy potentials. South Africa, Morocco, Egypt and Tunisia have the largest wind power capacity on the continent, i.e. 1 053 MW, 787 MW, 610 MW and 245 MW respectively (REN21, 2016).

Price and Probert (1997) stated that Africa is the most underdeveloped continent with regards to hydropower generation, estimated with only 6% potential exploited. By international comparison, SA is considered as a water scarce country, but it is believed that there are many untapped opportunities to generate electricity using hydropower technologies. Figure 2-12 shows hydropower potential by region.

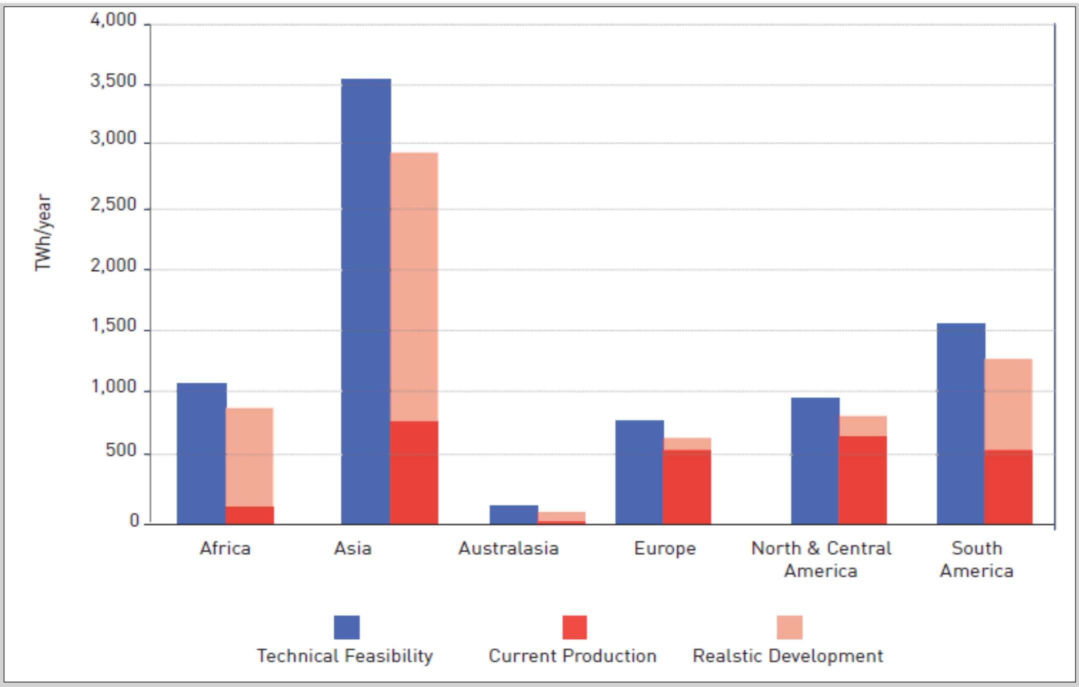


Figure 2-12: Survey of Energy Resources (WEC, 2007)

2.3.2 *South Africa*

In South Africa, power supply is mainly sourced from coal and hydro plants (DoE, 2018). In 1880 already, Coal was supplied to the Kimberly diamond fields from the Vereeniging region subsequently making Kimberley the first city with streetlights in the southern hemisphere (ESKOM, n.d.). South Africa has been challenged with an energy crisis for some time. This has included the remoteness of electricity in rural areas, as well as the negative impact on the environment due to an overreliance on coal as a source of electricity. To address this challenge, framework policies have been adopted to enable increasing portions of renewable energy in the national mix. The feasible renewable energy resources identified in South Africa include solar, wind, biomass, geothermal, hydropower, waste to energy, and the tidal (wave) energy.

South Africa's Integrated Resources Plan (IRP) plans for sufficient electricity generation from different resources to supply future demands and encourages the integration of electricity generated from renewable energy sources into the national supply grid (DoE, 2018). South Africa is among the countries with the largest coal production in the world and the only country in Africa that produces nuclear energy. Unfortunately, the use of coal-fired power has led to South Africa being a large contributor to greenhouse gas while the 2015 Paris agreement pursues the reduction of global carbon emissions. Its use as a fuel source is unpopular because of its effect on the environment, health issues and climate change. Although the Koeberg Nuclear Power Plant was built with the potential to be expanded, its affordability, safety and the nuclear waste that will be produced, is debated (Bungane, 2018).

The government has generally led the energy sector in South Africa, but it has been dominated by the national power utility, ESKOM. Continuous load shedding during 2008 has resulted in an increase of independent power producers since 2011. It was announced by ESKOM in 2016 that it would not enter in any power purchase agreements with private power producers. At the time the renewable energy industry contributed 2 145 MW electricity to the national grid and generated R195 billion (Bungane, 2018).

According to Ayodele *et al.* (2012), solar and wind are the two most favourable options in South Africa for RE sources, considering their cheaper cost to build compared to others (Green Economy Journal (GEJ), 2018).

So far employment for 30 405 job years have been created by the South African RE industry; one third is by the RE wind industry. Although construction phase offers employment opportunities that last only two years, the power plant operations phase can offer employment opportunities of up to 20 years (operational period). In terms of wind farm investments, 31% are owned by Black South African shareholders. Some utility-scale RE investments directly contribute to rural development (GEJ, 2018). In terms of water withdrawal and consumption, solar PV and wind energy exhibit the lowest demand for water. These make them considerably viable renewable options according to Sparks *et al.* (2014).

Among the renewable energy source, solar energy is the best option for South Africa as most areas on average receives 2 500 hours of sunshine per year and solar-radiation levels range between 4,5 and 6,5 kWh.m^{-2} in one day. Solar as the energy source is considered as the most reliable renewable energy resource (Kleissl, 2013) and freely available. However, the collection and transformation to this source is not very cost-effective (Kougias *et al.*, 2016).

The IRP 2018 allows for another 1 000 MW coal, 2 500 MW hydro (imported), 5 600 MW wind, 8 100 MW solar PV and 8 100 MW gas energy capacity to be procured by 2030. In Figure 2-13 the existing as well as the planned and projected capacities of energy sources in South

Africa from 2018 until 2030 are shown and Figure 2-14 is a graphical presentation thereof. These figures do not include the embedded generation capacities which refers to generation for own use allocation.

	Coal	Nuclear	Hydro	Storage (Pumped Storage)	PV	Wind	CSP	Gas/Diesel	Other (CoGen, Biomass, Landfill)	Embedded Generation
2018	39,126	1,860	2,196	2,912	1,474	1,980	300	3,830	499	Unknown
2019	2,155					244	300			200
2020	1,433				114	300				200
2021	1,433				300	818				200
2022	711				400					200
2023	500									200
2024	500									200
2025					670	200				200
2026					1,000	1,500		2,250		200
2027					1,000	1,600		1,200		200
2028					1,000	1,600		1,800		200
2029					1,000	1,600		2,850		200
2030			2,500		1,000	1,600				200
TOTAL INSTALLED	33,847	1,860	4,696	2,912	7,958	11,442	600	11,930	499	2,600
Installed Capacity Mix (%)	44.6	2.5	6.2	3.8	10.5	15.1	0.9	15.7	0.7	

Colour	Legend
(grey)	Installed Capacity
(yellow)	Committed/Already Contracted Capacity
(green)	New Addional Capacity (IRP Update)
(orange)	Embedded Generation Capacity (Generation for own use allocation)

Figure 2-13: Installed and planned capacities of energy sources in RSA (DoE, 2018)

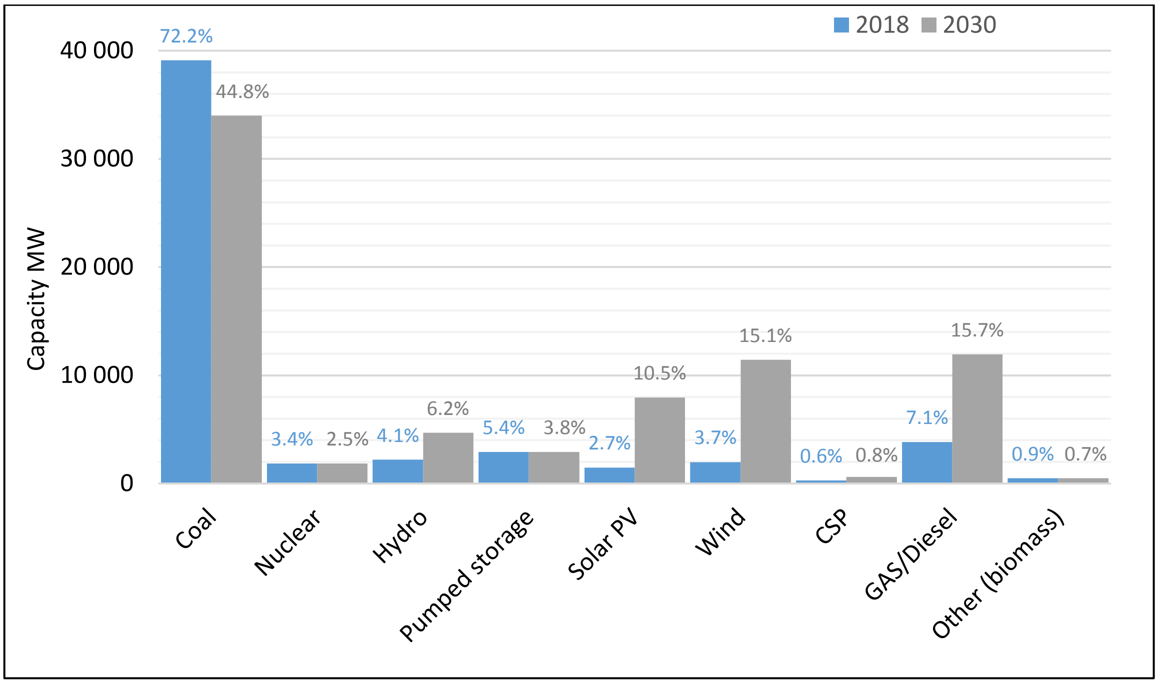


Figure 2-14: Current and future capacity of energy sources in RSA

Numerous information about the available RE sources in South Africa, shown in Figure 2-15, can be accessed through the website of the Department of Mineral Resources and Energy.

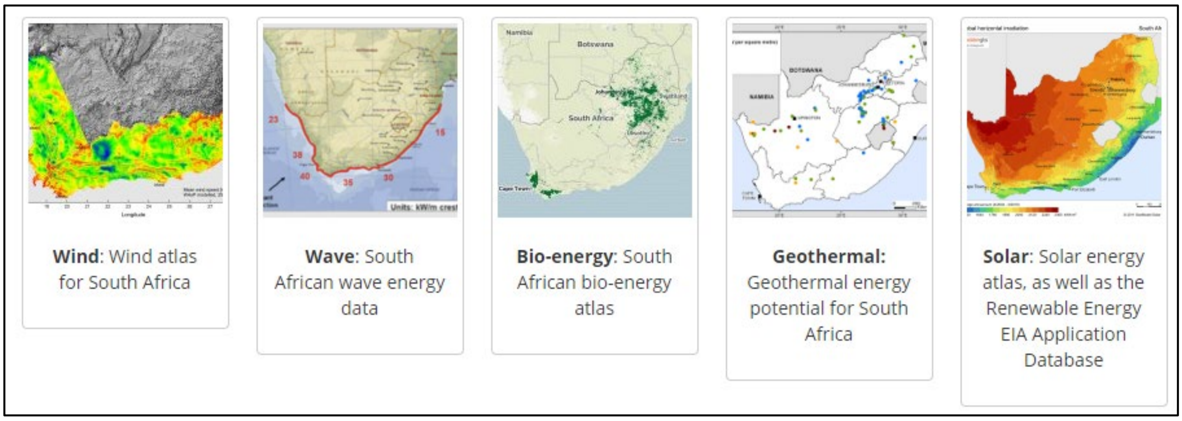


Figure 2-15: Maps of available renewable energy sources in RSA (DoE, n.d.2)

*2.3.2.1 **Solar***

The use of PV off-grid solar systems in South Africa has seen growth due to the rising cost of grid power, its erratic supply, as well as the remote location of some areas. Distribution provincially varies from 13 267 kW in Gauteng, to 605 kW in the Eastern Cape (PM and SANEDI, 2017). The sectorial distribution of registered solar PV installations is – Commercial (57%), Unspecified/Other (14%), Industrial/Manufacturing/Mining (13%), Agriculture (12%) and Residential (4%) (PM and SANEDI, 2017).

By May 2015, a voluntary database of small scale, typically rooftop, Solar PV installations had recorded a capacity of 43,8 MW. This has more than doubled since the database's first publication of 19 MW installed in 2011. The majority of these recorded installations were in the agriculture, commercial, industrial and mining sectors (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2015).

The costs of Solar PV installations are generally on a downward trajectory. This is evident from a total reduction of more than 80% in average tariffs for solar PV from the first to the last bid window in the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). This is also in contrast to the constant upward trend of the average electricity tariff. In the near future lower investments in solar PV will be needed to deliver the same benefits – thus the feasibility of solar PV projects will continue to increase (PM and SANEDI, 2017).

The development of a Solar Energy Technology Roadmap (SETRM) has an objective of preparing a comprehensive guide to develop the green technologies industry for the local development of solar energy technologies. The expectation is that this will create manufacturing capabilities and capacity, create employment and promote development of local industry. From the developed road map, it is envisaged that 40 GW of Solar PV and 30 GW of CSP (Concentrated Solar Power) can be developed in South Africa by 2050 (GIZ, 2015).

The development of solar data and resource mapping is currently underway to promote usage of solar energy in the Southern Africa Development Countries (SADC). It will also be used to improve the quality of satellite-derived solar data available for specific areas. Universities from

South Africa, Botswana and Île de la Réunion are in the process of collecting and compiling high-resolution, ground-based solar radiometric data. This is being done in cooperation with the Southern African Universities Radiometric Network (SAURAN) and data is collected from 15 stations across the Southern African region – 13 of which are located within South African borders. These locations are mapped and available at https://sauran.ac.za/. The GIZ has given extensive financial support to make this measurement data available to the public free of charge – all in support of the development of this industry (PM and SANEDI, 2017).

Furthermore, a renewable energy simulation model was developed by The Centre for Renewable and Sustainable Energy Studies (CRSES) to incorporate the influence of various RE technologies at locations around Southern Africa. The model platform gives an overview of the potential for different RE technologies in the Southern Africa region (CRSES, 2021).

2.3.2.2 ***Wind***

The wind speed in South Africa is projected to be between 7,2 m.s^{-1} and 9,7 m.s^{-1} around the Western Cape, specifically Cape Agulhas and Cape Point. The Jeffreys Bay wind farm supplies 460 000 MWh.year^{-1} to ESKOM. South Africa's wind energy is regulated by the government through the REIPPPP. More than 900 wind turbines are supplying to the grid. In terms of RE investments in rural development, 43% private RE power plants are hosted in the Eastern Cape, 43% in the Northern Cape and 14% in the Western Cape (GEJ, 2018).

The Wind Atlas for South Africa (WASA) is a RE project coordinated by the South African National Energy Development Institute (SANEDI) and funded by the Royal Danish Embassy (RDE) and the Global Environmental Facility (GEF). The project entails mapping of the wind resources in South Africa and the main objectives are to develop capacity enabling large scale exploitation of wind energy in the country and to verify and employ numerical wind atlas methods. The project proceeds in phases: WASA 1 (2009-2014) covered the Western Cape and areas of the Northern Cape and Eastern Cape provinces; WASA 2 (2014-2018) covered KwaZulu-Natal, Free State and remaining areas of the Eastern Cape province and WASA 3 (2017 to 2020) covers the remaining areas of the Northern Cape province and rest of South Africa (WASA, 2019). Some of the most recent available information, data and maps include:

- WASA 2 Final Reports Dec 2018
- High Resolution Wind Resource Map launched by the Department of Energy (6 May 2019)
- WASA 2 Final Seminar April 2019: Programme with Presentations
- WASA High Resolution Wind Resource Map for South Africa (all nine provinces) Dec 2020 and,
- WASA 3 masts WM16, 17,18 and 19 online

2.3.2.3 ***Hydro***

South Arica currently has approximately 3 700 MW of installed hydropower. There is potential for about 6 000 to 8 000 new sites for traditional hydropower installation. According to the Department of Minerals and Energy (DME), there is considerable potential for small- and large-scale hydropower generation. There have however not been any major hydropower developments in the last 30 years (Niebuhr, 2018).

According to South Africa's hydropower database there are currently 84 small scale and micro hydropower plants with a total installed capacity of 110 MW that are operational within the country (PM and SANEDI, 2017).

A database listing the decommissioned, operational, potential and sites under development for hydropower in Eastern and Southern Africa has been developed by Hydro4Africa. This database is kept up to date by Wim Jonker Klunne for the purpose of emphasising the boundless use of hydropower technology and give access to the information on the applications thereof (Hydro4Africa, 2021).

There are flow measurement gauging stations in most of the major rivers throughout South Africa. When considering a site for a hydro system, data records from these gauging stations can be useful to determine the water resource availability as a part of a pre-feasibility study. Water resource related information and data is available from the Department of Human Settlements, Water and Sanitation's (DWS) website.

Water resource models can be applied for detail analysis of water resource availability and assurance of supply. South Africa has rainfall records dating back as far as 1920. The WRSM2005 Model (Pitman model) is a basic South African derivative of the famous Stanford Watershed Model – the first deterministic rainfall-runoff model ever developed. This model has been further developed and updated with data in 2005 and again 2012 together with a website where the water resources of South Africa, Lesotho and Swaziland are described. The website allows water resource practitioners to access data, information, GIS maps, water resource models, spreadsheets and tools to investigate, analyse and plan their water resources studies accordingly (WRC, 2021).

There are still barriers to be faced for small-scale hydropower developments in South Africa. This includes long waits for approval from stakeholders, unclear government regulations, as well as inaccessibility to some sites. These delays can slow down the process of implementation. Other challenges include the lack of locally developed components and maintenance.

2.3.2.4 ***Bioenergy***

The Department of Science and Technology has funded the project developing the BioAtlas for South Africa which is coordinated by South African Environment Observation Network (SAEON). The Atlas shows the assessment of the potential, feasibility and application of biomass supporting the development of Bioenergy in South Africa (BioEnergy Atlas, n.d.). South Africa currently has a number of biodiesel manufacturing facilities (Banks and Schäffler, 2006) which is estimated to cover about 42 million hectares of natural woodlands and 1,35 million hectares of plantation.

The economic feasibility of biomass projects is enhanced by its ability to earn carbon credits and certified emission reductions. These add to its potential for implementation. Electricity generated by biomass also has various benefits. Biomass fuels can be produced, concentrated and stored – providing the user with dispatchable, non-interrupted renewable power. However, the implementation of biomass projects for the generation of electricity still faces financial barriers in comparison to other mainstream renewable technologies such as wind and solar energy. This is evident in the low penetration rate of biomass technologies in South Africa, as well as the low learning rates. Compared to other renewable energy resources in the procurement programme, levelized costs of electricity from biomass sources are the highest at R1,45.kWh^{-1} (PM and SANEDI, 2017).

The efficiency of biomass heating plants depends on various factors, which include the year of installation, the facility's size and the energy content of the biomass resource used. It is estimated that the efficiency of these heating plants ranges from 80% to 90%. The efficiency of a 20 MW wood chip installation is five percentage points more than a 1 to 5 MW installation. Commercially, small scale gasification plants are available, operating at less than 0,3 MW. It has not yet been established whether gasification on a large scale is financially viable. Plants in the range of 10 to 30 MW have been used as demonstration plants since the middle 1990s (PM and SANEDI, 2017).

According to The South African Terrestrial Carbon Sink Assessment, the total Green House Gas (GHG) mitigation potential of biogas from farm manure is estimated at 3,6 million tonnes CO_2. Generating biogas from this source has been identified as a major climate change mitigation opportunity in South Africa's land-use sector. Electricity can be generated from biogas by means of producing methane with the aid of digesters. The methane produced by the digester is then directly fed into a gas-fired combustion turbine to generate electricity. The sizes of bio-digesters typically range from 1 m^3 (for household or farm-based plants) to 1 000 m^3 (for large installations) (PM and SANEDI, 2017).

In South Africa, waste from municipal landfills is a widely available feedstock throughout the country. The possibility of using it has however not been investigated extensively. This is due to municipal waste having regulatory constraints. Suitable bioenergy resources are not available throughout South Africa and they also require specific conditions to be considered financially viable (PM and SANEDI, 2017).

2.3.2.5 ***Geothermal***

An evaluation was done on the thermal springs, heat flow, temperature at depth, geology, geophysics, and hydrogeology to assess the availability of geothermal resources in South Africa. These have suggested that low-enthalpy geothermal energy is a viable alternative form of energy. Binary-cycle geothermal plants are proposed as an electricity generating system with possible locations in the Limpopo Belt and the Proterozoic Namaqua-Natal Mobile Belt (Tshibalo *et al.*, 2015). The study by Dhansay *et al.*, (2017) also suggested that the country should consider geothermal as a renewable energy resource and confirmed the potential to harness low-enthalpy geothermal energy. Geothermal energy has a number of advantages over wind and solar energy – its availability 24 hours a day through the year being one of them.

2.3.2.6 ***Wave***

A Case Study of the South African Wave Energy Resource Data was completed by Joubert and Van Niekerk (2013). It was concluded that there is a significant wave energy resource along the southwest coast of South Africa and that spatial distribution maps for larger sections of South Africa's coast should be developed.

2.3.3 *Policy, procurement and promotion*

While rising electricity prices will improve the competitive position of renewable energy technologies in the future, these technologies will still need considerable support if they are to be deployed on a commercial, large-scale basis. This support is needed as soon as possible since investment cycles are comparatively long in the energy sector. The South African government has acknowledged this and consequently taken measures to support private investment in renewable energy and other clean technologies (Pegels, 2010).

A number of countries have had renewable energy in place. By 2009 at least 73 countries had come up with renewable energy policy targets. The policy instruments that have been used in support of these targets include feed-in tariffs, quota models and tax incentives or subsidies. The feed-in tariffs which has been implemented in over 40 countries was first successfully implemented in Germany. The idea behind a feed-in tariff is to guarantee producers fixed tariffs for power from renewable energy sources over a certain period of time, in most schemes 10 to 20 years as way of encouraging long term investment plans. In quota models the tariffs are not fixed but the quantity of the power generated from renewable energy sources.

In 2009, National Energy Regulator of South Africa (NERSA) approved the Renewable Energy Feed-In Tariff (REFIT) to achieve South Africa's government target of producing 10 TWh of electricity per year by 2013 and sustain growth beyond the target. However, before the REFIT could really take off, it was replaced by a public bidding process to promote renewable energy, but explanations for this surprising change of policy are scarce. This bidding process has become to be known as the REIPPPP. The other instrument would include the cost of the competing fossil fuel technologies to promote the adoption of the renewables (Msimanga,2014).

South Africa's severe power constraints which have been experienced since 2008, has opened a market for Independent Power Producers (IPPs). "In November 2010 the DoE and National Treasury (NT) entered into a Memorandum of Agreement (MoA) with the Development Bank of Southern Africa (DBSA) to provide the necessary support to establish the IPPPP Office and implement the IPPPP" (IPP Office, 2016). Professional advisory, procurement management and monitoring, evaluation and contract management services are provided by the IPPPP Office. An effective response to the urgently needed development of the country's power infrastructure is expected to be provided by the IPPPP (IPP Office, 2016).

ESKOM was the reason for a pause to the programme in 2016 due to their refusal to sign any more agreements. This had a negative effect on the investments in renewable energy from abroad. Two years later ESKOM's application to buy additional renewable energy from the producers who were involved in last bid windows of the renewable programme, was approved by the Minister of Public Enterprises, Lynne Brown. He said in a statement, "The conclusion of the power purchase agreements to enable the implementation of the outstanding projects under bid windows 3.5, 4 and 4.5 of the REIPPPP, is critical to implementation of the national energy policy as articulated in the IRP of 2010" (Groenewald, 2018).

To achieve the targets the IPPs have been considered capable despite the ESKOM's competitive advantage. The IPPs are faced with the uneven playing field in that they have to sell the power that they generated to ESKOM which is considered monopolistic buyer. ESKOM faces a conflict of interest as it is both a competitor and the single buyer of their electricity at the same time (Pegels, 2010). However, South Africa is considered in SADC in terms of renewable energy development due to policies such as the feed-in tariffs. As shown in Figure 2-16, a database and map has been developed to indicate the progress and status of the different IPP projects and programmes and is available at the following link: https://www.ipp-projects.co.za/ProjectDatabase.

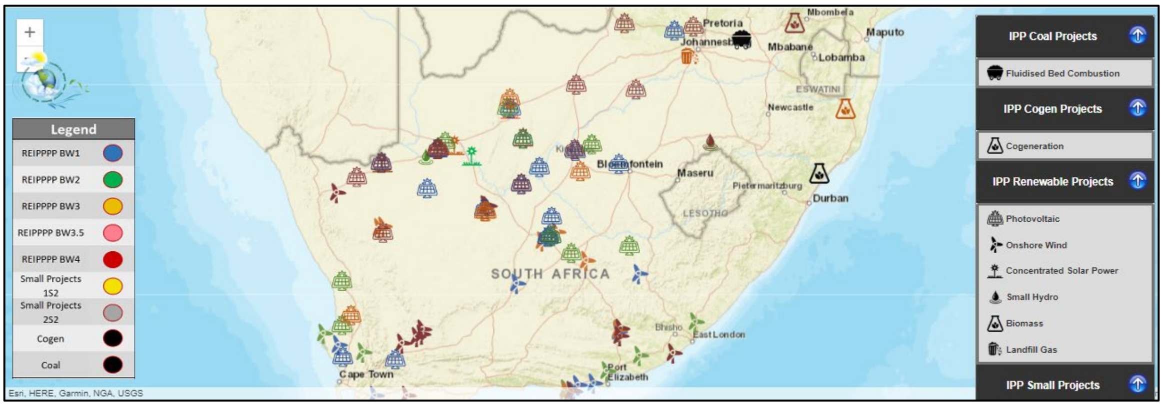


Figure 2-16: IPP projects map (IPP Office, 2019)

South Africa had set target of 10 000 GWh from renewable energy sources by 2013 in DME's White Paper of 2003. The renewable energy sources as spelled out in the paper include biomass, wind, solar and small scale hydro where the focus has been on large and economically viable projects rather than small electrification projects.

A database with spatial data for renewable energy applications and for environmental authorisation in South Africa together with a map, is accessible from the Department of Forestry, Fisheries and the Environment (DFFE) website. The map was produced in collaboration between the DEA, the Council for Scientific and Industrial Research (CSIR) and the CRSES. An example of the map is shown in Figure 2-17.

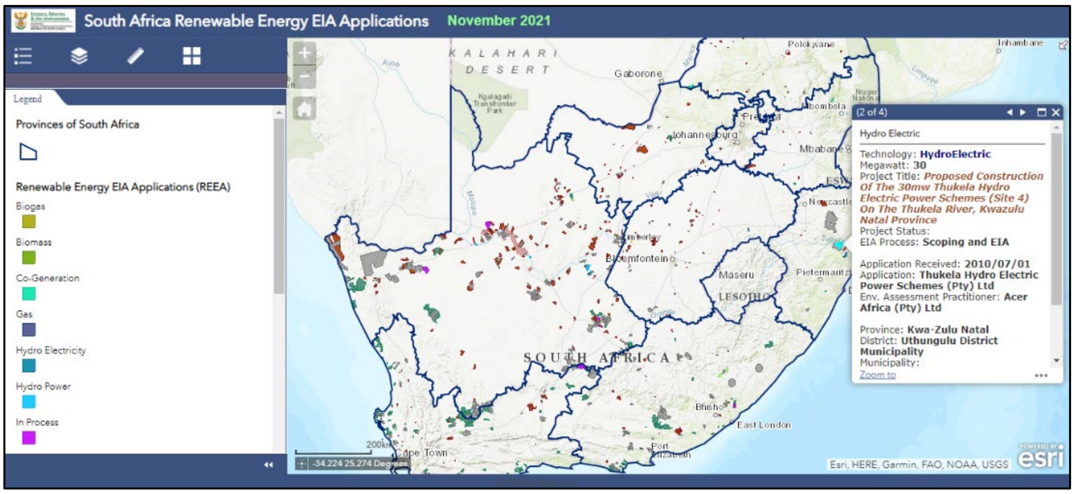
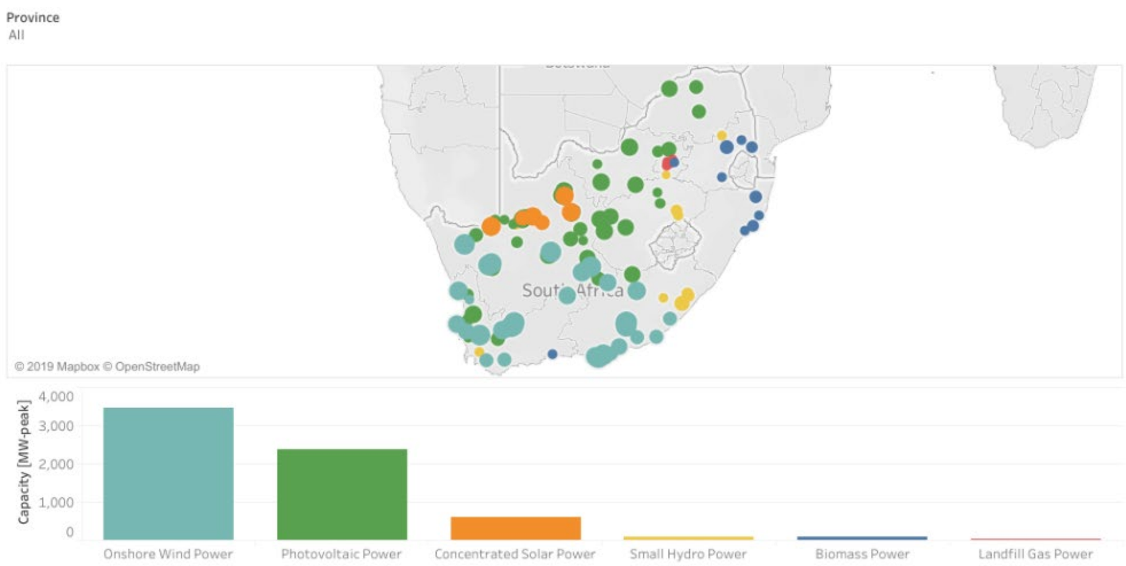


Figure 2-17: Renewable Energy EIA application map (DFFE, 2021)

The Department of Energy operates the Renewable Energy and Data Information Service where current production data for renewable energy in South Africa is mapped and listed (In Figure 2-18). The data includes IPPs, ESKOM plants and industrial co-generators under the wholesale electricity pricing system (WEPS) programme 2012-2019.



	Programme							
	Capacity [MW-peak]							Capacity [MW-..
Technology Category	Eskom	IPP 1	IPP 2	IPP 3	IPP 4	IPP Small	WEPS	Total
Landfill Gas Power				18				18
Biomass Power				17	25	10	33	84
Small Hydro Power	61		14		5		12	92
Concentrated Solar Power		150	50	400				600
Photovoltaic Power		627	417	435	813	80		2,372
Onshore Wind Power	100	649	559	787	1,363	9		3,466
Grand Total	161	1,425	1,040	1,657	2,205	99	45	6,633

Figure 2-18: RE sources in RSA (DoE, n.d.3)

All active producers, traders and consumers of Renewable Energy Certificates (RECs) in South Africa are automatically members of Renewable Energy Certificates market participants association – Southern Africa (RECSA). This voluntary REC market is administered by zaRECs (Pty) Ltd in line with the European Energy Certificate System (EECS) specifications. The certificates registry can be accessed via the website hosted by zaREC (Pty) Ltd where information of the registered devices and their locations are shown (zaRECs, 2021).

To promote renewable energy and energy efficiency, the South African government prefers to use tax incentives to disincentives. The tax incentives are as spelled out in the Income Tax Act No. 58 of 1962 (Republic of South Africa 1962). According to Section 12B of this Act, small scale embedded solar PV RE with generation capacity of less than 1 MW, can be granted 100% allowance in the first year. This took affect for years of assessment commencing on or after 1 January 2016. Section 12L of the act allows for a benefit of 95 cents per kWh energy saving and took affect for years of assessment commencing on or after 1 March 2015. It is important to note though while tax incentives do play a role in decision making, various other non-tax factors drive South African businesses' decisions to invest in Energy Efficient (EE) and/or RE projects. These businesses do not perceive the available tax incentives as effective, nor do they regard them as sufficiently motivating for businesses to change their environmental behaviour (Dippenaar, 2018).

On 1 June 2019, the Carbon Tax Act of 2019 (CBT) came into effect. All goods that have carbon dioxide equivalent of greenhouse gas emissions as defined in the CBT are subject to its enforcement. If an entity operates emission generations facilities at a combined installed capacity equal to or above the carbon threshold, the CBT is imposed. The carbon tax rate identified for the first phase is R120 per ton of carbon dioxide equivalent emissions. This rate is subject to an annual increase equal to inflation plus two percent until 2022 after which it will increase annually with inflation (SARS, 2021).

Links to the sources of information and maps discussed in these sections are listed in Table 2-4.

Table 2-4: Links to renewable energy information and maps

Renewable Energy Source	**Link to information and maps**
Solar	https://sauran.ac.za/
Wind	http://www.wasaproject.info/
Wave	http://www.crses.sun.ac.za/files/research/publications/technical-reports/SANEDI(WaveEnergyResource)_edited_v2.pdf
Bio	https://bea.saeon.ac.za/
Geothermal	https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/16054.pdf
Hydro	https://hydro4africa.net/
EIA Applications	https://egis.environment.gov.za/renewable_energy
Certificate Registry	https://www.zarecs.co.za/

2.4 Application of renewable energy in irrigated agriculture

2.4.1 *Background*

Energy used in agriculture has been increased over years due to a number of factors such as increasing population rate, limited supply of arable lands and a desire for higher standards of living. Irrigation is the engine to help improve yields, ensure food security by reducing vulnerability to changing rainfall patterns, and support multiple cropping (FAO, 2011). Globally, agriculture is estimated to emit 10 to 12 percent of greenhouse gases emission (Fami *et al.*, 2010), however RE can address several concerns linked to fossil energy use. Agriculture is both a consumer and provider of energy in the form of bioenergy (Alam *et al.*, 2005).

Reliable clean energy from various sources can be provided to farmers for irrigation. Operating costs are reduced as well as the challenges of having to deal with fluctuating fuel prices where diesel is used as the main source of energy. Connection to the electrical grid can be very poor in remote areas and the cost to operate and maintain pumps driven by diesel engines can be expensive (ICID, 2019). In addition, the productivity and reliability of yields for small-scale farmers reliant on rainfall, can be increased (Worthington, 2015). A sustainable livelihood can be enhanced in rural areas with sustainable water and electricity supply which is predominantly used for food production with the option of selling excess renewable energy to the national electric grid (ICID, 2019).

Zaki and Eskander (1996) states that PV water pumping systems are becoming more popular, especially in areas with no power lines. Solar energy presents a huge potential for crop production under irrigation. Irrigated agriculture is the backbone of local economic development in the majority of developing countries, hence reliable and affordable access to irrigation water is a crucial factor. Solar irrigation systems are very reliable and cost-effective, requiring little maintenance. However, the technological option of Solar Powered Irrigation Systems (SPIS) is rarely taken into consideration due to a lack of pertinent experience and the comparably high investment costs of the past. Other past projects have proven photovoltaic pumping systems to be technically mature and suitable for utilization in rural areas of developing countries. Cost-effective irrigation water supply systems can be installed when combining drip irrigation kits with affordable photovoltaic panels and 12-volt pumps (UCDAVIS, 2014).

In a study by Kaushik (2011) the direct use of solar radiation as a power source for irrigation is considered advantageous since the installation of the system is at the site of application and does not require the engagement of a distribution system. Different irrigation techniques including drip, micro sprinklers and rain guns can be successfully combined with SPIS. Table 2-5 shows the irrigation methods that are suitable and have preference in terms of solar powered irrigation (Piliso, 2017a). The second column in Table 2-5 was updated accordingly based on research by Burger *et al.*, 2003. An example of water pumping with solar PV is shown in Figure 2-19.

Table 2-5: Suitability of irrigation techniques to solar pumps (Piliso, 2017a)

Distribution Method	Typical system efficiency (%)	Typical head (m)	Suitability for use with solar pumps
Open channels (furrow)	86-93	0,5-1	Yes
Sprinkler	83-90	10-20	No
Trickle/Drip	95	1-2	Yes

Figure 2-19: Solar irrigation (Roblin, 2016)

According to Van Campen *et al.* (2000), solar energy in agriculture mostly benefits irrigation, specifically in arid regions. When the sun is shining it feeds irrigation systems ensuring that they work hardest in the hot summer months when they are needed most. These systems are not an option for energy intensive activities in rice mills and other agricultural processes.

In India, numerous studies have been done on the implementation of SPIS with micro sprinkler irrigation and drip irrigation. There is scope for more research on the implementation of SPIS with furrow irrigation systems and centre pivot irrigation systems. All of these can be designed with low pressure systems in order to make SPIS more economically feasible (Piliso, 2017a).

The design of small-hydro systems is done to generate two megawatts (MW) of energy or less. Industrial and agricultural operations have benefited from the use of hydropower. Examples of these are waterwheels in flour mills that are turned by means of a flowing stream to mechanically drive the flour grinders (Osborn *et al.*, n.d.).

2.4.2 *Global Experiences*

In Turkey the target is set to source one third of their power requirements from RE by 2023. The application of irrigation with renewables perfectly fits this target (Kaya and Köse, 2015). Worldwide, SPIS is increasingly being considered as an alternative to conventional electricity driven irrigation systems (ICID, 2019). This can mainly be attributed to its predictability in supply, scalability, and zero-fuel input (IRENA, 2016). The coupling of SPIS with micro-irrigation systems to grow commercial crops in arid and semi-arid parts of India have resulted in successful business models such as the Talwara Solar Powered Irrigation Project in Punjab (ICID, 2019).

Kaya and Köse (2015) found that, considering India's meteorological conditions, irrigation applications are best operated from wind energy water pumping systems. India has set the target to install 100 000 solar pumps by 2020 and Morocco the same amount by 2022. Bangladesh aims to have 50 000 solar pumps deployed by 2025. A government programme in Malawi, funded by the African Development Bank, intends to irrigate over 500 hectares from solar power (IRENA, 2016). In Malawi the use of solar water pumps is encouraged for organic fish farming and production (SABI, 2018a). In Uganda, Village Energy is responsible for the design and installation of solar energy technology in the business, agriculture and community institutions.

In Germany, two solar-powered pumping systems were developed by students in cooperation with the company SET GmbH and the UNAN University in León. These were installed in two farms in Nicaragua to pump underground water. The project has been running for over 10 years and 30 pumps are currently in operation in Nicaragua. Even in dry seasons, farmers are enabled to produce all year round. This benefit derived from solar energy thus increases their income and strengthens their position in the local market (Roblin, 2016).

The Wien Energie solar irrigation system comprises of a mobile solar energy system with photovoltaic modules that is connected to a wheeled pump. This pump can be used to pump water from wells or rivers and is connected to an app on your smartphone. Through this technology you can determine the amount of energy produced by the system. Water is distributed through the hoses, directly to the crops. A test of this system was successfully done on a 3,5 hectare organic cornfield in Guntramsdorf, Austria, and is now ready for production (Roblin, 2016).

Biogas-fuelled pumping in Pakistan or micro-hydro systems in Zimbabwe are also evident of the interest in other RE options (IRENA, 2016).

In terms of Small Holder Irrigation, the rope pump is used in Nicaragua and Cambodia. Classic windmills used widely in North and South America, Australia and South Africa are very expensive and not sold anymore. The Poldaw windmill is a good option for irrigation requirements of small holders pumping up to 8 $m^3.day^{-1}$ from depths of seven metres at wind speeds of 3 $m.s^{-1}$. However, according to Nederstigt and Bom (2014) small holders may find this model unaffordable. The Darrieus design wind-powered irrigation pump is the modern type used in the USA (Enochian, 1982).

In 2012, in an attempt to reduce energy costs, a farmer in Colorado retrofitted an existing pivot centre with a small hydropower turbine. A head flow of 38,4 metres and predictable flow of 2 120 litres per minute was assessed on site. These conditions could pressurise the sprinklers as well as produce 5,2 kW of power, which is equivalent to seven horsepower. This eliminated the need for pumps and drive systems, reducing maintenance and operating costs. An example of such an installation is shown in Figure 2-20.

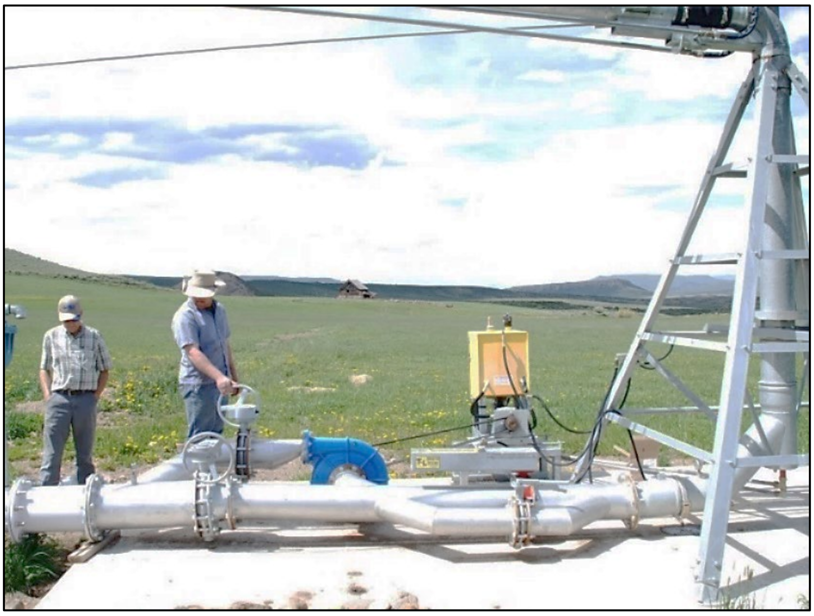


Figure 2-20: Small hydropower connected to centre pivot (Agri-Pulse, 2017)

The farmer's only out-of-pocket costs were to purchase a Cornell turbine. This was due to the incentives available for site and feasibility assessments. The NCRS EQIP grant covered approximately R52 179 of the total project cost of R113 054,50 thus the expense to the irrigator was R60 875,50 with an annual energy savings of approximately R 18 262,65. The payback period resulted in roughly 3,3 years. A turbine has a life expectancy of at least 20 years, calculating the total annual cost of the hydropower project at R3 139.$year^{-1}$ over 20 years (Osborn *et al.*, n.d.).

2.4.3 *South African Context*

In South Africa, irrigation is a power-intensive and water-use intensive system, (SABI, 2016) using 28% of the total electricity consumption in the agricultural sector (REEEP & SANEDI, 2016) and 60% of the total surface water use in the country (Bonthuys, 2018). Among the renewable energy sources available, solar energy seems to be the future for South African Agricultural industries. According to Bajpaye (2019) solar energy has huge potential for solar irrigation, pumping water not only for crops, but also livestock. Irrigation technologies that can be supported by solar energy include drips, sprinklers, and pivots – given that they are appropriately sized (Hartung & Pluschke, 2018).

AgriSA indicated that among their members there are already 500 applications for solar plants submitted to ESKOM. These plants are ready for implementation and can potentially contribute 1 400 MW to the grid. In so doing, the frequency and intensity of load shedding, as well as the strain on the grid can be reduced. With this contribution, at least phase one load shedding can be prevented. A decision lies with commercial banks on the use of solar plants as security to gain access to capital. With solar energy plants as security for funding, the agricultural sector can contribute enough electricity through solar energy to prevent phase three load shedding (SABI, 2019).

Uninterrupted power supply to remote areas is becoming more challenging with the unstable supply from the national grid. Farmers are therefore gradually making use of alternative power supply of which photovoltaic solar panels in combination with Variable Speed Drives (VSDs) is a favourable option. This combination is often fitted with boreholes in remote areas. A VSD allows the speed of the electric motor to vary, protecting it from fluctuations in energy flow of the solar panel since the strength of the sun's rays is not constant. A potential reduction in voltage over extended lengths of copper cable between the motor and source of supply can also be eliminated in this way. Motor sizes of typically 5,5 kW are used with this technology but larger motors can be operated if the solar power capacity is increased (SABI, 2018b). Despite high levels of solar direct normal irradiation in South Africa, only 2 000 hectares, of the 1,2 million hectares of land under irrigation, are estimated to be solar powered irrigation (Hassan, 2015).

Although South Africa has sufficient wind power resources, especially the coastal regions such as the coastal Cape areas, the investment in this renewable energy has mostly cantered on the wind farms solely for the generation of electricity. Wind farm projects generally refer to large-scale wind farming activities spread over very large areas, typically encompassing many properties. A 140 MW wind farm will cover an area of about 130 ha. This area will include the roads, turbine foundations, crane pads, construction camp and substation (Van der Walt, 2019). South Africa has a number of wind turbines that have been developed locally which can be used for pumping water and include Turbex wind turbines (Turbex, 2020) and Kestrel wind turbines (Kestrel, 2020).

2.4.4 *Hindrances*

According to the Colorado Department of Agriculture, the challenges relating to small hydropower generation include lack of industry knowledge as well as uncertainty of the application (Osborn *et al.*, n.d.). Other challenges with the integration of renewable energy into the grid is the fluctuation of its power supply (especially wind and solar energy sources) due to its dependence on the weather conditions. It can therefore not serve as baseload power plants such as coal and nuclear where electricity is supplied continuously throughout the year (DoE, 2018).

There are certain barriers to the achievement of the renewable energy targets. These are social acceptance, as well as technical and economic feasibility. Focusing on irrigation, the feasibility of this renewable technology largely depend on factors such as crop type, location, ground water depth, conventional costs, government incentives and carbon taxes (Kelley *et al.*, 2010).

There are two possible barriers associated with renewable energy in South Africa's unique context. These include energy innovation systems and the high cost of thereof (Pegels, 2010). The maintenance cost of solar energy is lower than that of the conventional energy during the lifetime of the systems it supplies electricity to. A disadvantage is its substantial initial installation costs. This poses a challenge to farmers to adopt SPIS as a feasible option. Subsidies from the government is often required to support farmers during the initial implementation phase (ICID, 2019).

The factors that influence demand for SPIS include that the electricity rates for the agricultural sector are still competitive, apart from price increases. South Africa also lacks the business case for solar irrigation technology is as well as the financial benefits amongst farmers. There is of course that expectation that the prices of solar components will continue to decrease. Solar powered irrigation systems require massive investments coupled with a perception that there is no available funding for such projects. The other factor influencing the uptake of this technology is that famers fear that components will be lost due to theft. South Africa has also relatively few service providers who are actively involved in SPIS. Solar power is not yet a viable option for large irrigation companies who service between 90% to 95% of the commercial irrigation farms (F. Du Plessis 2017, personal communication, 3 August).

Downfalls of solar systems are their limited use of 8 hours per day while the sun shines, and even less on cloud-covered days. They have to be sized at the maximum crop water requirement, which may only be needed for 30% to 40% of the total season, whereas a petrol or diesel pump can provide the extra water need by simply running more hours per day. Nederstigt and Bom (2014) addresses these limitations, as well as the risk of theft of these solar panels. In the case of a pump being out of order, a whole component (e.g. a panel, controller, or motor/pump unit) will need to be replaced. This is a challenge in the case of rural settlements where rural technicians might not be trained to perform this task and the parts are expensive (Nederstigt and Bom, 2014). A farmer using a solar PV pump can thus face irregular but high expenditures (Hartung and Pluschke, 2018).

2.4.5 *Viability and solutions*

The type of crops cultivated, the demand for water (both frequency and quantity), the land holding patterns (area and ownership), existing irrigation practices, access to grid infrastructure and availability of alternative energy resources will determine the suitability of a solution (Hartung & Pluschke, 2018). Water pumps powered by solar power creates a friendly environment for irrigation considering its low carbon footprint compared to the greenhouse gas emissions from electricity generated from fossil fuel (ICID, 2019).

Viable business models depend on the cooperation among the government providing subsidiary support, the private sector and its community involvement through capacity building, after-sale technical support, as well as the community of farmers themselves. Successful models predominantly include private sector involvement either in the form of contract farming where farmers receive subsidiary for the complete production value chain or the progressive farmers working in tandem with the private sector in terms of local technical support. Facilitation and support from the government can enhance sustainable development in rural areas, improving the conservation of natural resources, agricultural productivity and creating employment opportunities (ICID, 2019).

2.4.6 *Renewable Energy Systems for Irrigation*

2.4.6.1 ***Solar Powered Irrigation Systems (SPIS)***

Most pressurised irrigation systems are compatible with solar power. These include sprinkler, micro and drip systems. Water can be pumped into the systems or first pumped into a storage reservoir to gravitate or be pumped into the system when solar irradiance is not available. Over many years researchers from all the fields of engineering have contributed to make solar PV water pumping systems an efficient, technically simple and cost-effective water pumping system. This technology has seen a markedly increased take up by farmers to power their irrigation systems. With extensive availability of solar energy throughout South Africa, an increase in solar powered irrigation across the country is expected. These systems, in general, consist of the following minimum components (Nederstigt and Bom, 2014):

- Solar PV array
- Charge controller
- Pump controller
- Batteries
- Inverter
- Pump/Motor
- Mounting structure – fixed or tracking system, and
- Float switch to turn a pump on/off and low water cut-off electrode to protect the pump
- Wiring, discharge tubing or piping
- Storage tank
- Security fencing

These systems can either be battery coupled, directly coupled or grid-tied as shown in Figures 2-21, 2-22 and 2-23 respectively.

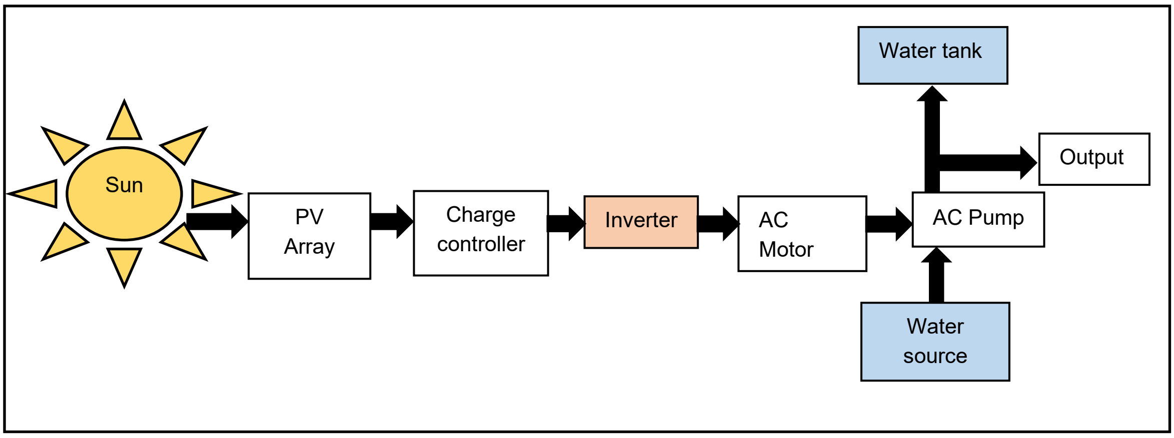


Figure 2-21: Battery coupled Solar Photo Voltaic system (Piliso, 2017b)

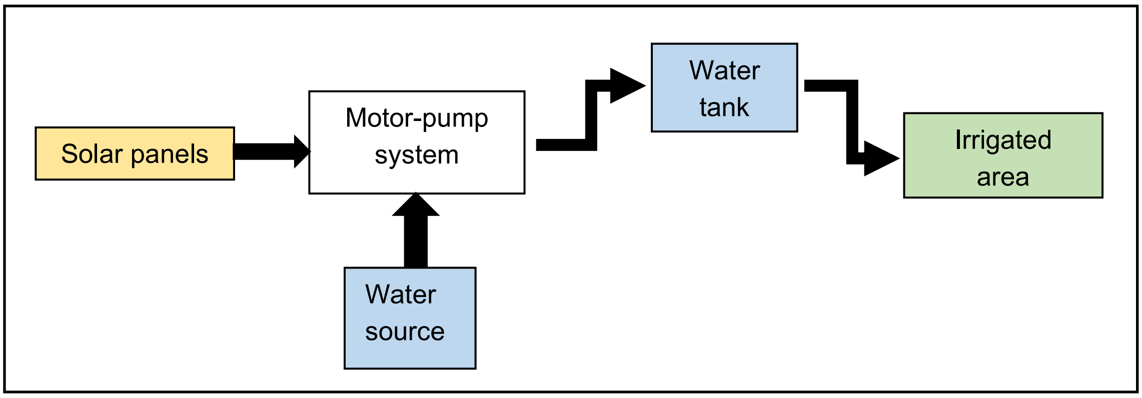


Figure 2-22: Direct coupled Solar Photo Voltaic system (Piliso, 2017b)

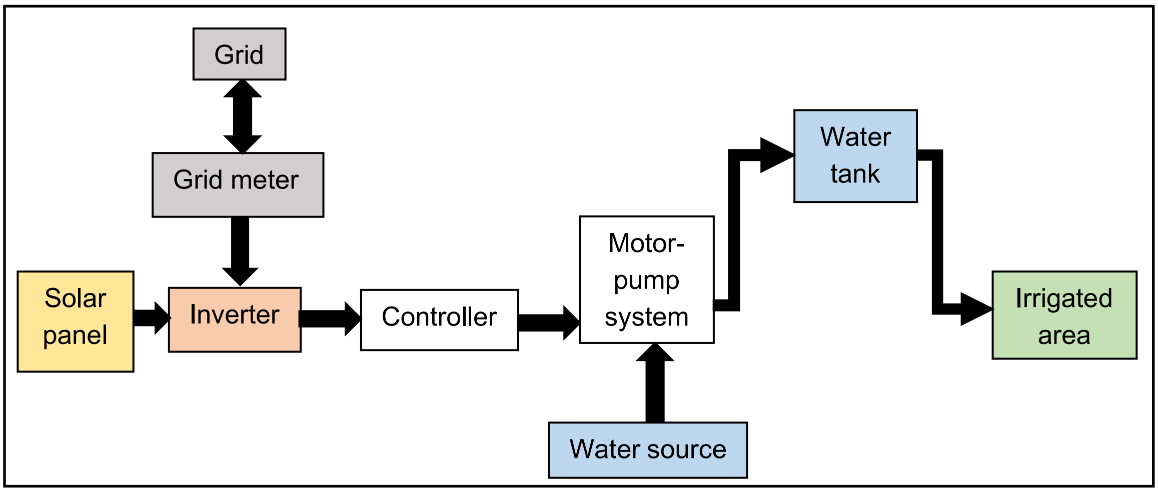


Figure 2-23: Grid-tied Solar Photo Voltaic system (Piliso, 2017b)

Solar-powered pumps used for irrigation are referred to as SPIS. The first solar-powered pumps were installed in the late 1970s. Nevertheless, it was not until 2009 when the price of solar panels started to decrease dramatically, making solar technologies affordable for agricultural purposes. Since then, there has been a race for the development of more powerful and efficient systems; every year, there are larger pumps on the market that can withdraw water from greater depths. The market potential for both small-scale and large-scale systems is great. These systems have many advantages, providing a clean alternative to fossil fuels and enabling the development of low carbon irrigated agriculture. In areas with no or unreliable access to energy, they contribute to rural electrification and reduce energy costs for irrigation (Hartung & Pluschke, 2018).

Solar pumps can also supply water to centre pivots. However, most existing systems still need an external energy source for their operation, control and drive units, even if the water used is being delivered using solar energy. Efforts are underway to run the entire operation of the centre pivot on solar energy – preferably without using batteries (Hartung & Pluschke, 2018). The Lorentz off-grid mini-pivot irrigation system is an example of such a system. It entails a single span solar powered pivot irrigation system (2.5 hectares) and allows remote plots of land to become productive without access to any infrastructure (Lorentz, n.d.).

SPIS Planning

These systems are relatively complex and their design requires not only a fit-for-purpose PV pump system and irrigation infrastructure (supply side), but also an assessment of water requirements and irrigation calendar (demand side), as well as skills and knowledge of the end user. There is a general trend toward suppliers planning and designing the entire solar powered irrigation system (including pump and irrigation equipment), installing it and offering service contracts for its operation. Solar powered irrigation companies can provide the layout and design of the whole system, including planning of agronomic aspects, and act as holistic service providers (Hartung & Pluschke, 2018).

Crop water requirements change with the weather and as the crop develops. Weather, water, soil and crop data will determine the crop water requirement at the specific site, which also depends on the irrigation system use. Software tools such as CROPWAT can be used to calculate the crop water requirements. The data requirements for SPIS planning are shown in Figure 2-24.

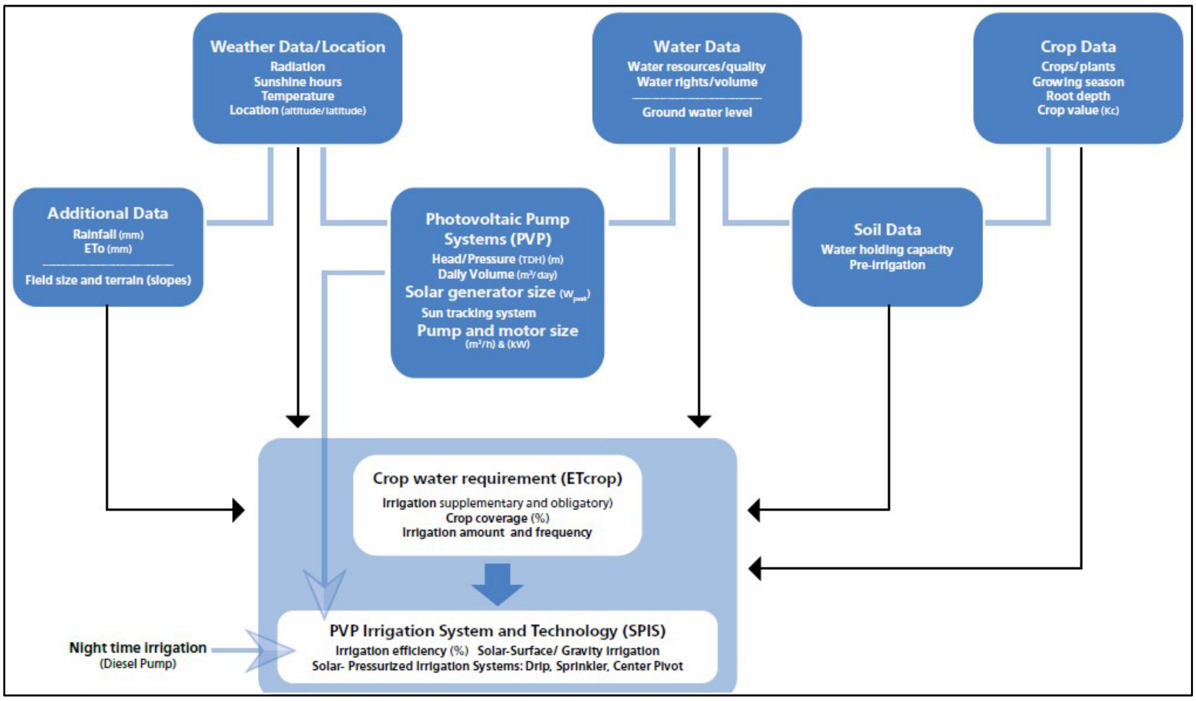


Figure 2-24: SPIS data requirements for planning (Hartung & Pluschke, 2018)

Floating solar systems
Some of the recent developments in SPIS include floating solar systems. To save on the land under PV panels, floating solar systems entail the installation of standard PV panels being installed on large bodies of water, such as drinking water reservoirs, quarry lakes, irrigation canals or remediation and tailing ponds. This improves on the efficiency of the panels due to the cooling effect of the water bodies. The floating panels will also reduce evaporation from the water bodies and the growth of algae (Hartung & Pluschke, 2018). An example of a floating solar system is shown in Figure 2-25.

Figure 2-25: Floating solar system (Business Insider, 2019)

Performance monitoring
This is done by use of sensors which are integrated into the production wells and the monitoring systems of solar pumps. The monitoring equipment is supplied by the international solar pump companies for operation of the water lifting system as well as data collection and monitoring. With increased availability of Internet and communication technologies, pumps can be remotely accessed from anywhere in the world and their performance checked at any time. Time series of important data can be easily displayed. This allows the monitoring of groundwater and surface water levels of critical water resources and their control by governments or dedicated institutions (Hartung & Pluschke, 2018).

Electricity Feed-in
If there is access available to the electricity grid, AC electricity can be fed into the grid especially at times when irrigation is not required. Prerequisites for this strategy are sound institutional framework conditions such as technical standards for electrical and measuring equipment to connect to the electricity grid and contracts with the relevant electricity company specifying conditions and the feed-in tariff (Hartung & Pluschke, 2018).

It has been challenging to find supporting financial mechanisms and business models for SPIS. Although the operating costs of these systems are often lower than that of other irrigation systems, the initial costs tend to be high. Possible ways to reduce costs include:
- Subsidies;
- Adding other uses of the energy produced;
- Selling extra energy;
- Cost sharing by organising farmers; and
- Carbon credits (although there is little experience to date on this point).

The agriculture sector in South Africa is dominated by commercial farms that are mainly reliant on surface water resources. Water productivity and production can be expanded with the implementation of solar irrigation. However, costs associated with solar irrigation are still competing with the electricity rates in the agricultural sector (FAO and GIZ, 2015).

The GIZ has developed a handbook and toolbox for SPIS. The shortcomings in information on demand based and site-specific design as well as the lessons learned, form the basis on which this manual was developed. Consultants for agricultural enterprises or who offer financing products is the main target group of this manual. The application of the manual is case-specific (FAO and GIZ, 2015).

*2.4.6.2 **Wind Powered Systems***

Irrigation pumps can be powered with direct mechanical power by means of wind turbines (Enochian, 1982). This is an effective scheme, reducing the dependence on imported fuel to generate power, as stated in Parigi *et al.* (2009). Other advantages of wind energy include its emission-free operation and rapid deployment and installation. The risk associated with wind energy, however, is the unpredictable nature of wind. In several countries this factor, together with high maintenance costs, has led to the replacement of windmills with solar-powered pumps (Enochian, 1982).

Parigi *et al.* (2009) explains how wind turbines can also drive a water pump to fill a water storage tank which can be used for irrigation purposes during irrigation seasons. The excess electricity generated can be sold to the electric grid. Windpumps have been used since the ninth century and applied extensively for irrigation purposes (Appa, 2015). Figure 2-26 shows a diagram of the water pumping system.

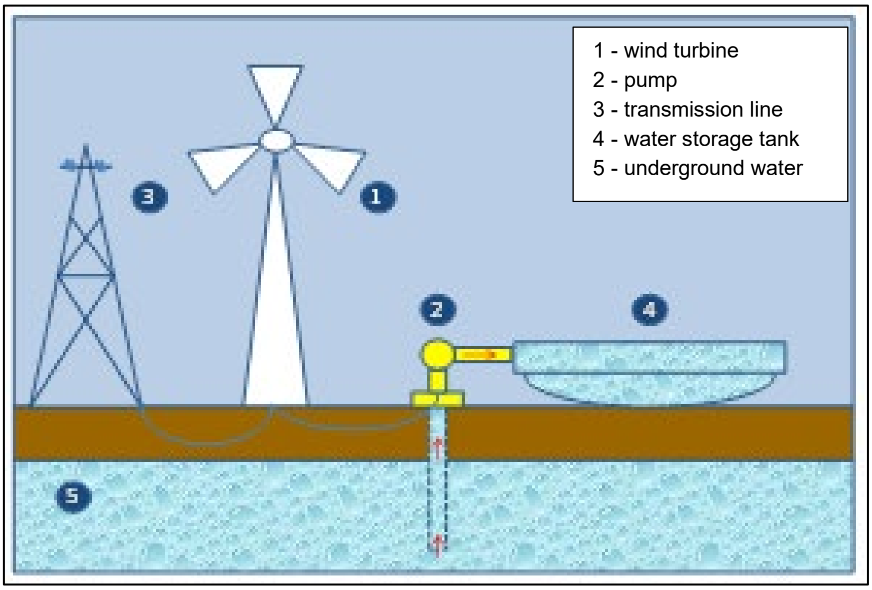


Figure 2-26: Diagram of the water pumping system *(*Parigi *et al.*, 2009)

Since the 1990s there has been a renewed interest in the application of wind energy in agricultural environments. The main drivers behind this are the maturity and reliability of the technology, its cost effectiveness and public interest in clean, renewable power (Van Dam *et al.*, 2008).

Today, wind pumps are located in rural and remote places where electricity is not readily available or where it is more affordable to install direct wind driven pumps than electric pumps. At small industries and farms where conventional electricity is used to power equipment, wind pumps can still be used to provide energy services if there are good wind resources available. By combining wind energy with other sources of energy, its variability can be overcome. Alternatively, pumped water can be stored in dams for times when wind energy is not available. These small-scale technologies typically have power output levels of less than 0,02 MW (pico) and 0,02 to 0,1 MW (micro) with a broad scope of application (PM and SANEDI, 2018).

Depending on the type of application needed, a water pumping windmill is simple, and efficient as shown in Figure 2-27.

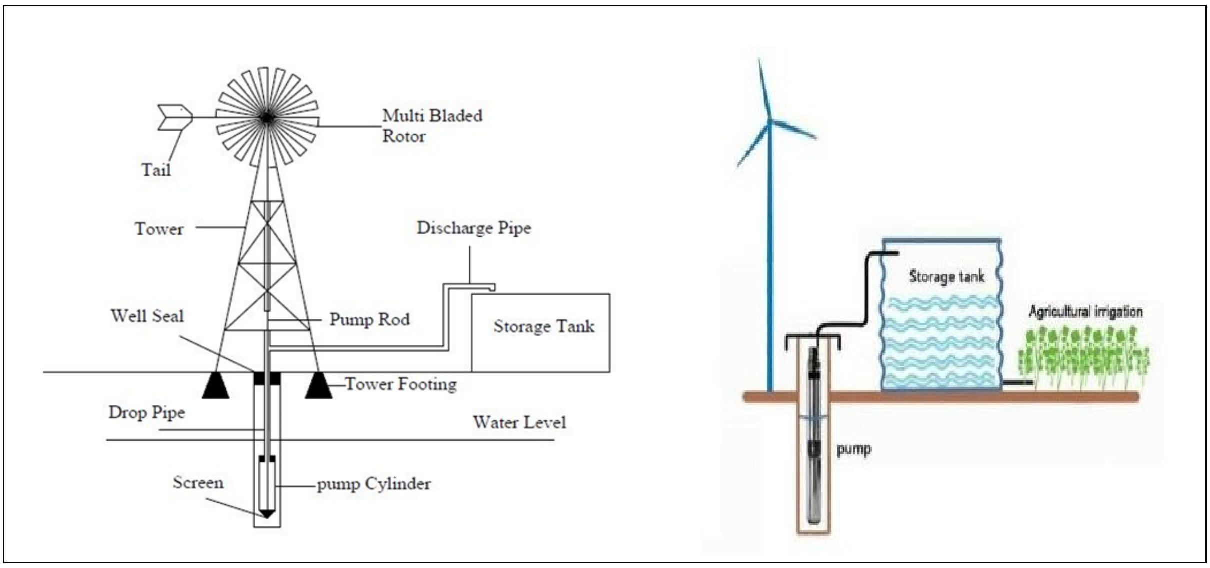


Figure 2-27: Wind powered water pump

The blades of the windmill wheel catch the wind, which turns the rotor. The wheel assembly is attached to a hub assembly, which drives a geared mechanism that converts the rotary motion to an up-and-down motion. This motion drives a pump rod, up and down inside of a pipe in the well. A cylinder with a sealed plunger, going up and down inside, forces the water up the pipe. Each upstroke pulls water into the cylinder, while on the downstroke, a check valve in the bottom keeps the water from being pushed out, so the water is forced up the pipe with the next upstroke. Wind is naturally intermittent, requiring some method of storage.

Pumping water up to a tank or to a pond, which then feeds the water by gravity is more efficient than transferring the energy to batteries. The amount of water a windmill can pump is controlled by the size of the pump cylinder, the elevation to which the water needs to be pumped, the size of the blades, and how windy it is where the windmill is installed (Calderone, 2018).

2.4.6.3 ***Hydro Powered systems***

Micro-hydro systems use the flow of water to generate electrical power. It consists of a water intake, a water turbine and a dynamo. The moving water rotates the turbine while the dynamo converts the energy from the rotating turbine into electrical energy (Nederstigt and Bom, 2014). These systems are mainly used for domestic and rural electricity supply. During the day and after midnight when electricity consumption is lower, excess energy can be used to pump water to storage tanks to irrigate nearby fields and crops (Osborn *et al.*, n.d.). Figure 2-28 shows a graphical example of a micro-hydro system.

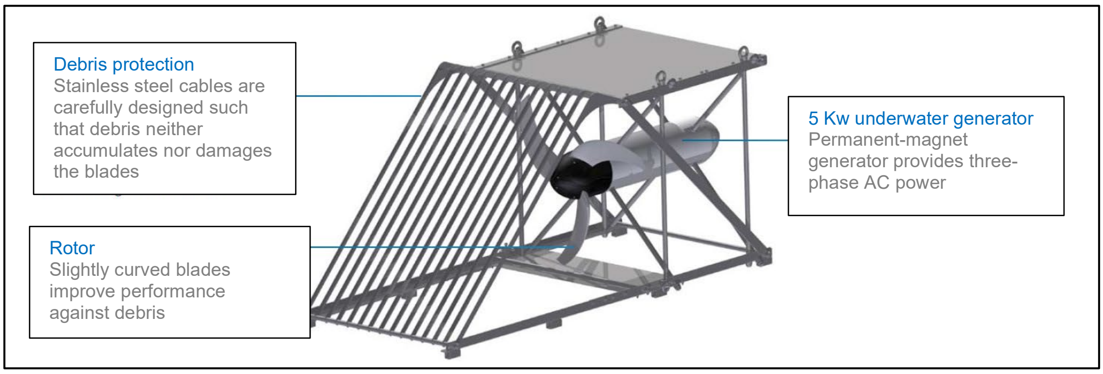


Figure 2-28: Micro-hydro system (SEA, 2017)

Reasons for implementing hydropower systems on farms are economic incentives, the reduction in pipe pressure and a transition to a more sustainable source of energy. Osborn *et al.* (n.d.) states that this transition would also lessen the environmental impact in comparison to conventional energy sources. Other benefits of a hydropower system include it being installed within existing infrastructure, which does not necessarily require a water use license. It has low operational and maintenance costs and can extend the life on existing pressure control valves. The technology is efficient and has a standard lifespan of 20 years (SEA, 2017).

There are however risks involved with the implementation of a hydro system. The installation of the system might interrupt water supply and wastewater treatment works operations. In this case the turbine must have large operating ranges. A bypass may need to be installed in order to not affect water supply during installation or when the turbine is not working. The part of the turbine that is in contact with the water must be stainless steel to eliminate any risk of water contamination due to abrasion or corrosion (Osborn *et al.*, n.d.). Alternatively, hydraulic ram pumps or hydrams can be used to transfer small volumes of a water flow to higher elevations by means of a hammering action. Although this invention is ideal for irrigation purposes, it is not commonly applied and limited to specific situations (Nederstigt and Bom, 2014).

2.4.6.4 ***Grid-tied Systems***

In grid-connected applications, DC power from solar cells runs through an inverter and feeds back into the distribution system. Grid-connected systems have proved their worth in natural disasters by providing emergency power capabilities when utility power was interrupted. Although, the PV power is generally more expensive than utility-provided power, use of grid-connected systems is increasing (Penick and Louk, 1998). In South Africa, farmers can apply to ESKOM to be connected to the grid. In essence, they bank (not sell) the excess power to use later in times when they cannot generate enough power to run the renewable energy system.

*2.4.6.5 **Hybrid Systems***

A combination of Solar and Wind systems can be installed in areas that do not have access to the electricity grid. It has to be noted that solar radiation and wind speeds are always changing for different locations, climatic conditions and times. For example, during the period of bright sunlight, the solar energy is utilized for charging the batteries, creating enough energy reserve to be drawn during night, while the wind turbine produces energy at any given time of day even though intermittent. Such a system will ensure that irrigation operations will proceed unhindered at any given time of the day. Figure 2-29 shows a schematic layout of a hybrid system.

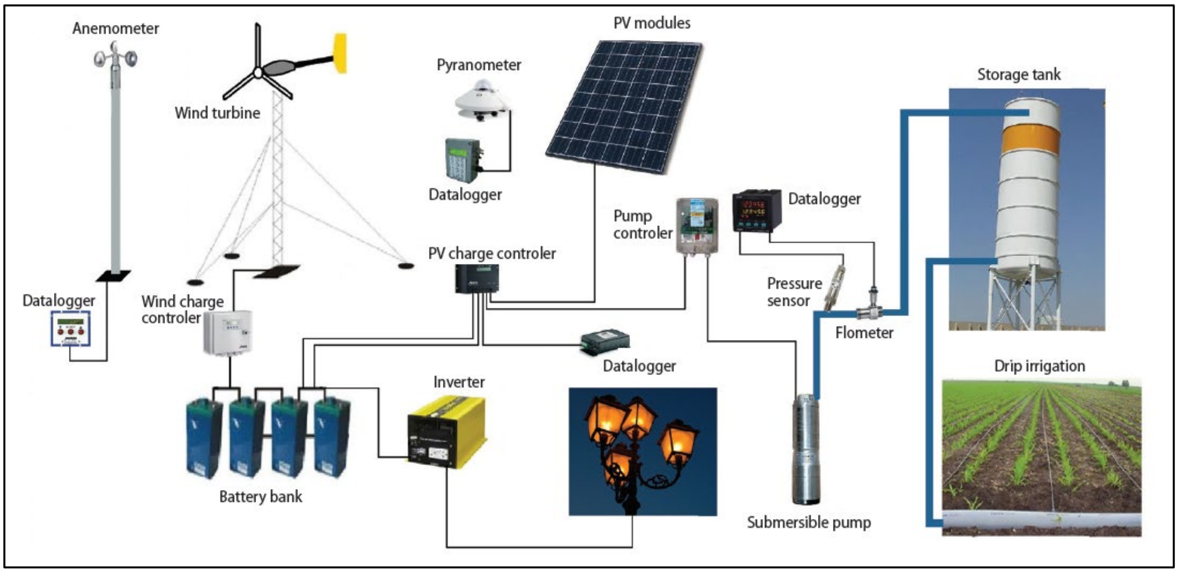


Figure 2-29: Schematic of the hybrid drip irrigation system (Kose *et al.*,2019)

*2.4.6.6 **Storage***

Energy storage is an important factor influencing the feasibility of RE systems especially in its application for irrigation. Various types of storage technologies with different characteristics are used in both the supply and demand of energy. The storage of energy is required for a stability in electricity supply and can either be for a short term or for several months (PM and SANEDI, 2018).

Battery arrays are the most commonly used storage systems for small scale renewable energy. For high capacities, batteries should be wired in parallel and for an increase in voltage they should be arranged in series. Batteries are available in units of 12 V which can be increased to 24 V or 48 V if coupled in series. If the voltage is higher than 48 V it becomes a safety hazard; the batteries must be electrically insulated. The electrons in a battery flow in one direction and therefore the electricity is referred to as DC. A high voltage is required for transporting electricity over long distances. This minimises losses. The voltage needs to be reduced again on the delivering end to values operated at household level. Therefore, the most electrical grids in the world consist of AC in order to directly transform electricity to various voltages (Brosius, 2009).

There are two options of rechargeable batteries for heavy duty service, i.e. deep-cycle batteries and starter batteries (most automotive batteries).

Deep-cycle lead-acid batteries
These batteries can deliver a consistent voltage when they discharge over a load and are often preferred in vehicles with modern electronics. A lower recharging current is required for these batteries. The lead plates are solid however some batteries are hybrid. Deep-cycle lead-acid batteries are designed to discharge down to 20% of its charge capacity over several cycles while it is recommended that hybrid batteries shouldn't be discharged beyond 50% of its capacity.

Starter batteries
These batteries are a good option for starting automotive engines since they can deliver much higher peak currents for the same size battery. They are designed to deliver sporadic current spikes and should not be exposed to deep discharge. If these batteries are repeatedly exposed to deep discharge, they can lose capacity and ultimately fail. To prevent sulphating, these batteries should be charged at least once every two weeks. Keeping these batteries on float charge can cause the electrodes to corrode resulting in premature failure.

Gassing can result from the overcharging of lead-acid batteries.

Renewable energy systems mostly make use of valve regulated acid batteries due to:
- lower electrolyte content,
- a higher ratio of power to "floor space" and
- a high peak power capacity (of relatively short duration)

It is advantageous to add a charge controller to the system layout as it limits the flow of the electric current to and from the electric batteries. It prevents overcharging, overvoltage and even deep discharging of a battery. Depending on the battery technology, controlled discharges can be performed to protect the battery life. A voltage control may be required to produce a usable voltage as the speed of the generator may vary as a result of the variability in resource availability and extent (Brosius, 2009).

2.5 Summary

Fossil fuels are used as an energy source for numerous applications in agriculture such as water heating, irrigation, etc. The high CO_2 emissions caused by the use of fossil fuels are a global concern due to the adverse effects thereof on the environment. For this reason, much emphasis is put on the promotion of renewable energy technologies in order to decrease CO_2 emissions associated with fossil fuels (Kaushik, 2011).

Agriculture, especially irrigation, like other sectors that heavily rely on electricity supply is faced with huge energy supply interruptions and increased costs. In South Africa, access to reliable and affordable power is becoming increasingly problematic, resulting in farmers switching to alternative power sources from renewable energy. Solar energy, as well as other renewable sources such as wind and hydro, enable farmers and agribusinesses to continue operating when there are interruptions due to load-shedding or cable theft, thus ensuring that productivity is not affected. The most common renewable energy sources that have been taken up by farmers for irrigation in South Africa are solar power and wind power. With the rapidly decreasing prices of solar panels and abundant sunshine, solar energy has emerged as the most popular alternative source of energy for many irrigation farmers in South Africa.

The uptake of the SPIS faces challenges such as access to finance especially for smallholder farmers as well as access to quality products and services. To avoid over exploitation of water resources, there is need to carry out water resources assessments and planning.

In terms of the hybridisation potential with solar or wind-powered pumping and irrigation, an important factor to consider is the resource availability. In terms of mechanical power from windmills or micro hydro, it is equally as important to take into consideration the retrofitting of equipment and the space availability. These applications are therefore site specific and not applicable throughout South Africa, however there are good small-scale wind and hydropower technologies available (PM and SANEDI, 2017).

From the literature review it can be concluded that there is a need to verify the feasibility among different renewable energy sources for application in irrigated agriculture. It is important to evaluate the most viable irrigation system with renewable energy source combination.

3 POTENTIAL RENEWABLE ENERGY SOURCES IN SOUTH AFRICA FOR IRRIGATION

3.1. Overview

The potential of RE sources is not the same across the different provinces. Mpumalanga and KwaZulu-Natal have the highest potential for biomass while solar energy is the resource with the highest potential in the other seven provinces. Limpopo province has the second highest potential for biomass while the resource with the second highest potential in the Frees State is hydro energy. The Northern, Western and Eastern Cape provinces have the second highest potential for wind energy. Due to South Africa's geology, mild annual temperature range and low demand, the use of geothermal energy in the hybridisation technologies is considered not applicable (PM and SANEDI, 2017). In Figure 3-1 the most prevalent RE source opportunities are indicated per province. Other RE sources do exist but are comparatively small to those highlighted on the map (GIZ, 2015).

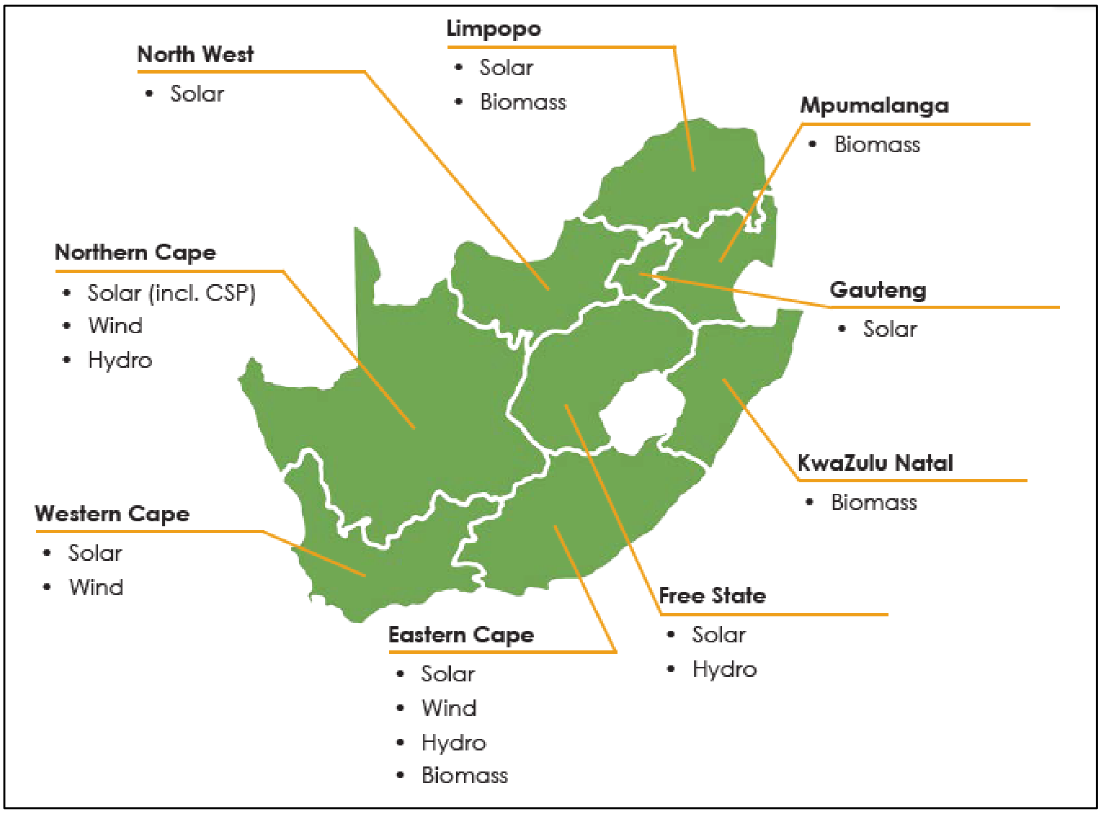


Figure 3-1: Distribution of RE sources among provinces in South Africa (GIZ, 2015)

3.2 Solar energy

Solar energy, used to generate electricity, is the second most utilised category of renewable energy in the Department of Energy's IPPPP. In South Africa, most regions receive an average of 8 to 10 hours of sunshine a day. The annual average hours of sunshine are 2 500 hours, with a 4,5 to 6,6 kWh.m^{-2} level of radiation. Solar is widely accessible in South Africa when compared to other countries in Africa, USA and Europe. It is targeted for both PV and thermal applications (PM and SANEDI, 2017). South Africa has a potential to harness a total of 547,6 GW nominal capacity by using the concentrated solar power plants only (Fluri, 2009). The country has some of the highest solar irradiance in the world and experiences some of the highest levels of yearly horizontal solar irradiation globally. The annual PV generation of optically inclined systems in some of the metropolitan areas are Kimberley 1 854 kWh.kWp^{-1}, Pretoria 1 731 kWh.kWp^{-1}, Cape Town 1 621 kWh.kWp^{-1} and Durban 1 409 kWh.kWp^{-1} (WWF, 2017).

The research hub, CRSES, at Stellenbosch University has worked in collaboration with the Group for Solar Energy Thermodynamics (GSET) at the University of KwaZulu-Natal to initiate the Southern African Universities Radiometric Network (SAURAN). The aim of this initiative is to avail high-resolution ground-based solar radiometric measurement data from stations located in the region of Southern Africa. Data for DNI, GHI and DHI, is retrieved from Kipp and Zonen radiometers at daily, hourly and 1-minute averaged intervals. A list and map with the stations are provided on the website indicating the names, locations (with co-ordinates), elevation and the topography. Maps displaying the GHI and the DNI for South Africa are also available for download. Colour contours are used to indicate the exposure of one unit area (square metre) to total irradiance (kWh) over a period of one year (SAURAN, 2021). See Figure 3-2.

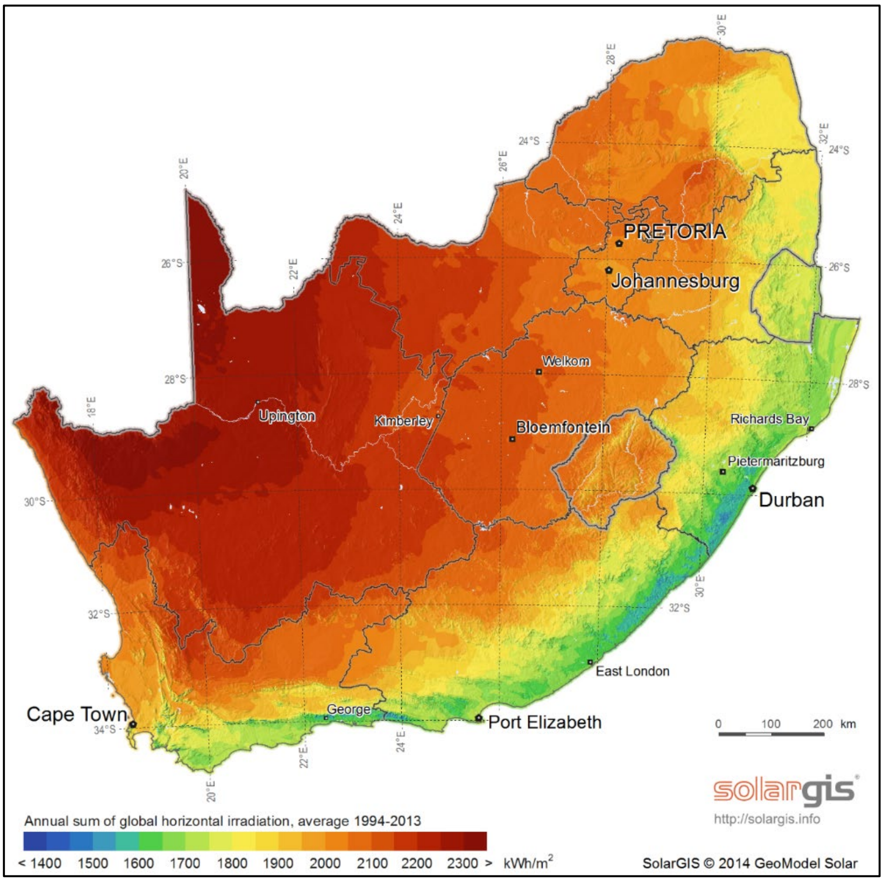


Figure 3-2: Mean annual Global Horizontal Irradiance for South Africa (SAURAN, 2021)

The Global Solar Atlas has been developed by the World Bank Group in addition to a series of global, regional and country GIS data layers and poster maps, to support the scale-up of solar power in their client countries. The Global Solar Atlas provides easy access to photovoltaic power potential and solar resource data around the world. There is also a section where poster maps, showing resource potential for the globe, regions and countries, and GIS layers can be downloaded. The Knowledge Base section provides more information on the how to use the Atlas as well as the data provided and the methodology for approximating solar resource potential (Global Solar Atlas, 2021).

The average GHI per year for South Africa as retrieved from the Global Solar Atlas is shown in Figure 3-3. The map indicates the available solar resources in South Africa for one year based on a long term average. It is important to note that the areas with lower levels do not have lower radiation, it is merely less available throughout the year due to weather conditions, such as cloud cover.

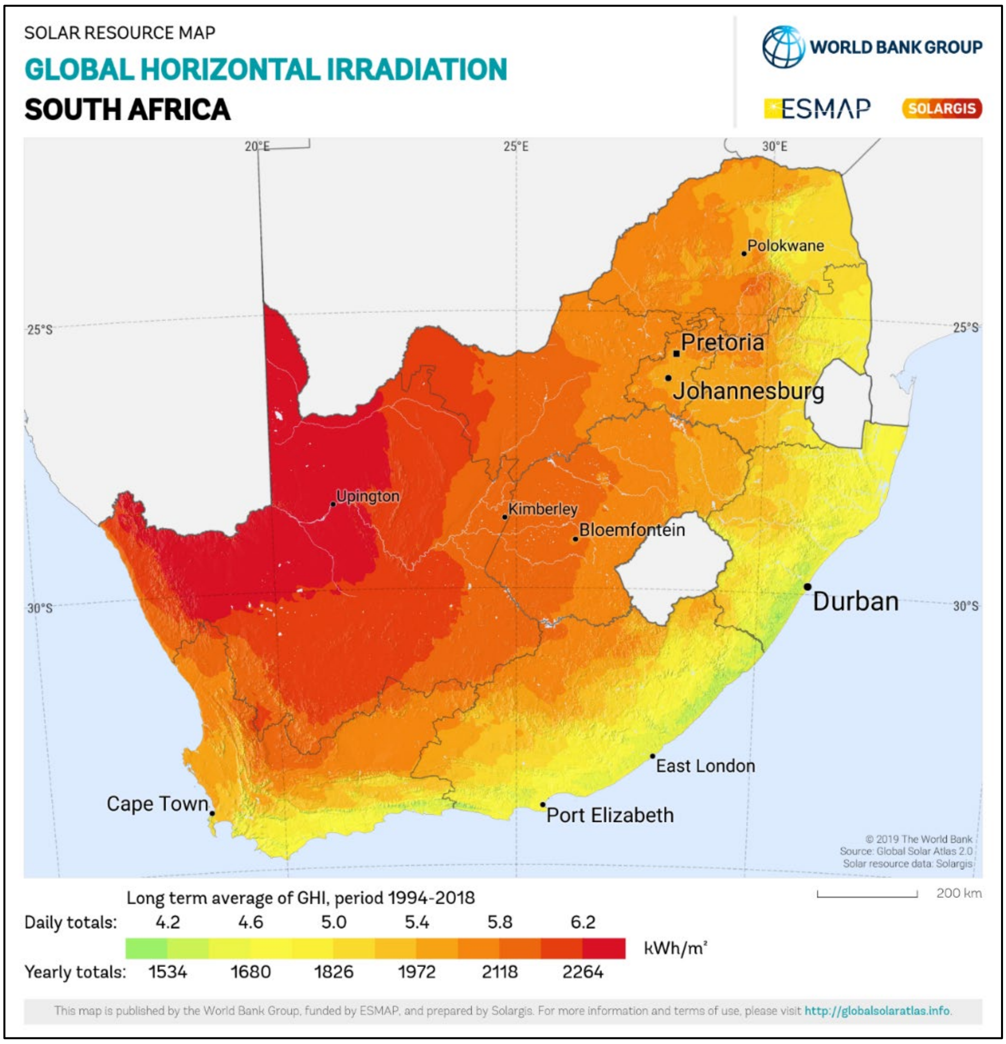


Figure 3-3: Mean annual Global Horizontal Irradiation for South Africa (Global Solar Atlas, 2021)

Data from the Global Solar Atlas can be used to quantify the photovoltaic energy potential for a specific site. A solar resource map for South Africa is available from the Global Solar Atlas. The underlying solar resource database is calculated from atmospheric and satellite data with a 14-minute and 30-minute time step, and a spatial resolution of 1 000 m. A high-resolution map can be downloaded from the Global Solar Atlas as shown in Figure 3-4.

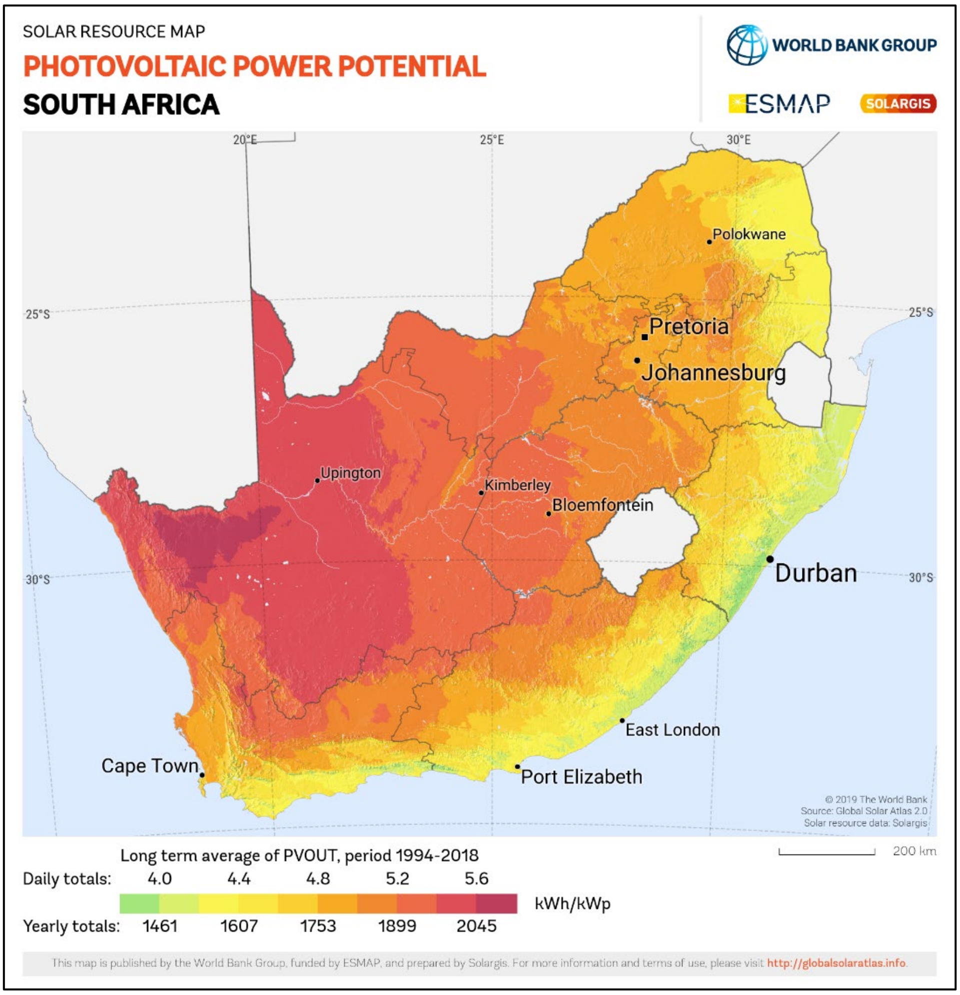


Figure 3-4: Mean annual Photovoltaic Power Potential South Africa (Global Solar Atlas, 2021)

3.3 Wind energy

According to research by the CSIR, the potential of solar resources in South Africa is similar to that of wind resources. Adequate resources with the potential for high load factors can be found countrywide There is substantial wind energy resource potential in the Eastern Cape resulting in approximately 43% of the procured wind power being sourced from this province. Wind is therefore considered as the least-cost option in an increasing number of markets in terms of new power generating capacity (PM and SANEDI, 2017).

As part of the WASA project, a high-resolution wind resource map for South Africa was developed. The map depicts the mean wind speed in (m.s^{-1}) at an elevation of 100 m above ground level and is based on 3,3 km WRF + 250 m WAsP modelling. See Figure 3-5. For the duration of the WASA project, a total of 19 observation masts have been established to obtain meteorological data concerning wind energy. These sites are also indicated on the map by means of black dots and labelled for example "WM19". Mast data including the project information, project documents and measurements can be downloaded from http://wasa.csir.co.za/web/welcome.aspx. The South African Wind Atlas Guide which was developed by the CSIR in 2014 can also be downloaded from this site (WASA, 2021).

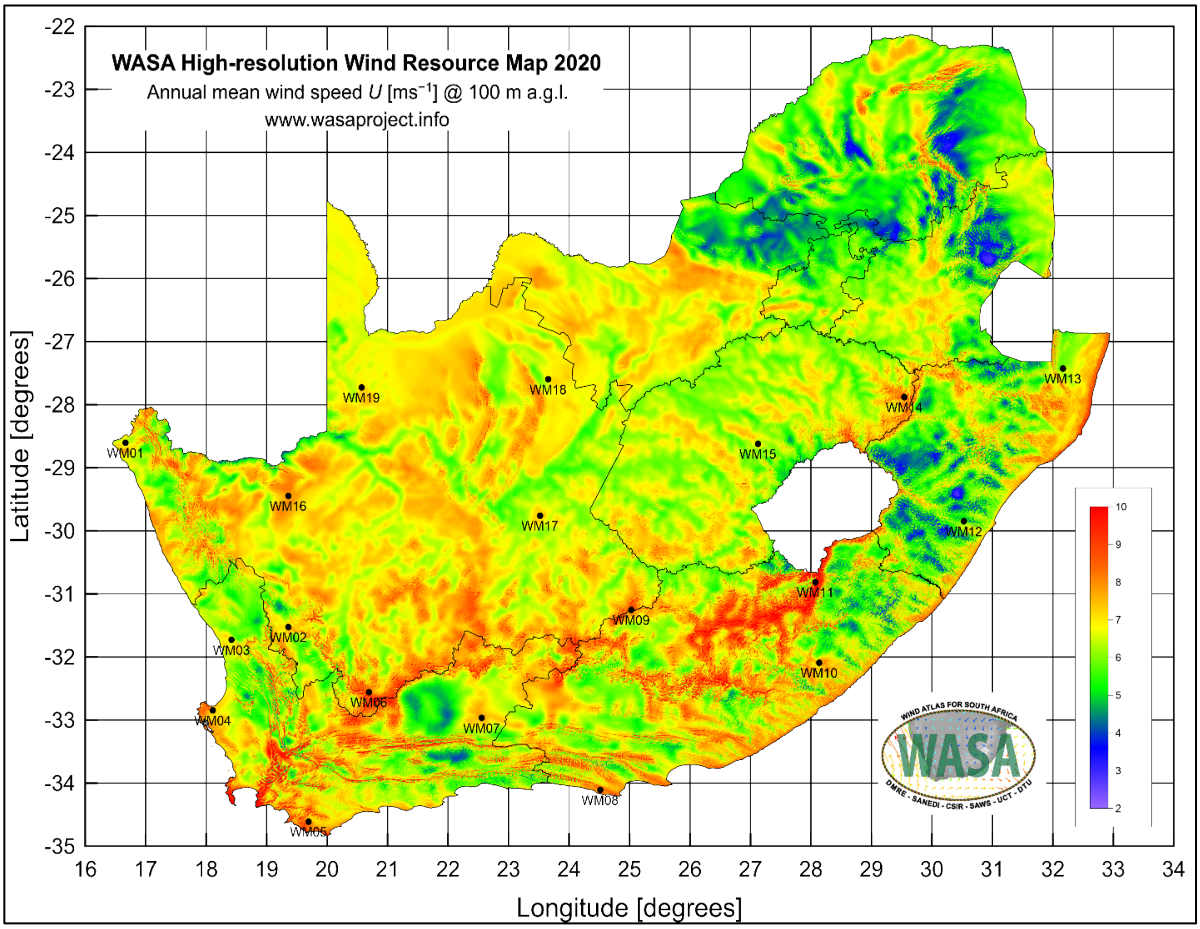


Figure 3-5: High-resolution wind resource map for South Africa (WASA, 2021)

Mean annual wind speeds of 4 $m.s^{-1}$ are experienced at elevations of 100 m in most parts of the country. Although small-scale wind turbines operate effectively at this wind speed, they are normally mounted at elevations less than 50 m. The mounting elevation often poses a problem since wind speeds tend to be significantly less at lower heights. By taking these parameters into consideration, regions in the country with the potential to produce electricity from wind energy can be identified (Schmidt, 2019).

A WASA time series portal was developed in response to requests for long time data series with information reflecting annual, seasonal and diurnal variations of wind speed and wind direction for South Africa. There are more than 285 000 grid points in the mesoscale model domain, each with 30 years of 30-minutely data at 14 vertical levels. Wind speed and direction are measured at 20, 60, 100 and 120 metres above ground level. Temperature is measured at two metres above ground level. The period ranges from 01 January 1990 to 31 December 2019 (CSAG, 2021).

The Global Wind Atlas can be used for preliminary calculations to identify high-wind areas for wind power generation all across the globe. It is a free, web-based application developed to assist policymakers, planners, and investors (Global Wind Atlas, 2021).

It is estimated that there is a total of 300 000 wind-driven water pumping systems currently in operation in Southern Africa (IRENA, 2015). A local manufacturer of small wind turbines in

South Africa is Kestrel Wind Turbines – a subsidiary of Eveready (SA). In order to harness the power of these small wind turbines, they use stand-alone battery-charging systems, hybrid systems with PV panels, as well as grid-tied systems. These systems have benefits such as minimising the impact of load shedding, as well as feeding renewable electricity back into the national grid as an energy storage option. Their turbines range in sizes from 600 W (e160i) up to 3,5 kW (e400nb). Diesel generators are an ideal partner to wind turbines due to their ability to ramp up and down at high rates. These systems could therefore potentially be hybridised. This is useful in remote regions where wind is a more abundant resource than solar power.

3.4 Hydro energy

Hydropower has the potential to provide a continuous supply of electricity, subject to water availability, in comparison to other renewable energy sources. In South Africa there are few perennial rivers and the country is often challenged with water scarcity (Schmidt, 2019).

Small-scale hydro power plants operate on the same principle as large-scale hydro power plants. They are part of the REI4P and are generally smaller than 10 MW (WWF, 2017). A Baseline Study on Hydropower in South Africa undertaken in 2002, highlighted that there is potential for 247 MW new small-scale hydro developments (PM and SANEDI, 2017). Barta & Grøn (2002) suggested that unconventional hydropower development can be implemented in the rural and urban areas of South Africa, such as tapping hydropower from irrigation canals, water supply pipelines, and deep mining undertakings. Rural areas of the Eastern Cape, Free State, Mpumalanga and KwaZulu-Natal are suitable locations for these potential developments (especially for small and micro hydropower plants). South Africa also has a lot of potential for embedded water transfer and gravity-fed systems (GIZ, 2015).

The benefits of small-scale hydropower schemes are that they can provide electricity to rural communities, especially in mountainous areas in the Eastern Cape, Western Cape and KwaZulu-Natal. It also provides potential for localised farming industries. On-site dams on these farms could work in proximity with rivers and river networks with consistent water flows which could also serve as a source of hydro-energy (Schmidt, 2019). Small-scale hydropower schemes are dependent on various factors to determine the cost of energy (ZAR.kWh^{-1}). These factors include the size, cost, location and operation of the specific plant. Due to these factors, the cost of energy can vary significantly. Additional costs may also be required to conduct the necessary social and environmental impact studies. Other fees to take into consideration include fees associated with the use of dams, obtaining a water use licence from the Department of Human Settlements, Water and Sanitation (DWS) as well as obtaining an electricity generation licence from the NERSA (Schmidt, 2019) (only for applications larger than 100 MW).

The potential of developing hydrokinetic hydropower systems for isolated and rural areas in South Africa has been investigated. It was proven that HK power generation could be the most cost-effective supply option in comparison to wind and PV and diesel. A multitude of structures such as syphons, control gates, weirs, chutes and drops exist in the irrigation canals all across South Africa. All of these hold large unexploited HK potential (Niebuhr, 2018).

Rural areas of the Eastern Cape, Free State, Mpumalanga and KwaZulu-Natal are suitable locations for these potential developments (especially for small and micro hydropower plants). South Africa also has a lot of potential for embedded water transfer and gravity-fed systems (GIZ, 2015). The potential for small hydro power systems in the Eastern Cape of South Africa has been identified. This is shown in Figure 3-6.

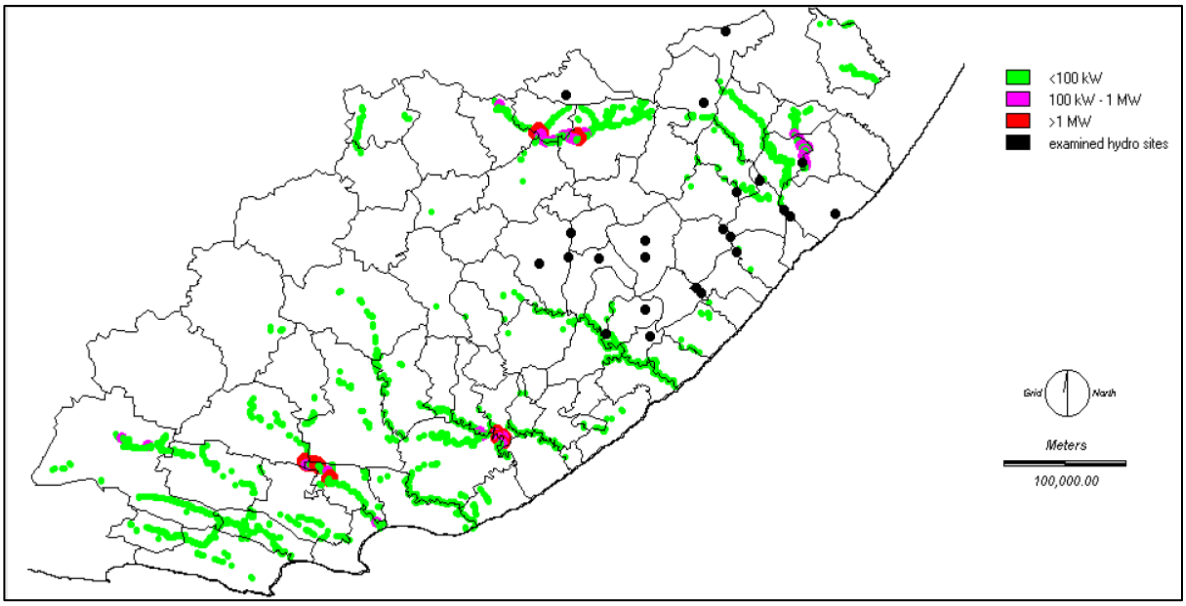


Figure 3-6: Small hydro power potential in the Eastern Cape of South Africa (PM and SANEDI, 2017)

The Department of Water and Sanitation asset management study database revealed a network of more than 6 500 km of canals in 47 schemes in South Africa. Their locations are shown in Figure 3-7. A multitude of structures such as syphons, control gates, weirs, chutes and drops exist in these canals. All of these hold large unexploited HK potential (Niebuhr, 2018).

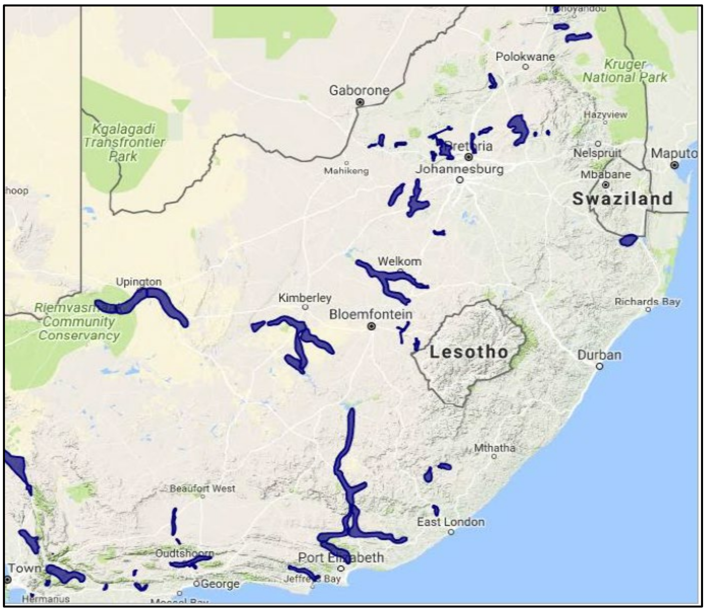


Figure 3-7: Canal schemes in South Africa (Niebuhr, 2018)

There are flow measurement gauging stations in most of the major rivers, and canal networks, throughout South Africa. When considering a site for a hydro system, data records from these gauging stations can be useful to determine the water resource availability as a part of a pre-feasibility study. Reliable hydrological data sets are important for undertaking reliable water resource analysis. Hydrology is the main factor influencing the resulting yields and estimated risk of failure of a water supply system.

3.5 Bioenergy

The South African BioEnergy Atlas is a newly developed web-based tool used for crop-based biomass – not organic waste streams. This tool was developed and launched by The Department of Trade and Industry to guide the identification of potential wood biomass resources – specifically those which can be used as alternative energy sources. Invasive alien plants, oil producing plants, sugar cane and a variety of woody biomass are all examples of these crop-based resources. The atlas indicates the availability of these biomass crops. The Department of Energy did an assessment on the availability of the four main biomass sources. These are: plantation forest residues, bagasse, invasive alien plants and bush encroachment. It is estimated that 22,2 million tonnes are available to be used for the generation of energy (PM and SANEDI, 2017).

In South Africa, the eastern coast is an ideal location for biomass powered facilities in comparison to the inland or western regions. This is due to its typically wetter climate in which plant-based sources proliferate better (PM and SANEDI, 2017).

Factors such as climate, soil, land use practice and population density influence the availability and types of feedstocks available for bioenergy production in South Africa (BioEnergy Atlas, n.d.).

The availability of feedstocks such as forestry and agricultural residues varies according to the management objectives of the activities that produce the feedstock while the volume and availability of certain feedstocks follow a seasonal cycle. One of the aims of the BioEnergy Atlas Project was to assess the factors that determine the availability of the bioenergy feedstocks in South Africa.

The raw potential or baseline for biomass production is expressed as Net Primary Productivity (NPP) and it is extensively modified by land use. The modification of the baseline NPP is influenced by the local soil types, current land cover, extent of degradation, and improved yields due to intensive agriculture (BioEnergy Atlas, n.d.). Figure 3-8 shows the NPP for South Africa.

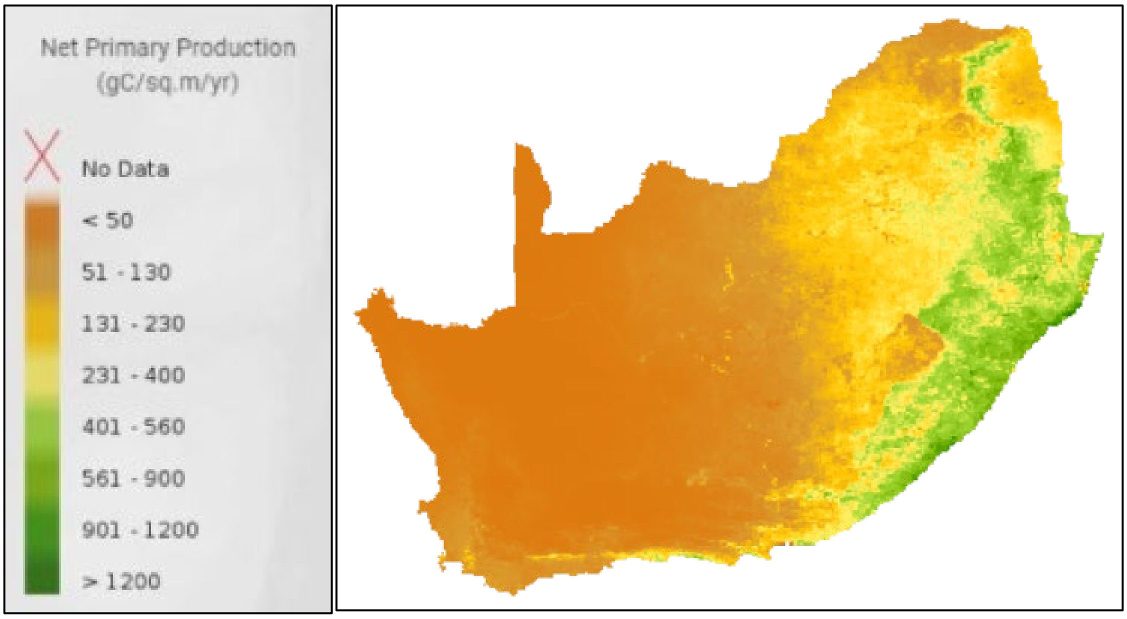


Figure 3-8: Biomass Net Primary Productivity (BioEnergy Atlas, n.d.)

The baseline NPP can be modified significantly by changes in Land use and Landcover. The volume of biomass produced in an unproductive area can be increased by intensive agriculture practices. The opposite will be true for changes from one land cover type to another, such as forestry to crop agriculture.

Although the areas for biomass production is reduced by processes such as urbanization, activities such as transportation and the production of fuel and food for growing urban populations together with the resultant waste streams, may contribute to the availability of biomass. Figure 3-9 shows the Landcover of South Africa.

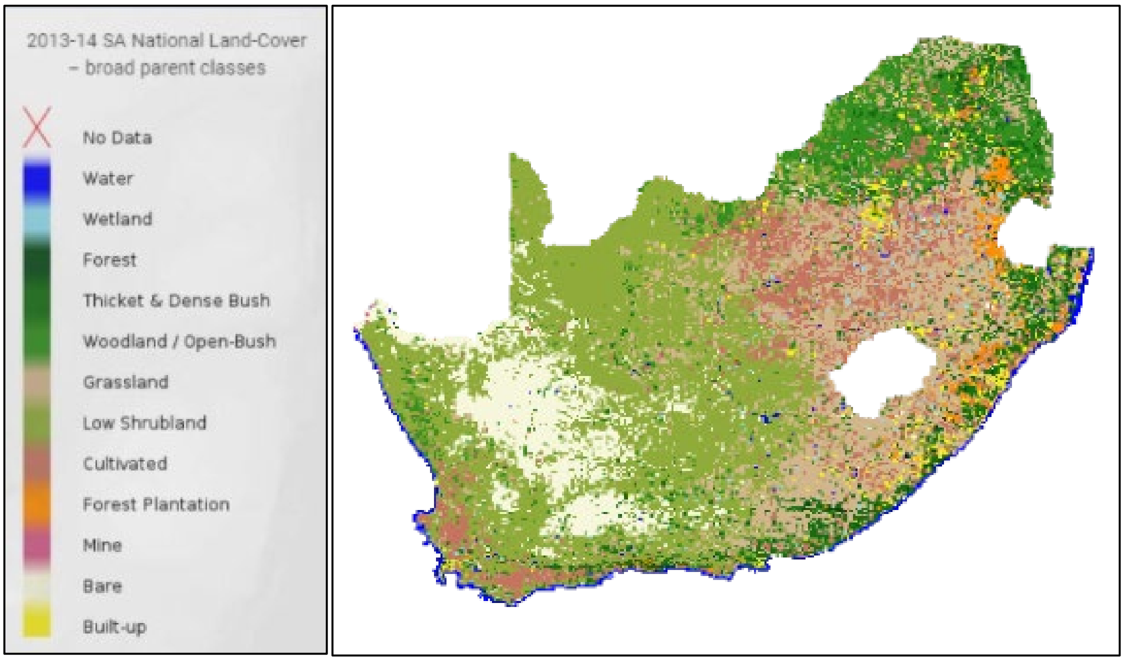


Figure 3-9: Landcover of South Africa (BioEnergy Atlas, n.d.)

A biogas plant requires a high initial capital investment. This amount consists of three main components: the digester, the biogas generator and the installation costs. It has a payback period of approximately five to eight years, depending on the plant's capacity to produce electricity. The financial viability of these plants only starts showing from a 350 kWe plant and upwards. This is due to the capital and operating costs, as well as the electricity tariffs (ESKOM and municipal). These cost implications mean that the majority of farming operations in South Africa would not be able to afford a biogas project. Practical and cost-effective biogas solutions are being developed by BiogasSA. These projects will allow the farmer to participate in the process of constructing the biogas plant, at a considerable reduction in costs. BiogasSA is also developing a dual fuel generator that can run on diesel as well as biogas. This eliminates the need for two separate generators to be bought and operated (Biogas Consulting SA, 2020).

In terms of powering pumps on a small scale, biogas is not commonly used as fuel. Pumps are usually not used near biogas tanks and storage of gas is required when biogas is not needed. Although the use of bioenergy to drive pumps is technically feasible, practical limitations make it an unusual option. Similarly, large (communal) bio-digesters are not used for pumping water for irrigation either (Nederstigt and Bom, 2014). Bioenergy as a renewable resource for irrigation pumping is therefore not elaborately discussed in this research study.

3.6 Summary

A lot of research has been done on the potential of solar energy in South Africa as an alternative energy source. South Africa has some of the highest solar irradiance in the world and experiences some of the highest levels of yearly horizontal solar irradiation globally (WWF, 2017). Most regions receive an average of 8 to 10 hours of sunshine a day. The annual average hours of sunshine are 2 500 hours, with a 4,5 to 6,6 $kWh.m^{-2}$ level of radiation. Solar resource maps have been developed for the country and data from the Global Solar Atlas can be used to quantify the photovoltaic energy potential for a specific site. An initiative has also been implemented to avail high-resolution ground-based solar radiometric measurement data from stations located in the region of Southern Africa.

According to research by the CSIR, the potential of wind resources in South Africa is similar to that of solar resources. Adequate resources with the potential for high load factors can be found countrywide. There is substantial wind energy resource potential in the Eastern Cape resulting in approximately 43% of the procured wind power being sourced from this province. As part of the WASA project, a high-resolution wind resource map for South Africa was developed. Mean annual wind speeds of 4 $m.s^{-1}$ are experienced at elevations of 100 m in most parts of the country. A total of 19 observation masts have been established to obtain metrological data concerning wind energy as part of the WASA project. The Global Wind Atlas can be used for preliminary calculations to identify high-wind areas for wind power generation all across the globe. It is a free, web-based application developed to assist policymakers, planners, and investors.

A baseline study on hydropower in South Africa undertaken in 2002, highlighted that there is potential for 247 MW new small-scale hydro developments (PM and SANEDI, 2017). Rural areas of the Eastern Cape, Free State, Mpumalanga and KwaZulu-Natal are suitable locations especially for the development of small and micro hydropower plants. South Africa also has a lot of potential for embedded water transfer and gravity-fed systems (GIZ, 2015). Structures such as syphons, control gates, weirs, chutes and drops in the irrigation canals all across South Africa hold large unexploited HK potential. There are flow measurement gauging stations in most of the major rivers, and canal networks, throughout South Africa. Data records from these gauging stations can be useful to determine the water resource availability for generating electricity.

The eastern coast of South Africa is an ideal location for biomass powered facilities in comparison to the inland or western regions. This is due to its typically wetter climate in which plant-based sources proliferate better. The BioEnergy Atlas Project was initiated to assess the factors that determine the availability of the bioenergy feedstocks in South Africa. A newly developed web-based tool used for crop-based biomass and various maps for determining bioenergy potential have been developed. The implementation of biomass projects for the generation of electricity however still faces financial barriers in comparison to other mainstream renewable technologies such as wind and solar energy. Bio-digesters are generally not used for pumping water for irrigation.

4 ASSESSING RENEWABLE ENERGY USE IN SOUTH AFRICA RELATED TO IRRIGATION

4.1 Overview

To establish the application of the discussed renewable energy systems for irrigation purposes, a process was undertaken to identify case studies in South Africa. Visits were arranged to some locations to establish the extent of the use of such irrigation systems on the ground. Ample information was collected with the different approaches followed. This section elaborates on the current implementation of alternative renewable energy systems related to irrigation, the users as well as the suppliers and products identified. A database with various clients and suppliers, the type of RE system they installed or plan and the dates when they were contacted is included in Appendix A. The database also lists all the relevant case studies that were mentioned in the REEEP and SANEDI research report. In addition, it lists case studies from the Association of Renewable Energy Practitioners (AREP) Solar PV directory – a platform where Solar PV installations, businesses and services are listed. The reader is referred to a study by Brosius (2009) where different wind turbine technologies are listed and a study by Van Dijk *et al.* (2013) where hydro turbine technologies are listed.

4.2 Approach for collecting information

Information about potential case studies was collected from meetings with specialists, literature, associations, webinars as well as suppliers of renewable energy sources identified during the course of the research study.

Meetings were conducted with the following specialists:

- Two scientists from SANEDI who shared their knowledge and suggested that the study team look at the Switch Africa Green "Sustainable Energy Consumption and Production (SECP) in Agriculture and Integrated Waste Management" Research and Training Report.
- A specialist from Nano Energy who shared some information about regulations and possible sites.
- Two advisors from ESKOM who shared their knowledge about grid-tied systems and mentioned a database with co-ordinates of where users are located and information about their systems.

The following literature was used to source information:

- Landbouweekblad magazines
- SABI magazines
- Switch Africa Green report

A series of online webinars about Solar PV systems were attended by members of the study team. These webinars were arranged by SAIAE (South African Institute of Agricultural Engineers) and presented by Nicolaas Faure van Schalkwyk. The topics include the following:

- Different solar PV systems for farms
- Solar PV design principles
- Solar PV compliance and quality assurance

- Solar PV system design calculations and O&M
- Realistic solar PV finances and benefits

Site visits are one of the best instruments to obtain information especially when it comes to site specific installations and operations. Following the process to identify case studies, it had to be decided how many case studies would be selected for site visits. This initiated a screening process. The information sourced from the previous processes was incorporated into a database with the following main headings:

- Client
- Contact person
- Contact details
- Location
- Type of farming
- Related to irrigated agriculture (yes/no)
- Renewable energy source (wind, solar, bio, hydro)
- What type of system (grid-tied, off-grid, hybrid)

A second screening was done based on the information in the database. If the identified case study was related to irrigated agriculture, it was considered for a potential site visit.

A questionnaire was prepared which could be completed at site visits or with telephonic/email correspondence. Information included in the questionnaire entail a general description of the case study such as a description of RES type, location, weather, type of farming (crop) and scale, water authority and service provider (municipality/ESKOM). The technical information required, specifically related to the RES, include the drivers for adopting renewable energy source, service provider, classification/characteristics of the system, legalities/agreements and operation.

4.3 Current implementation identified

The current implementation of alternative renewable energy systems related to irrigation that are already installed or in planning in South Africa were identified. The sites identified to be visited are shown in Figure 4-1. In Table 4-1 to 4-3 the location, crop type, irrigation area and system, the RE system size, the configuration of the RE system as well as its payback period and lifespan of all the identified sites are listed. The sites that were visited are indicated with an asterisk symbol. The information of the different case studies collected during the site visits is summarised in Appendix B.

In addition to the sites identified, correspondence with experienced suppliers and consultants in the field of renewable energy included valuable comments and feedback which is summarised in the Workshop Report in Appendix C.

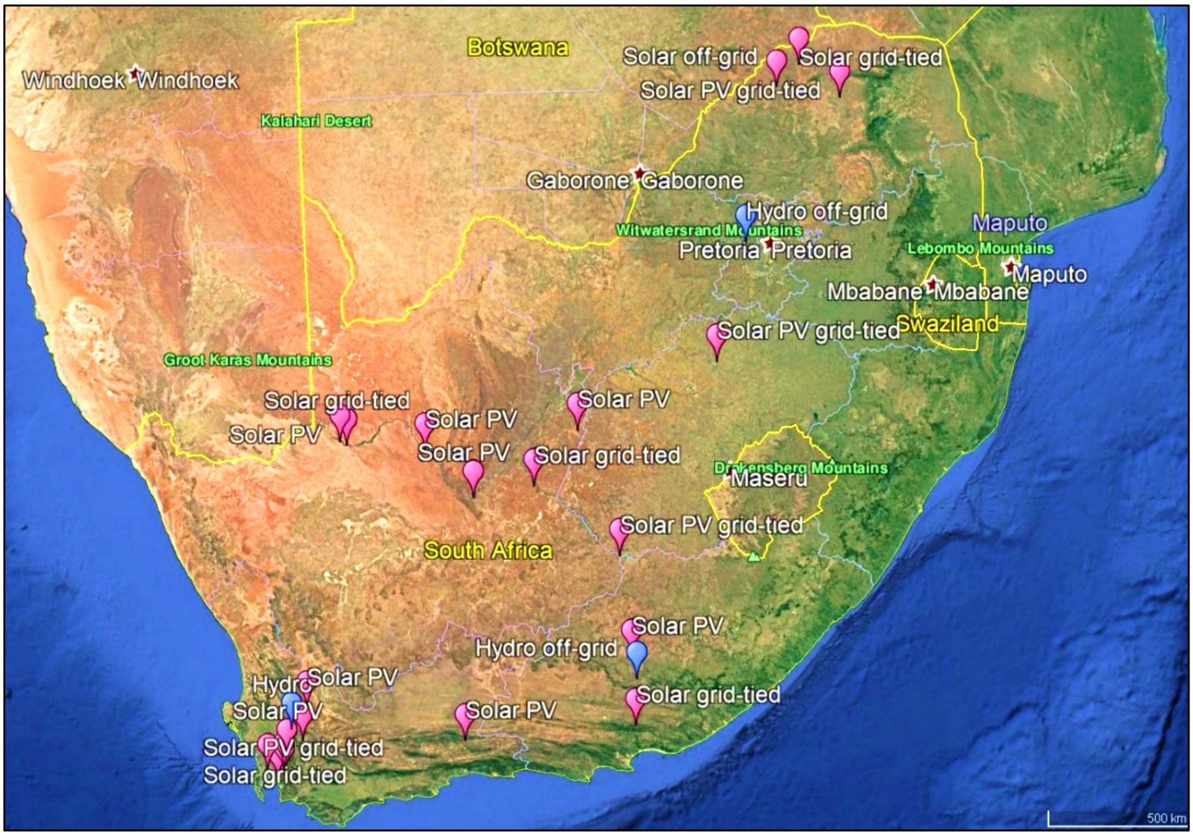


Figure 4-1: Identified RE systems related to irrigation in South Africa

Table 4-1: Solar energy sites

Location	Crop & area irrigated with system	RE System Size	Configuration	Payback & Lifespan
Kakamas (NC)	Table grapes & Raisins	500 kWp & 340 kWp	Grid-tied	P: 6 years
Groblershoop (NC)	Grapes	30 kW		
Hopetown (NC)		181 kWp (drives 75 kW pump)	Grid-tied with ESKOM wheeling	
Vanderkloof (NC)	Maize, wheat, lucerne centre pivot	198,25 kWp	Grid-tied	P: 20 years L: 20 years
Kimberley (NC)				
Prieska (NC)		240 kW – 1 MW		
Augrabies (NC)				
Thabazimbi (LP)				
Swartwater (LP)				
Brits/Thabazimbi (LP)	2 500 ha	4 MW	Grid-tied	
Tolwe (LP)*	Potatoes, onions, lucerne, pecan nuts 200 ha	240 kWp	Grid-tied, Storage dam with diesel generator standby	P: 5 years L: 20 years

Location	Crop & area irrigated with system	RE System Size	Configuration	Payback & Lifespan
Baltimore (LP)	Variety 15 ha centre pivot	120 kW	Off-grid	
Makgodu (LP)	Centre pivots	120 kW		
Lichtenburg (NW)*	Maize 15 ha drip	18,5 kW	Off-grid	P: 1 year
Stellenbosch (WC)	Grapes 180 ha	140 kW		L: 25 years
	Grapes	45 kWp	Grid-tied	
Wellington (WC)	Fruit	88 kWp & 35 kWp	Grid-tied	
De Bron (WC)	Centre pivot	209 kW	Grid-tied	
Franschhoek (WC)	Apples, citrus, pears and peaches > 100 ha	594 kWp	Grid-tied	P: 5 years L: 20 years
Raithby (WC)	Organic vegetables	16 kWp	Grid-tied	
De Rust (WC)	Olives	3 kW		P: 5 years
Cederberg (WC)	Rooibos drip			
Cradock (EC)			Solar PV grid-tied and off-grid	
Humansdorp (EC)		260 kW	Grid-tied	
East-London (EC)		400 kW	Grid-tied	P: 4 years

***Sites visited**

Table 4-2: Hydro energy sites

Location	Crop & area irrigated with system	RE System Size	Configuration	Payback & Lifespan
Brits (NW)*	Citrus & peppers	Ram pump h =45 m	Off-grid	P: 1 year
Cradock (EC)*	Centre pivot	280 kW & 520 kW	Off-grid	P: 5 & 2 years L: 35 years

***Sites visited**

Table 4-3: Hybrid energy sites

Location	Crop & area irrigated with system	RE System Size	Configuration	Payback & Lifespan
Brits/Thabazimbi (NW)		4 MW	Hydro/solar grid-tied with diesel generator standby	
Northern Cape		Pumps 15 $m^3.h^{-1}$	Wind/solar off-grid	

The site located near Baltimore in the Limpopo province, as listed in Table 4.1 is one of the sites where the company All Power installed an off-grid solar energy system. It is a standalone system (no ESKOM) with a 120 kW solar kit driving 12 submersible pumps (boreholes), a reservoir, a 15 kW booster pump and a three-tower centre pivot of 15 ha where a variety of crops have been planted. It seems as if 12 hours of irrigation can be achieved during a full sunshine day in summer. The electricity for all 12 submersible pumps is supplied by cables with the furthest being 725 m and 690 m from the panels. Figure 4-2 shows some photos of the installation on the farm near Baltimore.

Figure 4-2: Off-grid solar irrigation system near Baltimore

4.4 Users identified

Villiera Wines (Stellenbosch, Western Cape)

This wine estate spans a 400 ha property with 180 ha planted vineyards and 200 ha set aside as a wildlife sanctuary. The average annual output is 1,3 million bottles of wine. In 2010 Villiera Wines implemented the largest roof-mounted solar installation in South Africa at the time. In total, 539 solar modules with a combined production capacity of 726 kWh per day, were mounted on three of the cellar's roofs covering a total area of 900 m^2. The Winery's entire daytime energy requirement, which include electricity to its staff housing, offices, kitchens, processing and bottling facilities, cellars as well as cooling and irrigation systems, can be supplied by the energy

Figure 4-3: Roof-mounted solar at Villiera Wines (The Green Times, 2011)

They produce 240 000 kWh of solar and save a further 360 000 kWh through energy efficiencies per year. They rely on ESKOM during night and peak times (harvesting). Electrical energy reduction results in a 600t carbon footprint saving.

The project was outfitted by EnerGworx using locally designed and manufactured products:

- MLT Drives supplied the inverters, and two AfriSun70 systems
- The polycrystalline photovoltaic modules were procured from Solaire Technologies

Sonvrucht & Chargo-trust (Kakamas, Northern Cape)

There are two MV-systems (500 kVa and 340 kVa) installed on this user's farms. An LV-system is also being considered since it is easier to get permission to install these systems. Water is abstracted from the Orange River to irrigate table grapes (80%) and raisins (20%). Pumps and cold storage use the most electricity between May and September.

The farm does not use a lot of electricity in the winter while ESKOM does. ESKOM will therefore take electricity from the farm's "reserve" during the winter and the contrary will realise during the summer. The total installation cost on both farms was R19,2 million. The internal connection of power lines with transformers cost an additional R1,265 million. With the tax benefit, the system can be paid off within six years. The system at Chargo-Trust (500 kWp) generates 254 134 kWh in 80 days of which 97 084 kWh is used by the farm and 157 050 kWh goes to the ESKOM grid. This farm has already saved R205 214 (2020 rates) with R27 088 worth of electricity banked that should be utilised before April.

The system at Sonvrucht (340 kWp) generates 171 010 kWh of which 78 153 kWh is used by the farm and 92 857 kWh goes to the Eskom grid which equates to R125 604 saving and R31 424 worth of electricity "banked". Other savings achieved by these farms include the cancellation of many existing ESKOM transformers eventually to only make use of one. The user, Dr. Van den Heever, said that the big capital expenditure was worth it (Du Preez, 2020).

Figure 4-4: Solar energy system at *Sonvrucht* & *Cargo-trust, Kakamas*

De Rustica Olive farm (De Rust, Western Cape)

De Rustica has invested in Solar PV panels to meet the electricity demand required for the cooling of their olive storage rooms and to provide electricity for their irrigation pumps. In addition, De Rustica Farm is looking at installing VSD's on their irrigation pumps to save electricity. The Solar PV panels host a capacity of 20 kWh. The Solar PV panels meets peak demands through summer. De Rustica's total monthly electricity bill is R60 000 to R70 000, using Solar PV to generate energy provides a minor monthly saving of R3 000 per a month. The cost of the Solar PV panels, installed by contactors in the area, was R450 000. De Rustica paid for this themselves. The payback period is four to five years as stated by De Rustica (REEEP and SANEDI, 2016).

Wind and solar hybrid system (Northern Cape)

Installation by Kestrel Renewable Energy. The electricity generated by this hybrid system powers an 8AS Grundfos water pump. The average water delivered by this pump is 15 000 $\ell.hour^{-1}$ (Kestrel, 2020). Figure 4-5 shows an installation of a hybrid system in the Northern Cape.

Figure 4-5: Kestrel hybrid system in the Northern Cape (Kestrel, 2020)

Klipopmekaar Rooibos Farm (Cederberg, Western Cape)

Klipopmekaar Farm has invested in Solar PV panels to power their 3 kWh water pump. The Irrigation systems at Klipopmekaar are sustainable closed-loop solar-powered systems. They are all designed for the long term. Since solar has been a such a feasible solution for Klipopmekaar Farm, they are considering investing in additional Solar PV panels to feed electricity into the grid. Klipopmekaar Farm funded the panels themselves and received non-financial assistance with the project from the Green Alliance. Savings on their electricity bill was the biggest benefit and the payback period is three to four years (REEEP and SANEDI, 2016).

Murludi (Tulbagh, Western Cape)

Murludi farm is in the Tulbagh Valley is highly dependent on electricity to cool and dry 80% of the stone and pome fruit crop they produce. Power failures and an electricity bill peaking at R360 000 in 2013, have convinced Kobus van der Westhuizen to use the water he withdraws from the springs in the Witzenberg mountain to also generate electricity. This seemed like a feasible solution to produce alternative energy with minimum water waste. He therefore installed hydro-electric turbines. A small portion of the water in the stream form the mountain is withdrawn and diverted into a 200 mm HDPE pipe to a reservoir at a lower elevation where a pressure of 1 200 kPa is measured. Along the path, water moves through the hydro-electric turbines to generate electricity during high-tariff periods. Water then returns to the main stream and lower reservoir from where water for irrigation is abstracted. Water can be pumped back to the upper reservoir during low-tariff periods when electricity is less expensive.

There are two hydropower units. The first unit consists of four parallel water turbines with induction-alternators generating asynchronous electricity that can be fed to the national grid. Each turbine has the potential to generate 11 kWh allowing this unit to deliver 29 kWh and more. The advantage of more than one turbine in a parallel configuration is that the system can still generate electricity when the flow in the river is low and when maintenance is required. The second unit has the potential to generate synchronous energy up to 30 kWh. The system consists of a large turbine and an ordinary alternator which switches on automatically when a power failure occurs. Unfortunately, synchronous electricity cannot be fed into the national grid. Variations in water flow can cause electricity fluctuations which can damage machinery. An additional investment was therefore made by purchasing battery banks to alleviate this risk. The bank consists of sixty 100A deep-cycle batteries with a total storage capacity of 30 kWh. Only the energy that is stored into the batteries is used.

Water for irrigation is only withdrawn on weekends to fill the reservoir and irrigate orchards from the reservoirs during the week. This arrangement is advantageous in that it enables him to generate more electricity during the week, when electricity is more expensive. During the fruit season, the turbines can meet a demand of up to 124 kWh. In 2014 Kobus's electricity bill reduced by half because of using alternative energy. The total cost of the plant was about R485 000 and the pipeline an additional R250 000. Energy savings and savings from maintenance and repair allow for a payback period of five years (REEEP and SANEDI, 2016).

4.5 Suppliers and technologies identified

All Power

All Power is a supplier of solar borehole pumps which can operate at any head and require no batteries. System configuration can either be standalone or grid-tied and works on any three-phase pump. They have installed 36 000 solar pump systems of all sizes. The DC to AC conversion capability of their systems is sufficient to drive any irrigation system with solar energy for 12 hours. Their WaterMax formula allows for outstanding performance with low radiation levels.

Van Heerden Solar Power

Supplier of solar energy pumps for irrigation and solar and wind energy systems.
Cost of PV panels are as follow:

- 100 W PV panels @ R1 100 + VAT;
- 320 W PV panels @ R2 700 + VAT

Cost of wind chargers are as follow:

- AN 400 W Land 12 V @ R9 800 + VAT
- AN 600 W Land 24 V @ R12 800 + VAT

Sonfin

SONFIN has more than five years' experience in consultation and administration of solar PV systems. Their product offering includes grid-tied, grid-interactive and off-grid systems. System designs include site surveys and drawing, landlord negotiations and system approvals with Eskom or Council. Their system financing entails bank finance and rebate applications. System installation consists of transport to site, construction works, system assembly and connection and system commissioning. System Monitoring and Servicing include performance and warranty monitoring as well as warranty replacement. Their affiliated with Canadian Solar, SolarWorld, Schletter Inc. and SMA Solar Technology.

Ultimate Solar

Ultimate Solar is a family-owned business established in 2008 and ventured into renewable energy in 2013. They specialise in top-end European equipment complying with international standards. They make use of German monitoring equipment enabling unique solar design solutions as no two solar systems are the same. Their technicians are trained and internationally accredited. Ultimate Solar is part of the Claasclan 2 cc group.

Grundfos

Grundfos supplies solar-powered water pumps and complete solar water solutions. The Grundfos IRS inverter is an ideal product for directly powered solar irrigation systems. It is an inverter with speed control that can convert solar energy for pump applications to 400 V AC. Direct irrigation systems need to be designed for seven to nine-hour cycles since the system needs the required pressure immediately. These solar systems mainly consist of the pump and motor, solar panels and the RSI-inverter. Models ranging from 1,5 to 37 kW are available. In 2020, the costs for the RSI-inverters ranged from R31 638 to R68 790 accordingly. Other RE products provided by include Polycrystalline panels, 100 W and 270 W, for R3 004 and R4 973 respectively as well as submersible pumps, with build in inverters for solar, wind and AC power source which run on both AC and DC voltage. The cost for these pumps ranges from R9 627 to R37 472. SAW Africa is an implementation agent for some of the Grundfos products (SAWAfrica, 2020).

RSI-inverter	Submersible pumps	Polycrystalline solar panels
		

Figure 4-6: Grundfos solar energy products (SAW Africa, 2020)

Solis

The Chinese company Solis has a new inverter, the Solis Energy Storage 4,6 kW, which can be configured to decide if electricity generated with the solar panels needs to be canalised to the farm directly or to the national grid or to the battery bank. These inverters can typically be operated from the national grid at night and if there is load-shedding it can automatically switch to provide electricity from the battery bank. A reseller price in 2020 was R32 000.

Kestrel

Kestrel specialises in water pumping, grid-tied, off-grid and telecommunication solutions. Their water pumping solution can deliver water at a rate up to 3 600 ℓ.hour^{-1} (head-dependent). It is a cost-effective and versatile option for pumping water in areas where grid electricity is unavailable or unstable, providing efficient water delivery from a wind speed of just 3 m.s^{-1}. The required size wind turbine, a Grundfos pump, galvanized 12 m monopole tower, float switch and CU200 Controller as well as a pump interface box with a Genset change over switch are items included in the water pumping system. Kestrel have more than 400 of these installations.

This solution can be powered by solar, wind, or a combination of both renewable sources. It uses the electricity generated by these renewable energy sources to deliver up to twice the water volume of a traditional mechanical windmill. Figure 4-7 shows some of the installed Kestrel hybrid systems. The hybrid system in Figure 4-7c supplies power to a farm in Aliwal North and produces 10 kWh.day^{-1}. The user is saving R1 198 on electricity per month.

a. Off-grid hybrid system, NC	b. Off-grid hybrid system, NC	c. Hybrid system in Aliwal North

Figure 4-7: Various Kestrel hybrid solutions

4.6 Summary

Many associations indicated that they will also take time and significant effort to change the conventional agricultural mindset of farmers and their behavioural tendencies to embrace sustainable agriculture. The major motivator for farmers adopting Sustainable Energy Consumption and Production (SECP) practices and shifting towards sustainable agriculture is the anticipated cost savings, which can reduce operational costs and increase agricultural Micro, Small and Medium Enterprises (MSMEs) competitiveness, followed by the need to reduce their carbon footprint in terms of the Carbon Tax Bill.

Solar PV appears to be the most common alternative means of electricity generation implemented by farmers in South Africa using renewables. It reduces their reliance on the grid and sensitivity to electricity price hikes; therefore, resulting in electricity savings for agricultural businesses. It is also the most feasible solution recommended by agricultural associations within South Africa. The average payback period for this technology experienced by farmers ranges between three and five years. Farmers have however highlighted a number of challenges when implementing this technology, which include:

- Theft of solar PV panels;
- High cost of battery banks if a large storage capacity is required;

- Sourcing of funding for the investment in solar panels.

Local suppliers will select a specific location and do a detail PV solar analysis with either 5- or 30-minute intervals to see how much electricity can be generated. An irrigation schedule is requested from the user to determine how much water is required for the entire year. The solar availability can then be superimposed onto the irrigation schedule. Sometimes the user requires more water during the wintertime; then the solar panels can be tilted for wintertime production. Or accordingly for summertime. The size of the dam needs to be calculated if elevated storage is an option for gravitational irrigation.

It should also be noted that investing in solar panels is a viable means of renewable energy generation; however, implementing a hybrid renewable energy system can be considered to go completely off-grid. An investment in battery banks to meet a full off-grid capacity required to run a farm is usually not financially feasible. If a grid-tied system is planned, it can cost up to three million rand just for an ESKOM connection; if that is added to the investment cost of a solar system, it is cheaper to go completely off-grid. Additionally, the industry needs to look at combining wind and solar. Wind will be present at the most unexpected times of the day. In the Ceres and Tankwa Karoo and northern plateau regions, wind starts blowing from 4 am to 8 am and again from 4 pm to 10 pm at night. Wind farms are not considered economically viable because the total hours of wind available in a day are not enough. When there is enough sun at a specific area, a combination of these two has the chance that it will give you best of both worlds.

The implementation of bio-digesters on South African farms for energy generation is not as common as solar PV technology. The payback period for bio-digesters, though, is much higher than that for solar PV technologies and averages between eight to 12 years. Furthermore, incentives and funding available for installation of bio-digesters on farms are limited in South Africa; thus, further constraining its wider adoption and deployment in the country. Some other challenges associated with the use of bio-digesters include requirements for extensive management of variable input to determine how much biogas is produced.

5 SPATIAL ASSESSMENT OF TECHNICAL AND FINANCIAL FEASIBILITY OF RENEWABLE ENERGY SOURCES

5.1 Overview

The natural potential to harness energy from natural resources such as solar radiation is spatially differentiated which requires a framework to assess the technical and economic feasibility of alternative pumping systems for a specific location. Tools for renewable energy and energy efficiency projects are used to assess the economic and financial implications of projects within sustainable agriculture. In addition, they provide an informative database, assisting with project implementation and providing tools to conduct assessments prior to implementation. Farmers could access tools via internet portals in order to assist them with assessing the viability of renewable energy and energy efficiency projects. It addresses the gap in financial and economic assessment skills farmers may lack in determining risk and viability of projects. Examples of such tools are listed in Table 5-1.

Table 5-1: Feasibility assessment tools

Tool Description	Link to access
Solar Irrigation Potential	http://sip.africa.iwmi.org/
SPIS Toolbox	https://energypedia.info/wiki/Toolbox_on_SPIS
Helioscope	https://www.helioscope.com/
BioEnergy Atlas Feasible options – Dashboard	https://bea.saeon.ac.za/feasible-options-dashboard/
HydroCALC 3.0	https://www.netafim.com/en/products-and-solutions/tools/hydrocalc-3.0/
Carbon calculator	https://www.climatefruitandwine.co.za/Products.aspx

A prefeasibility report will typically include the following:

- Site description and data (e.g. flow rates)
- Design concept
- Modelled design results (e.g. plant output)
- Grid connections details (location, cost, line length, etc.)
- Infrastructure costs
- Financial modelling (based on capital and operational expenditure, funding, interest, energy produced, etc.)
- Conclusions and recommendations (e.g. recommendation of sites / aspects to be investigated in a feasibility report)

5.2 General framework for evaluating renewable energy systems

A general framework to evaluate the planning and design of renewable energy systems was developed. The framework provides a means to conceptualise the different components and processes necessary to develop a renewable energy system in an integrated way. Figure 5-1 provides the schematic presentation of the framework, adapted from Elkadeem, Wang, Sharshir and Atia (2019). To evaluate the planning and design of renewable energy a framework shown below was developed.

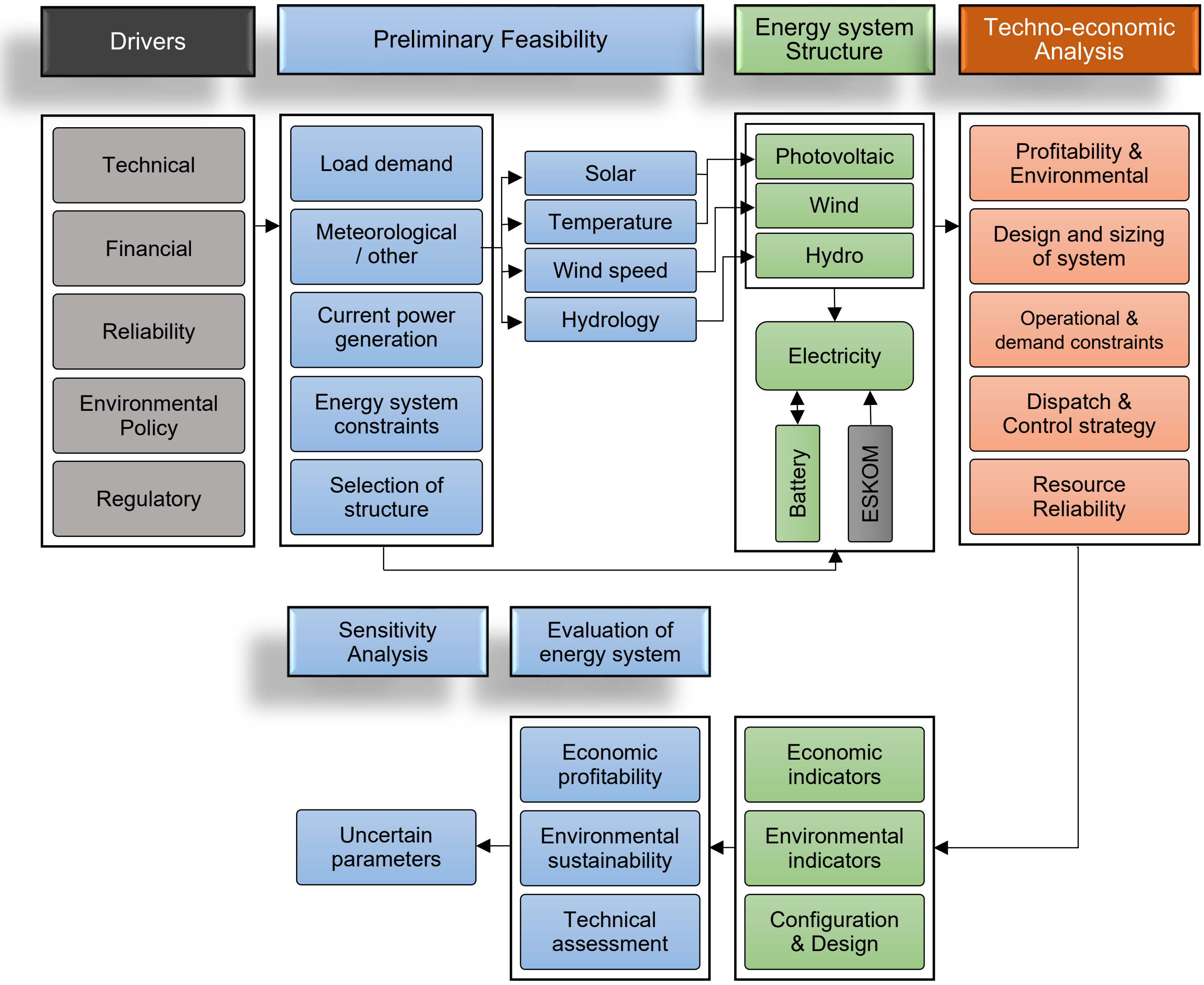


Figure 5-1: General framework for planning and design of renewable energy systems

Several factors may drive the interest in renewable energy sources and it is important to understand these drivers since these drivers provide the business case of the system. Within the South African environment reducing the cost of electricity and increasing the reliability of electricity during high demand periods are probably the most important. Furthermore, the conventional coal-based methods used in South Africa to generate electricity have high carbon footprints and it is environmentally beneficial to reduce these carbon footprints.

The second phase of the of the planning and design of a renewable energy system involves a proper feasibility study to determine the sources of renewable energy available and whether appropriate technologies are available to balance the electricity generation with the load demand. More specifically the feasibility analysis requires the evaluation of meteorological and hydrological data to determine potential generation capacity of a specific location, estimating the demand profile and identifying any energy system constraints that may prohibit the adoption of a specific renewable energy source.

The next step is to conduct a proper techno-economic analysis on the candidate energy technologies identified by the preliminary feasibility study. The techno-economic analysis includes determining the design objective, which could be economical or environmental or both. Typical examples of economic objectives include minimising total net present cost (NPC) of energy and reducing the unit cost of electricity supply while environmental objectives may include reducing the carbon footprint of electricity supply.

A crucial part of the techno-economic analysis is to simulate the energy system and associate cost implications to evaluate alternative configurations of the system. Consequently, an appropriate energy design simulation model needs to be developed or applied in conjunction with the necessary cost estimation procedures to determine the life cycle cost (LCC) of alternatives. Key to the techno-economic analysis is balancing the electricity demand load with the cost of generating the electricity.

Consequently, estimating the electricity demand load becomes a crucial part of the analysis. The supply of renewable energy is in many cases highly variable since it is dependent on climatological conditions, which complicates the design and operation of the energy system. It is therefore essential to consider the reliability of renewable energy supply in conjunction with the operational management of the energy system.

The output from the techno-economic analysis provides the necessary economic and environmental indicators to judge the profitability and environmental impact of alternative energy systems. The analysis furthermore provides the detail technical data to judge the technical performance and energy supply reliability of the proposed energy system. Lastly the designed system is subject to a sensitivity analysis to determine the financial sensitivity of the energy system to factors beyond the control of the designer.

5.3 Factors affecting the technical feasibility of an energy system

5.3.1 *Energy demand load*

Energy load demand determines the size of the combination of renewable energy systems that needs to be designed to supply the energy load demanded. The required energy load necessary to pump a certain amount of water within a specified time period is calculated using Equation 5-1.
The EDL is a function of the kilowatt (kW) required to drive the water through the irrigation system including the water distribution network and the total amount of hours (PH) the system is used to pump water. The kW requirement was labelled TECHNOLOGY since it is a function of the design process and choice of technology. The second component is labelled MANAGEMENT because this component is a function of the irrigator’s choice of crops, area irrigated and irrigation scheduling strategy. The assumption is made that the EDL could be supplied in full by conventional energy sources supplied by ESKOM. Utilisation of renewable energy sources requires balancing the EDL with the potential capacity of renewable energy sources. Furthermore, the utilisation of renewable energy sources imposes important constraints on the level of EDL achievable within a specific period.

$$EDL = P_i \times PH \qquad (5\text{-}1)$$

Where:

EDL	Energy demand load (kWh)
P_i	Input power requirement (kW)
PH	Pumping hours (hours)

TECHNOLOGY:

$$P \quad = \frac{\rho \times gr \times q \times H}{36000 \times \eta_{\text{pump}} \times \eta_{\text{motor}}} \qquad (5\text{-}2)$$

Where:

P_i	Input power requirement of the electrical motor (kW)
ρ	Constant (density of water)
gr	Gravitational acceleration ($m.s^{-2}$)
q	Flow rate ($m^3.h^{-1}$)
H	Pressure requirement (m)
η_{pump}	Pump efficiency (%)
η_{motor}	Motor efficiency (%)

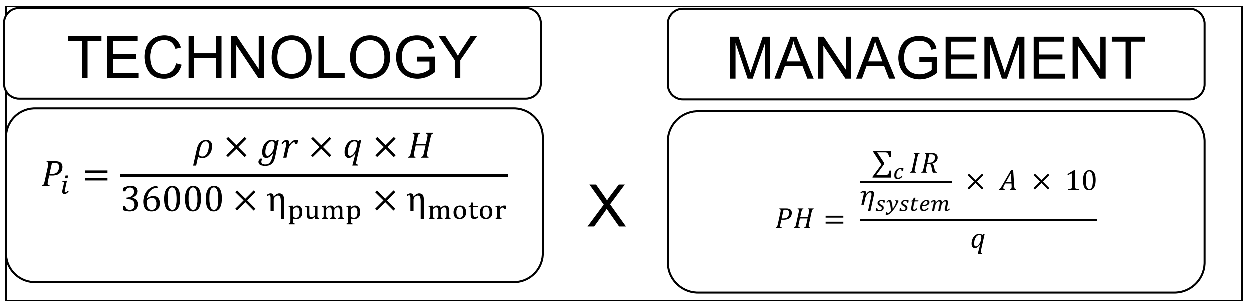
MANAGEMENT:

$$PH = \frac{\frac{\sum_c IR}{\eta_{system}} \times A \times 10}{q} \qquad (5\text{-}3)$$

Where:

PH	Pumping hours (hours)
IR	Irrigation requirement for a specific crop (mm)
η_{system}	Irrigation system efficiency (%)
A	Irrigated area (ha)

An important observation from Figure 5-2 is that the flow rate (q) under "Technology" cancels out the q under "Management". Thus, the irrigation system discharge (q) does not influence EDL per se. However, the discharge will determine the water application rate which may influence decision-making.



Q (discharge)

- Gross irrigation requirement
  - Crop
  - Climate
  - System efficiency
  - Leaching fraction
- Time available
  - Management
  - Automated/Manual system
  - Soil characteristics
  - Renewable energy source
- Size of the system (ha)

H (pressure requirement)

- System working pressure
- Static Height
  - Topography
  - Boreholes
- Friction loss
  - Type of pipe, Length
  - Flow rate (q)

Pump station

- Single pumps
- Multiple pumps
- VSD
- Pump and motor efficiencies

How much water and when?

- Crop choice
- Irrigation scheduling practices
  - Soil water holding capacities
  - Climate
  - Irrigation intervals
  - Deficit irrigation
  - Available pumping hours
- Irrigation system
  - Size (ha)
  - Application rate
  - Labour (move sprayers)
  - Repair and maintenance
- Energy source availability
  - Eskom tariff structure
  - Alternative energy
- Water supply restrictions
- Pump station/Distribution network
  - Boreholes
  - Single / Multiple pumps
  - VSD
  - Balancing dams

Figure 5-2: Schematic showing factors influencing electricity demand load (Venter. *et al.*, 2017)

The remaining variables shows that EDL is a function of the following:

$$EDL = f(H, NIA, A, \eta_{pump}, \eta_{motor}, \eta_{system}) \quad (5\text{-}4)$$

Where:

EDL	Energy demand load (kWh)
H	Pressure requirement (m)
NIA	Net irrigation applied (mm)
A	Area irrigated (ha)
η_{pump}	Pump efficiency (%)
η_{motor}	Motor efficiency (%)
η_{system}	Irrigation system efficiency (%)

5.3.2 *Technology*

Technology is represented by the total kW requirement to drive the water through the system when considering the calculation EDL. Evaluating the factors influencing kW is the output from the design process. Figure 5-3 is used to represent the design process resulting in the kW requirement.

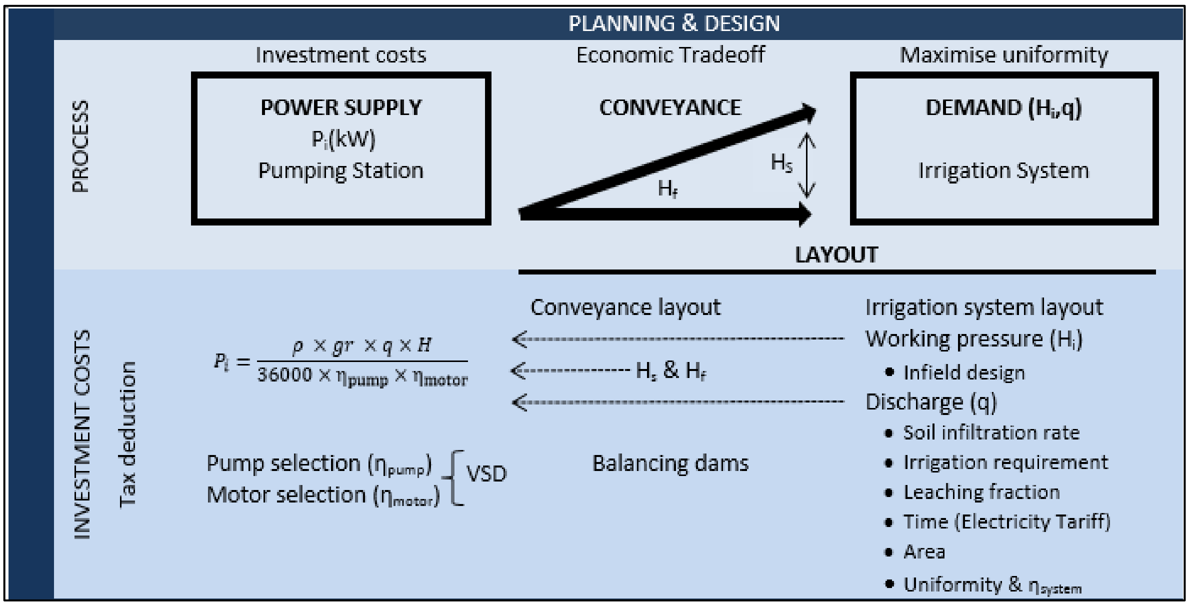


Figure 5-3: Irrigation system design process (Venter *et al.*, 2017)

The planning and design phase is characterised by three distinct components or steps as depicted in Figure 5-3. Firstly, a demand for a specific discharge of water (q) with a specific pressure (H) is created through the infield design of the irrigation system. Once the infield design is completed the next step is to design the water distribution network that is used to convey the water from the source to the irrigation system. Together conveyance and demand will determine the layout of the system. The main output from conveyance and demand components is the kW requirement to drive the water through the system. The last step is to match a specific pump and motor according to the required operating point (q and H) of the system. Special care should be taken in the selection of pumps and motors when using renewable energy sources.

5.3.3 *Demand*

Demand represents the infield design of the irrigation system to determine the required irrigation system water discharge (q) and the pressure (H). The main objective during the design process is to design the system such that the distribution of water over the area is as uniform as possible. The design uniformity of the system is mainly a function of the infield irrigation system design and therefore controlled by the designer.

Inputs from the irrigator are required to determine the appropriate discharge of the irrigation system, which is defined as the maximum volume of water that can be applied within a set time interval with an irrigation system of a certain size. Specifically the discharge of the irrigation system is a function of the design area of the system, the gross irrigation requirement and time available to apply the required amount of water. The gross irrigation requirement is determined by the crops grown in a specific climate and the irrigation system efficiency (η_{system}).

Utilising renewable energy sources places additional constraints on the time available to pump water. A photovoltaic pumping system reduces the time available to the sunshine hours during the day, which is much lower than the typically assumed design norms.

Flow rate is directly proportional to the power requirement. A larger system discharge (resulting in higher power requirement) will be required under the following conditions:
- Climatic regions where the potential evapotranspiration (PET) is higher
- Crops for which the PET is higher
- Selecting an irrigation system with a lower system efficiency
- Reducing the number of hours available to complete an irrigation event
- Irrigating a larger area

5.3.4 *Conveyance*

The conveyance component has to do with the design of the water distribution network. Designing the distribution network has a direct influence on the pressure requirement (H) at the pump station through the hydraulic design process, which aims at defining the system that will be able to deliver the discharge (q) to the desired area. The hydraulic design process consists of two basic components – static head and friction loss. The static head component makes provision for overcoming the topographical height difference between the pump station and the irrigation system, dynamic fluctuations of borehole water levels, as well as providing water at the correct working pressure to the irrigation system. The friction loss component is variable and depends on the system discharge through the pipes, length of the pipe, type of pipe as well as the inside diameter of the pipe.

The design of the main line of an irrigation system presents a problem to the designer. If a smaller pipe diameter is used, the capital costs of installing the system will be lower than when a larger diameter is used. On the other hand, the pump costs will be higher if a smaller pipe diameter is preferred to a larger pipe diameter.

Pressure head is also directly proportional to the power requirement. A larger pressure requirement (resulting in higher power requirement) will result under the following conditions:
- In steep terrain, where the elevation differences are bigger
- For irrigation systems with higher working pressure requirements
- If the pipe diameters of the system are reduced for a certain required system discharge
- If excessive safety factors are included in the design calculations
- Larger dynamic head

5.3.5 *Power supply*

The outputs from the irrigation system design process (DEMAND) and the water distribution network design process (CONVEYANCE) provides the required irrigation discharge as well as the total pressure requirement to overcome the hydraulic gradient known as the operating point of the system. The main objective of the pump station design is to combine a hydraulic pump and an electrical motor in such a manner that it will supply the necessary pressure and flow at the operating point using the lowest amount of kW.

Choice of a specific pump might not be straight forward because it might be impossible to choose a pump that will provide enough flow and pressure at high efficiencies. Thus, some form of modification is necessary to modify the pump curve to supply the correct amount of flow and pressure. Two alternatives exist for modifying the pump curve. The first method requires cutting the impellor of the pump. With the second method the speed of the pump is altered through the application of VSD. Both methods are highly effective, however, the circumstances under which each apply is situation specific.

Typically, a VSD is appropriate for situations that are characterised by multiple operating points. Another complicating factor is that modifying the pump curve also modifies the efficiency of the pump. Each pump and motor in the system will operate at specific energy efficiency (input / output ratio). This efficiency will be determined by two factors:

- The quality of the technology used as defined by the efficiency rating of the pump or motor
- The duty point or load factor of the technology as defined by the design and selection process

The efficiencies are indirectly proportional to the power requirement and therefore a decrease in efficiency will lead to an increase in power requirement. Efficiencies are optimised by selecting high efficiency pumps and motors, operating them at the correct duties or loads, and by performing timely and effective maintenance.

5.3.6 *Management*

The second focus area, MANAGEMENT, is concerned with operating the designed irrigation system with the overall objective of maximising profit. According the (Burger *et al.*, 2003) the total operating hours can be calculated on an annual basis for all the fields or systems supplied from one pump station with Equation 5-5:

$$PH = \frac{\frac{\sum_c IR}{\eta_{system}} \times A \times 10}{q} \qquad (5\text{-}5)$$

Where:

PH	Pumping hours (hours)
IR	Irrigation requirement for a specific crop (mm)
η_{system}	Irrigation system efficiency (%)
A	Irrigated area (ha)
q	Flow rate ($m^3.h^{-1}$)

This calculation is usually done on an annual basis but a different time step such as a season, month or week can also be used.

The total amount of operating hours is highly dependent on choices the farmer makes with regards to irrigation technology, crops, areas irrigated and irrigation scheduling. All of these factors are important factors affecting the overall profit margin of the farm. The discharge of the irrigation system and the efficiency of the system are fixed during the irrigation system planning and design process. Although provision is made during the design process to oversize the system within reasonable limits to make provision for application losses, the way the producer manages the system also influences the number of losses that occur.

As the system efficiency is indirectly proportional to the power requirement, it is in the producer's interest to manage the system in such a way as to minimise losses. Practices to be avoided include:

- Applying small amounts of irrigation water at very short intervals
- Irrigating with overhead systems during very windy periods of time
- Neglecting system maintenance that is essential to prevent poor system uniformities

Choices regarding crops and areas are fixed at the beginning of the season. Although the system may have a certain discharge capacity (q) as determined for typical potential evapotranspiration values for the selected crop in the specific climatic region, it is up to producer to decide how often and how much will be irrigated during the growing season.

Irrigation system efficiency only determines the relationship between the amount of water leaving the irrigation system and the amount of water entering the soil profile. As a result of the uniformity with which the irrigation system applies water, a portion of the field will be over irrigated and another portion under irrigated. In order to achieve high yields some percolation will occur if irrigation applications are increased to sustain crop yield in the section with the under irrigated portion of the field. The uniformity of the irrigation system therefore has an important impact on the profit margins of the crop (Li, 1998; Lecler, 2004; Mantovani *et al.*, 1995). The impact of the last mentioned can only be quantified trough the evaluation of daily soil water budget calculations.

Several factors may influence the total amount of hours irrigated within a specific time period. These factors include the soil water holding capacity of the soil, irrigation water supply limitations and labour requirements to move sprinklers. The stochastic nature of renewable energy generation adds additional constraints on the number of hours an irrigator can irrigate. Inappropriate design of the irrigation system discharge rates will increase the severity of these restrictions.

Finally, the way in which the water distribution system is laid out, can also influence the total number of hours that power is consumed (Moreno *et al.*, 2010). Elevated storage systems can be used to decrease the number of pumping hours, or to move the pumping hours to periods where renewable energy is generated.

5.4 Estimation of power requirement of irrigation water pumping

The power requirement (kW) to drive the required amount of water through the system is calculated as follows:

$$P = \frac{\rho \times g \times h \times Q}{3.6 \times 10^6 \times \eta_{\text{pump}} \times \eta_{\text{motor}}} \quad (5\text{-}6)$$

Where:

P	Input power requirement of the electrical motor (kW)
ρ	Density of water (1 000 kg.m^{-3})
g	Gravitational acceleration (9,81 m.s^{-2})
h	Pressure requirement (m)
Q	Flow rate (m^3.h^{-1})
η_{pump}	Pump efficiency (%)
η_{motor}	Motor efficiency (%)

The pressure requirement (h) of the pumping system is made up of the static and dynamic heads, friction losses and the operating pressure of the irrigation system. Dynamic head only applies to situations where water is pumped from a borehole where head changes with the level of the water in the borehole.

The flow rate (Q) is important as it determines the amount of water that could be applied to a specific irrigation area within a specified time period. The maximum require flow rate is calculated as follows:

$$Q = \frac{\frac{IR}{1000 \times \eta_{system}} \times A_f}{t} \quad (5\text{-}7)$$

Where:

IR	Maximum irrigation requirement for a specific crop (mm)
η_{system}	Irrigation system efficiency (%)
A_f	Irrigated area (m^2)
t	Pumping hours (hours)

In the absence of rainfall and the contribution of shallow groundwater the irrigation requirement is equal to the maximum evapotranspiration (ET) rate of the crop. Not all the water that is applied is consumed by the crop due to losses. The extra water that needs to be pumped is accounted for by dividing the irrigation requirement with an efficiency factor (η_{system}) for the pumping system.

Substituting (5-7) into (5-6) provides a means of determining the water pumping power requirement as a function of irrigation requirement area irrigated and time necessary to pump water as follows:

$$P = \frac{\rho \times g \times h \times \frac{IR}{1000 \times \eta_{system}} \times A_f}{3.6 \times 10^6 \times \eta_{\text{pump}} \times \eta_{\text{motor}} \times t} \quad (5\text{-}8)$$

Multiplying (5-8) with t gives the energy requirement (kWh) to pump the required volume of water.

"The difference between power and energy is that power (kilowatts [kW]) is the rate at which electricity is consumed while energy (kilowatt-hours [kWh]) is the quantity consumed." (U.S. Department of Energy, 2021).

5.5 Factors affecting the economic feasibility of an energy system

Economic feasibility is determined by calculating the present value of the Life Cycle Costs (LCC) that will result in a levelised cost of energy (LCOE) that is equal to the current cost of energy supplied by ESKOM under the Ruraflex electricity tariff. The LCC of a RES is an expression of how much it costs to purchase, install, operate, maintain and dispose of the system during its lifetime.

The present value of investing of the LCC is given by:

$$LCC = \sum_{n=1}^{N} \frac{I_n + OM_n + R_n - T_n - S_n}{(1+d)^n} \tag{5-9}$$

Where:

LCC	present value of the life cycle costs of the renewable energy source (R)
I_n	initial investment costs in year n (R)
OM_n	operations and maintenance cost in year n (R)
R_n	replacement costs in year n (R)
T_n	tax benefits from investing in year n (R)
D_n	salvage income from disposing of renewable energy system at the end of its lifetime (R)
d	discount rate (fraction)

The LCOE is calculated as follows:

$$LCOE = \frac{LCC}{\mathrm{TEP}} \tag{5-10}$$

Where:

$LCOE$	levelised cost of energy production (R.kWh^{-1})
TEP	total energy production over the lifetime of the system (kWh)

The RES is deemed economically feasible if the LCOE is less than the tariff currently paid for electricity which is known. Substituting the current tariff for the LCOE in (5-10) and rearranging give the breakeven LCC of the RES investment as follows:

$$BLCC = \mathrm{CET} \times \mathrm{TEP} \tag{5-11}$$

Where:

$BLCC$	breakeven life cycle cost of the renewable energy source (R)
CET	current electricity tariff in (R.kWh^{-1})

The motivation of using the BLCC is the fact that it is free from product specific data regarding the investment costs, maintenance and operation. Energy will be generated with an economically feasible investment if the LCC of the investment is less than BLCC.

5.6 Assessing the feasibility of solar energy sources

5.6.1 *Overview*

A solar-powered irrigation system is deemed technically feasible if enough land is available to construct a solar array that is able to generate enough power to pump the required amount of water during peak sunshine hours. A necessary first step is to determine the energy requirement of the specific irrigation pumping system.

Solar energy generation through the course of a day varies according to the intensity of sunshine. Consequently, SPIS will not be able to operate continuously for the full 24 hours within a day at peak performance. For a SPIS the operating hours of the system is constrained by the total amount of solar insolation at a specific location.

The following factors influence the techno-economic viability of PV installations:
- the space available (strength, suitability, size)
- the design of the system (in relation to the space and resource available)
- the system installation cost
- the system operation and maintenance cost
- financing options (such as own financing, a grant or a loan)
- the electricity usage profile of the site
- the generation profile of the plant
- how often the system will be offline (due to faults or maintenance)
- applicable electricity tariffs

The two primary reasons for the importance of finding technically and economically feasible ways of applying solar energy for irrigation pumping are:
- non-renewable fossil fuels are used to provide large quantities of energy for irrigation pumping;
- Solar energy is particularly compatible with irrigation – maximum irrigation requirements are at times, and in locations, of maximum solar radiation (insolation). During periods of lower insolation, less water evaporates from crops and land and less solar energy would be available for powering irrigation systems.

Possible methods to improve the feasibility of solar energy include:
- alternative uses for solar produced energy when not used for irrigation;
- government incentives, such as a deduction in tax due to the installation of RE system;
- the use of a hybrid system combining solar energy with a conventional system;
- reduction of peak energy demand for irrigation; and
- extending the period of use by modifying irrigation and cropping practices (Enochian, 1982).

In addition, a small size solar system can be quite inefficient and the utilisation factor of onsite solar irrigation systems can be low if it is only used for a few days in a year (Enochian, 1982).

5.6.2 *General configuration of solar energy systems*

All the configurations of SPVWPS have its relative advantages and disadvantages. Selection of an optimum system for a particular application depends upon a variety of factors.

According to a review by Sontake and Kalamkar (2016) SPVWPS can broadly be classified into following types:
- On the basis of energy storage
- On the basis of form of electric power input
- Basis of types of pumps
- Basis of tracking of power source.

<u>*On the basis of energy storage*</u>
The classification of SPVWPS can either be Battery-coupled where the generated electricity is stored in the battery/battery bank or Direct driven where the solar energy is directly utilised to drive the pump.

Battery-coupled
With Battery-coupled SPVWPS, the solar panels convert the solar energy into electrical current which then charges the batteries. Water can then be pumped when needed with the power supplied from the batteries to the pump. In so doing the water pumping duration can be prolonged and pumping can continue during lowlight periods, cloudy days and during the night. Both, surface and submersible pump can be used in this type of SPVWPS. This type of configuration can increase the cost of the system and complexity. The overall efficiency of the system tends to be reduced since the operating voltage is dictated by the batteries rather than the PV panels. The voltage supplied by the batteries can be one to four volts lower than that produced by the PV panels, depending on the temperature and charging of the batteries. Therefore, it is not recommended to use battery coupled solar PV pumping systems. The components of a SPVWPS are shown in Figures 5-4 and 5-5. These include a solar panel, charge controller, batteries, pump controller, pressure switch, storage tank and a DC water pump.

Direct driven
With Direct driven SPVWPS, PV modules supply the electricity they generate directly to the pump which then uses the power to pump water. These systems can only pump water during the daytime, when the solar energy is available, since there is no backup power available. The volume of water pumped during the daytime depends on the intensity of the solar irradiation incident on the solar. Compared to the battery coupled system, this direct driven system has a simple configuration and operates without a battery allowing lower overall costs. Disadvantages are that the system cannot pump water during the night and the intensity and angle of the solar radiation onto the PV panel changes throughout the day. This poses some inconsistency in terms of the volume of water that can be pumped during the day. The Direct driven solar PV water pumping system is as shown in Figure 5-6.

These pumping systems can operate at or near 100% efficiency and pump the maximum volume of water during late morning to early afternoon on clear sky days (optimum sunlight duration). On the contrary lower volumes of water is pumped during early morning and late afternoon when the pump efficiency is. Cloudy days will also affect the efficiency. These different sunlight conditions requires that the pump and the solar module are matched properly to compensate for these flowrate variations and run the SPVWPS efficiently.

Larger SPVWPS designs than that required can help overcome the problem of little or water being pumped during cloudy days and at night. Large water tanks can be used to store the extra water pumped during sunny days from where the water can gravitate to the small water tank when needed. Storage for two or five days should be sufficient. Cost should however be considered, and the size of water storage tank can be optimised.

The current generated by solar PV panel is DC. This can be converted into AC by an inverter. Accordingly, SPVWPS is classified as DC or AC driven as illustrated in Figure 5-7.

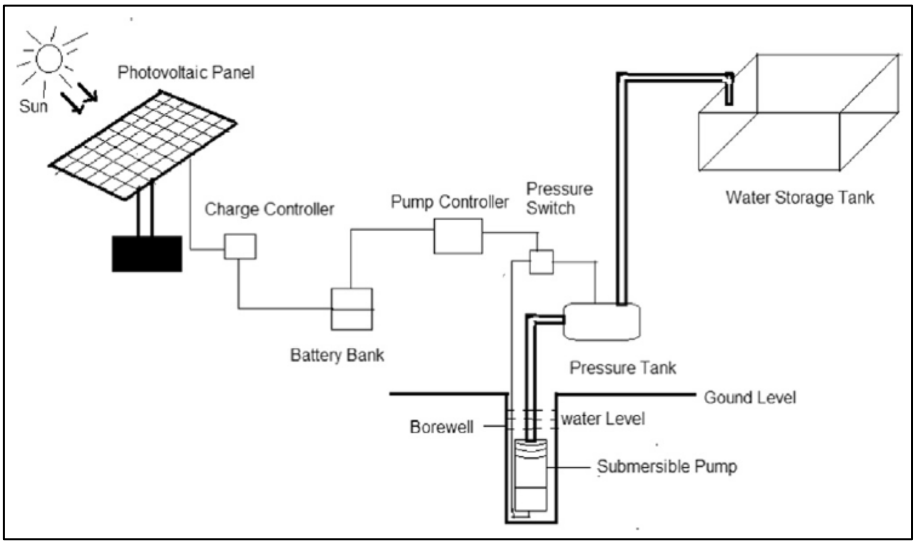


Figure 5-4: Battery coupled solar PV water pumping system using a submersible pump (Sontake and Kalamkar, 2016)

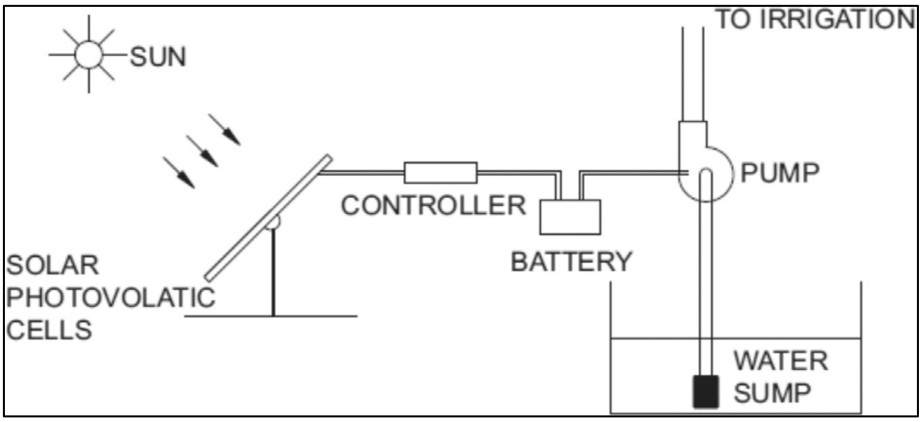


Figure 5-5: Battery coupled solar PV water pumping system using surface pump (Sontake and Kalamkar, 2016)

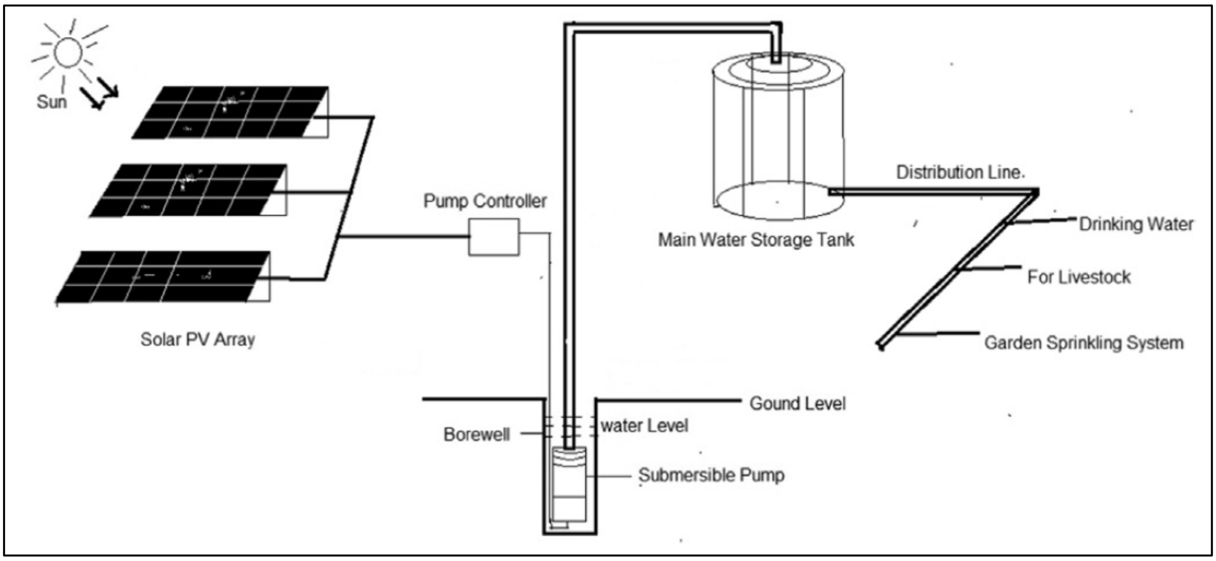


Figure 5-6: Schematic of direct-coupled solar PV water pumping system (Sontake and Kalamkar, 2016)

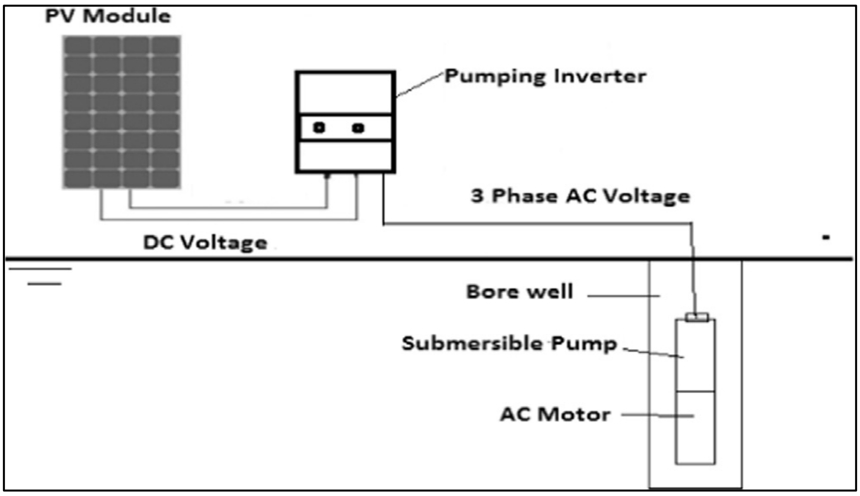


Figure 5-7: Schematic of solar PV water pumping system (Sontake and Kalamkar, 2016)

On the basis of form of electric power input

DC SPVWPS

Motors configured for direct current (DC) are normally used for SPVWPS. The most common DC motors work at a nominal voltage of 24, 36 and 48 volts, which can perform at 32, 42, and 64 volts (Enciso and Mecke, 2007). The two types of DC motor include – conventional DC motor with brushes and brushless DC motor (BLDC). With conventional DC motor, carbon brushes are utilised for the transferring process of electric power from the PV array to the motor shaft. These brushes need to be replaced since they wear out with use. Consequently, operation and maintenance cost of the motor is increased. The magnetic induction principle is applied with BLDC when transferring PV power to the motor shaft. An advantage of BLDC motors is that they are self-synchronous machines with an electronic commutator. The most popular choice in SPVWPS is the Permanent brush less DC motors (PMBLDC) with a submersible pump is. The reasons for this include: the absence of brushes, high efficiency, silent operation, compact size, high reliability, and low maintenance requirements. The configuration for a DC water pumping system can either be or directly coupled or battery coupled.

AC SPVWPS

The PV panels generate DC electricity. Therefore, a suitable inverter is required to convert DC to AC electrical power for an AC motor driven pump. Since power is lost during the DC to AC conversion, the overall efficiency of SPVWPS can however be reduced by the use of an inverter.

In the case of the non-availability of PV power, AC water pumping systems can operate on grid power. The type of AC motors used to run the pump are induction and synchronous AC motors. An AC water pumping system consists of an AC motor driven pump set as shown in Figure 5-7.

Basis of types of pumps

Pumps can be classified as either deep well or surface mounted. The classification depends on the location of the installation with respect to the water level. For moving pipelines, surface mounted DC/AC motor pump sets are primarily used since they can be located near the water surface. Water can be moved to high heads or long distances by using surface mounted pumps. When applied in deep wells though these pumps are generally discouraged because of their suction limitations. The use of submersible pumps is recommended.

Basis of tracking of power source

This classification refers to the configuration of the SPV panels in such a way that they either follow the path of the sun or not throughout the day of its operation.

Fixed SPV panels/arrays

For a SPVWPS with fixed mounting, metallic structures inclined at a fixed tilt angle are used to mount the PV arrays on. The latitude angle of the pumping site is normally used as the value of the tilt angle. Compared to tracking mounting systems, the cost of the fixed mounting systems is relatively low. The performance of the water pumping systems with fixed mounting is however lower than that of tracking systems.

Tracking SPV panels/arrays

The performance of SPVWPS can be enhanced by implementing tracking SPV panels. The modes of tracking can either be manual, passive or auto. Hot dip galvanised iron (GI) is normally used as the support structure in this pumping system. These metallic structures should be of appropriate design and adequate strength with the capacity to withstand the load of the modules mounted thereon and higher wind velocities.

5.6.3 *Estimating solar energy potential*

Once the energy requirement of the specific irrigation pumping system has been established, the photovoltaic energy potential of the specific location needs to be determined. The first step in determining the technical feasibility of a solar power plant is to determine the photovoltaic energy potential of the specific location. Maps can be downloaded from the Global Solar Atlas or a specific site can be selected for which a system analysis can be undertaken.

The solar energy projected onto a solar panel (i.e. solar irradiance) takes on a normal distribution between sunrise and sunset. Solar insolation quantifies the total amount of irradiance (area under the curve) received within one day. It is generally accepted that the peak irradiance under standard conditions is equal to 1 kW.m^{-2}. The number of peak sunshine hours is given by the equivalent level of insolation at peak solar irradiance of 1 kW.m^{-2}. The potential solar energy generation capacity for a specific geographical area within a day is typically expressed as the kWh solar energy generated per m^2 of peak irradiance (kWh.kWp^{-1}). Stated differently, the metric also gives the number of peak sunshine hours at which the solar energy could be harnessed at a rate of 1 kW.m^{-2}. The metric is calculated as follows:

$$H_p = \frac{I_t}{I_p} \tag{5-12}$$

Where:

H_p peak sunshine hours (h)

I_p peak solar irradiance (1 kWp.m^{-2})

I_t total insolation (kWh.m^{-2})

I_t is location specific and depends on the specific climatic conditions and geographical area. H_p defines the maximum number of hours power will be available to pump water and therefore t in (5-8) will be equal to H_p.

5.6.4 *Calculating the power output of a PV system*

Power output of a PV system can be globally calculated as:

$$E = ArHPR \tag{5-13}$$

Where:

E = Energy (kWh)

A = Total solar panel Area (m^2)

r = solar panel yield or efficiency (%)

H = Annual average solar radiation on tilted panels (shadings not included)

PR = Performance ratio, coefficient for losses
(range between 0.5 and 0.9, default value = 0.75)

5.6.5 *Estimation of solar panel array area*

Relating the energy requirement to pump water to H_p gives the total area where solar energy needs to be generated at a rate of 1 kW.m^{-2}. The following equation calculates the area necessary if solar energy is generated under peak conditions:

$$A_p = \frac{\rho \times g \times h \times \frac{IR}{1000 \times \eta_{system}} \times A_f \times t}{3.6 \times 10^6 \times \eta_{\text{pump}} \times \eta_{\text{motor}} \times t \times H_p} \tag{5-14}$$

Where:

A_p solar array area (kWp)

The actual area of the panel array will be larger since the efficiency with which solar panels are able to convert solar energy into usable energy is low. The performance of solar panels is standardised by expressing the output of a solar panel per hour of peak solar irradiance (kWp). When installing a panel with a 0,25 kWp will require four panels to generate 1 kW in an hour.

5.6.6 *Application of assessment*

5.6.6.1 ***Location of case studies***

The calculation procedure for determining technical and economic feasibility of investing in a solar renewable energy source is demonstrated for Douglas and Vaalharts. The location of the two case studies relative to the distribution of photovoltaic power production potential is given in Figure 6-1. Both areas have good potential to generate solar energy. Douglas has no restriction on the area available to install the system whereas Vaalharts irrigation scheme has a restriction on the available area to install the system.

5.6.6.2 ***Technical Feasibility***

<u>*Photovoltaic energy potential*</u>

Data from the Global Solar Atlas is used to quantify the photovoltaic energy potential for a specific site near Douglas and Vaalharts. Data was retrieved for a large ground-mounted system with a tilt of 30° for Douglas and a floating system for Vaalharts with a tilt angle of 10°. A floating system was selected for Vaalharts due to the fact that the only place space was available to install the system is on the irrigation dam. The retrieved monthly total potential energy production was disaggregated into daily average monthly totals shown in Figure 5-8.

The photovoltaic production potential has strong seasonality especially in Vaalharts. The reason is the tilt angle of the floating system. Interestingly the highest potential is during spring and early summer when temperatures are not so high.

The next step is to size the solar plant in relation to the photovoltaic potential.

<u>*Solar plant sizing*</u>

The size of the solar plants was estimated using (5-14). The size is determined by relating the energy demand to irrigate 20 ha of maize to the photovoltaic potential in the area. The estimated sizes of the solar installations in Douglas and Vaalharts were respectively 29,5 kWp and 20,5 kWp. The actual area required when using 0,36 kWp solar panel with an approximate size of 2 m^2 will require an area of respectively 404 m^2 and 311 m^2 Douglas and Vaalharts. Technically the systems will be feasible in both areas.

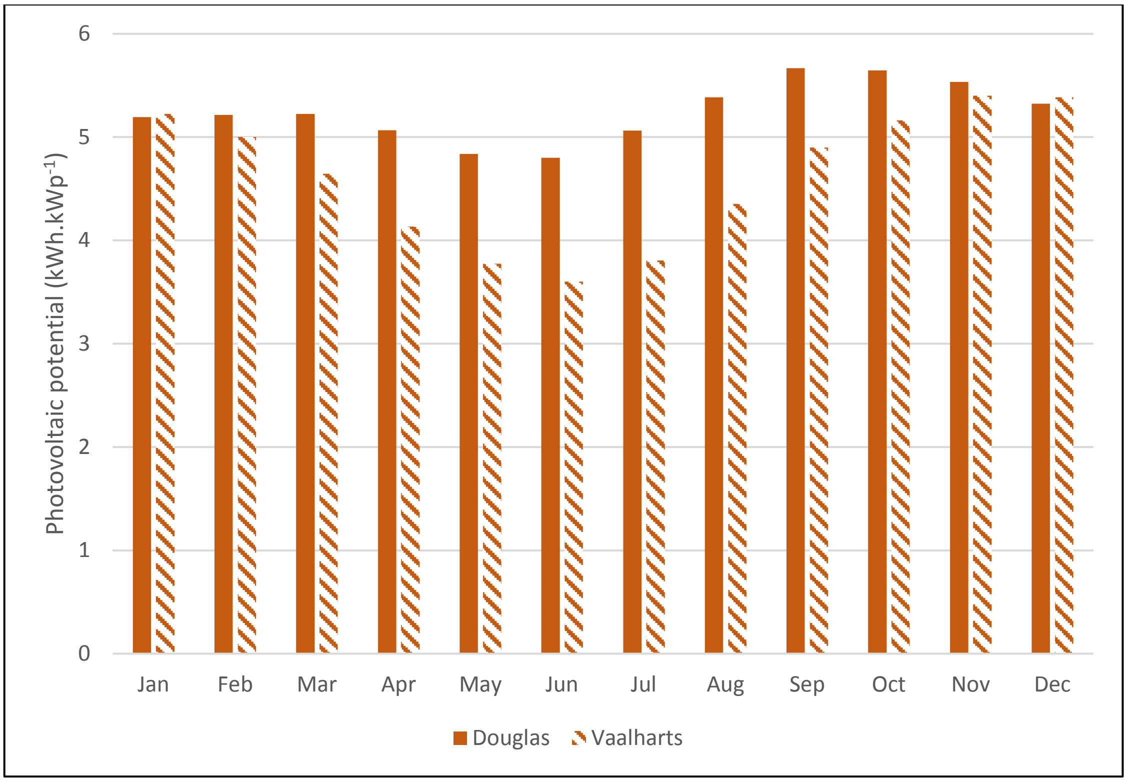


Figure 5-8: Distribution of monthly daily average kWh.kWp^{-1} photovoltaic potential near Douglas

5.6.6.3 Economic feasibility

The BLCC was estimated using the weighted electricity for Ruraflex under the assumption that the distribution of peak, standard and off-peak hours was respectively 15%, 35% and 50%. The fixed costs of the Ruraflex tariff were divided by the total kWh generated to calculate the fixed cost per kWh. Consequently, the calculated tariff for Vaalharts is higher due the lower capacity of the system. These findings are summarised in Table 5-2.

Table 5-2: Breakeven life cycle cost of solar power plants in Douglas and Vaalharts

		Douglas	**Vaalharts**
Energy generated	kWh.year^{-1}	56 590	34 598
Energy consumed	kWh.year^{-1}	14 297	9 532
Electricity Tariff	R.kWh^{-1}	1,24	1,35
BLCC	R	1 402 787	935 360

The BLCC shows that solar energy plants are economically feasible if the investor is able install the solar plant, operate and maintain the plant over a period of 20 years for less than R1,4 million in Douglas and less than R935 360 in Vaalharts. Cognisance should be taken that the actual cost of energy will be much higher if the BLCC is divided by the actual amount of energy consumed.

5.6.6.4 Concluding remarks

Ruraflex is the most common electricity tariff used by irrigators. Ruraflex allows their users to change the average tariff that they pay for electricity based on their energy consumption patterns during a day, specific day of the week and month of the year. Consequently, the electricity tariff used in the breakeven analysis is highly dependent on the management factors. Cognisance should also be taken of the fixed cost associated with the ESKOM tariffs. The fixed cost is paid irrespective of the level of electricity consumption. Higher electricity consumption will therefore result in lower fixed costs per kWh of consumed electricity. The solar plant generates energy throughout the year while energy consumption is periodic. The economic feasibility of the system could be enhanced if the excess energy generated could be sold, stored or consumed.

New ESKOM policies allow small users to offset and bank unused electricity. These grid-tied options need to be explored further. The solar plant is sized according to the peak sunshine hours. By implication it is assumed that the irrigation system could only apply water during peak sunshine hours which requires increased flow rates. The technical feasibility analysis does not include irrigation system design, soil infiltration rates and management considerations. More detailed research is necessary with regards to the management of solar powered irrigation systems especially if such a system is grid-tied with the possibility to offset and bank (not sell) electricity using the ESKOM grid.

5.6.7 *Deriving solar feasibility maps for South Africa*

Maps were developed for daily energy requirements of 100 kWh, 500 kWh and 1 000 kWh which is also the technical feasibility if there is space on the user's property for the area and number of solar panels required. Solar panels with a standard performance of 0,325 kWp and a solar panel area of 1,937 m^2 were selected for the feasibility maps. Different solar panel performance and area figures will result in different total number of panels and surface area required. The daily average PV power output data was downloaded from the SolarGIS website and converted to point shapefiles to show the potential PV output at each point. With a spatial resolution of 900 m x 900 m, the area between a set of four points represents approximately 81 ha. This scale should be sufficient for initial assessment.

Data was processed using ArcMap 10.8. A potential Photovoltaic Output (PVOUT) raster dataset was obtained from SolarGIS then imported into ArcMap. The data was then converted to points using a Raster to Point tool under Conversion toolbox; this allows data to have editable tables. The fields added to the existing attributes table are shown in Table 5-3.

Table 5-3: Fields added to attribute table

Pk_Sun	Ene_Req	kWp_For100	Pan_Req	Area_Req	Tech_Fs	BLCC	Annually

The metadata description is shown in Table 5-4.

Table 5-4: Metadata description

Field	Description	SI Unit
Pk_Sun	Peak Sunshine	$kWh.kWp^{-1}$
Ene Req	Energy Required	kWh
kWp_For100	kWp for 100 kWh required	kWp
Pan_Req	Panels required	-
Area_Req	Area_Required	m^2
Tech_Fs	Technical Feasibility	kWh
BLCC	BLCC	$R1,5.kWh^{-1}$
Annually	Annually	R

The calculations for 100 kWh, 500 kWh and a 1 000 kWh were done respectively using the Field calculator tool in the attributes table. Following, are the equations used to calculate corresponding field:

- Pk_Sun = known value
- Ene_Req = Constant
- kWp_For100 = Ene_Req ÷ Pk_Sun
- Pan_Req = kWp_for 100 ÷ 0.325
- Area_Req = Pan_Req × 1,9327
- Tech_Fs = Pan_Req × 0.325 × Pk_Sun
- BLCC = Tech_Fs × 1.5
- Annually = BLCC × 365

After calculations, data was exported as shapefiles, dbf file from each shapefile was used to create a Microsoft Access Database file. The data can unfortunately not be viewed in excel since there are 1,731 million data points for South Africa at this resolution and only 1,049 million rows in Excel. The files are available for daily energy requirements of 100 kWh, 500 kWh and 1 000 kWh at points across South Africa as well as for each of the nine provinces. Table 5-5 to Table 5-7 show the attributes for the three different solar system sizes based on the max and min peak sunshine ($kWh.kWp^{-1}$) per day in South Africa.

Table 5-5: Attributes of a 100 kWh solar system based on peak sunshine per day

ID	Peak sunshine per day	Energy required	kWp for 100 kWh required	Panels required	Area required	Technical feasibility	BLCC	Annually
Unit	**$kWh.kWp^{-1}$**	**kWh**	**kWp**	**-**	**m^2**	**kWh**	**R**	**R**
max	5,59	100	17,90	55	106,62	100	150	54 750
min	2,59	100	38,68	119	230,12	100	150	54 750

Table 5-6: Attributes of a 500 kWh solar system based on peak sunshine per day

ID	Peak sunshine per day	Energy required	kWp for 100 kWh required	Panels required	Area required	Technical feasibility	BLCC	Annually
Unit	**kWh.kWp^{-1}**	**kWh**	**kWp**	**-**	**m^2**	**kWh**	**R**	**R**
max	5,59	500	89,48	276	256,79	500	750	273 750
min	2,59	500	193,42	596	555,10	500	750	273 750

Table 5-7: Attributes of a 1 000 kWh solar system based on peak sunshine per day

ID	Peak sunshine per day	Energy required	kWp for 100 kWh required	Panels required	Area required	Technical feasibility	BLCC	Annually
Unit	**kWh.kWp^{-1}**	**kWh**	**kWp**	**-**	**m^2**	**kWh**	**R**	**R**
max	5,59	1 000	178,89	550	1066,19	1 000	1500	547 500
min	2,59	1 000	386,10	1188	2301,16	1 000	1500	547 500

It can be seen from the tables that for places where maximum peak sunshine occurs, less solar panels and surface area is required than for places where minimum peak sunshine occurs. Although the BLCC is the same for both maximum and minimum output, the latter is however considered less feasible since the cost impact will be bigger because of the number of solar panels required. The solar feasibility maps are included in Appendix F.

5.7 Assessing the feasibility of wind energy sources

5.7.1 *Overview*

Various factors determine the feasibility of wind power projects. These are the wind speed factors, air density, capital costs and economies of scale. High capital costs of small-scale wind turbines have been the biggest restriction of the uptake thereof when compared to grid electricity. These costs range from R36 500 for a 1 kW turbine, to nearly R100 000 for a 3,5 kW turbine, according to the online trading portal Sustainable.co.za. The Tesup wind turbine (manufactured in England) sells at a price of R17 000 for a 5 kW turbine and surely is worth looking into. Throughout their lifetime, the annual maintenance and operational costs for these small-scale turbines are assumed to be 1% of their initial capital investment cost (PM and SANEDI, 2017).

Wind can also be used for mechanical power. An example of this is wind pumps which can be used in remote and rural areas where the costs of these pumps are less than electric pumps and their installations. Water can be stored in dams in areas where wind varies. Although the scale of these technologies is small (pico and micro level), their scope of application is broad – they can be utilised in regions with regular low or mild breezes and can pump between 10 000 and 100 000 ℓ.day^{-1}. Depending on the location and with the advantage of having elevated storage, these systems can be applied for small scale gravity irrigation. Over 200 000 wind pumps have been installed in South Africa, with a cost range between R40 000 and R75 000. This cost is dependent on the required pressure and average flow rate (PM and SANEDI, 2017).

5.7.2 *General configuration of wind energy systems*

The typically small-scale wind energy systems are 100 kW or smaller. These systems are used for residential, business, industrial or agricultural applications. They can be on-grid or off-grid, stand-alone or hybrid (e.g. with solar or diesel) as illustrated in Figures 5-9 to 5-12.

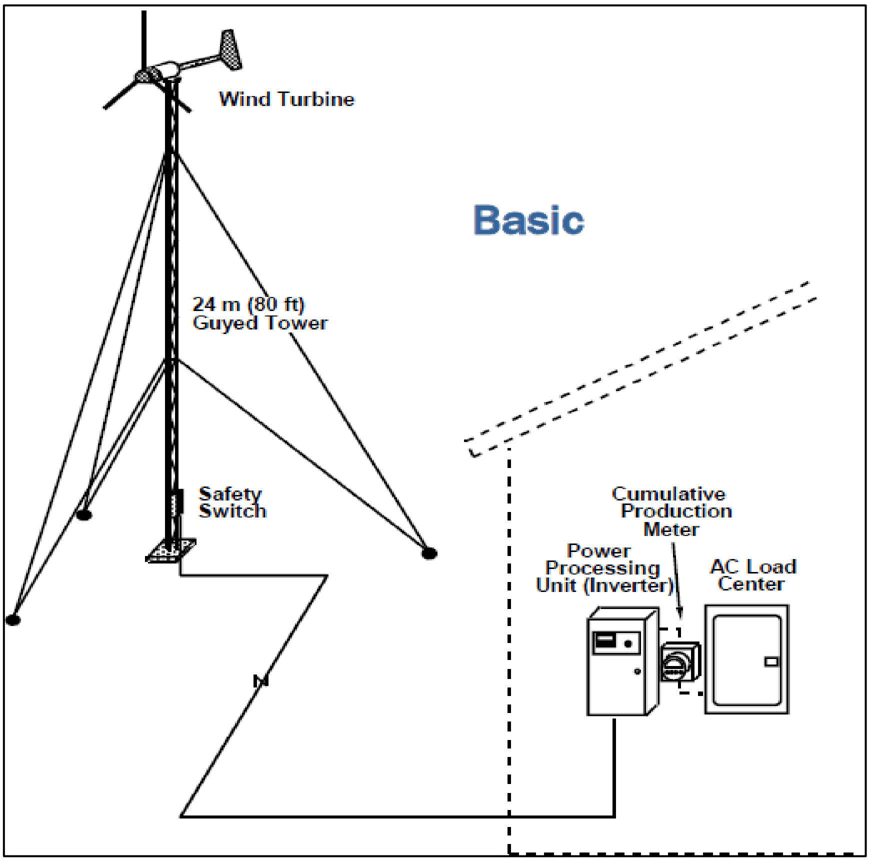


Figure 5-9: Basic layout of wind turbine energy system (Van Dam *et al.*, 2008)

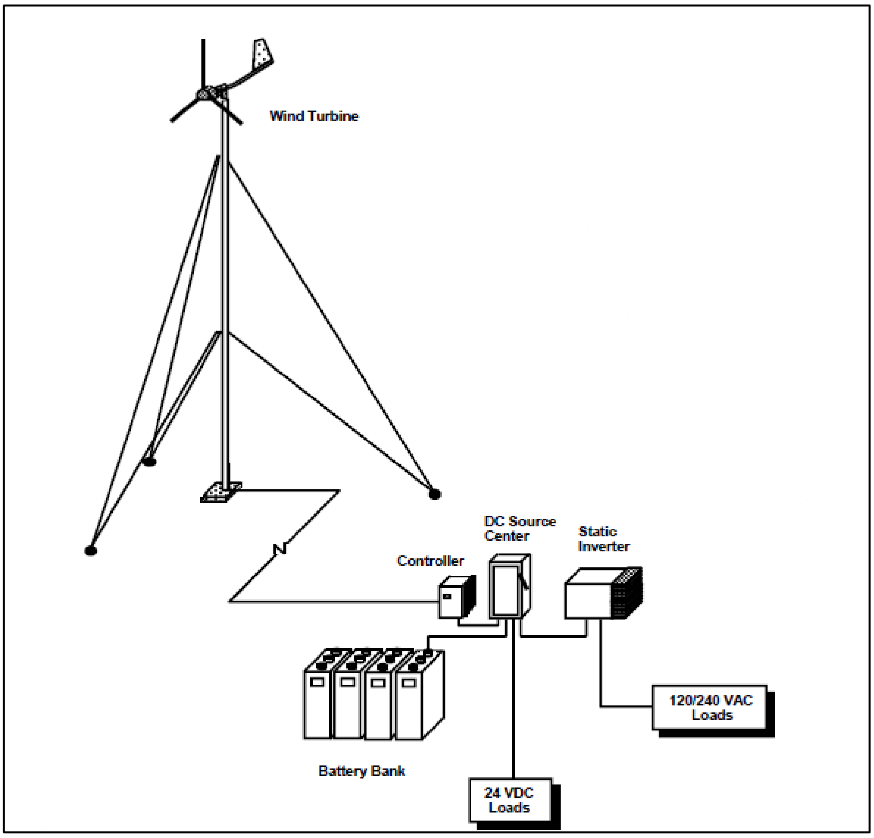


Figure 5-10: Layout of off-grid wind turbine energy system with storage (Van Dam *et al.*, 2008)

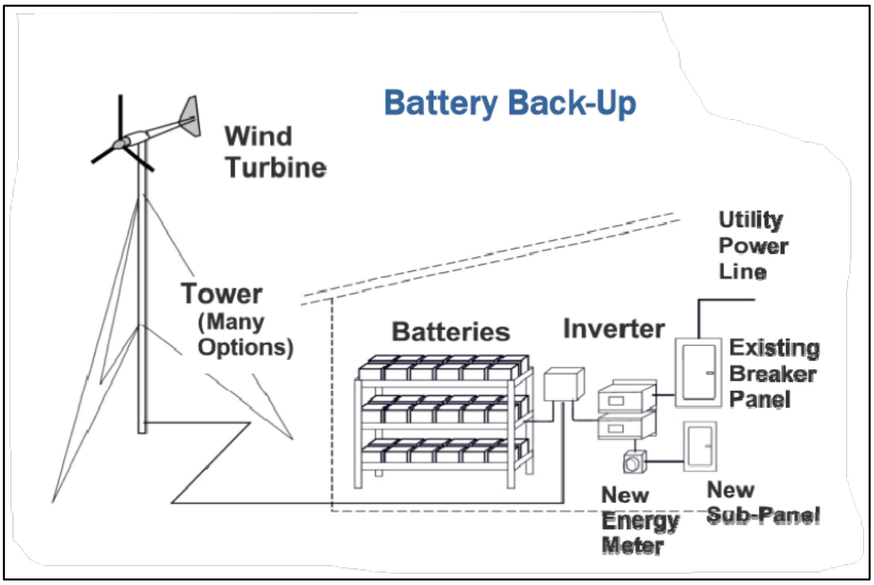


Figure 5-11: Layout of on-grid wind turbine energy system with storage (Van Dam *et al.*, 2008)

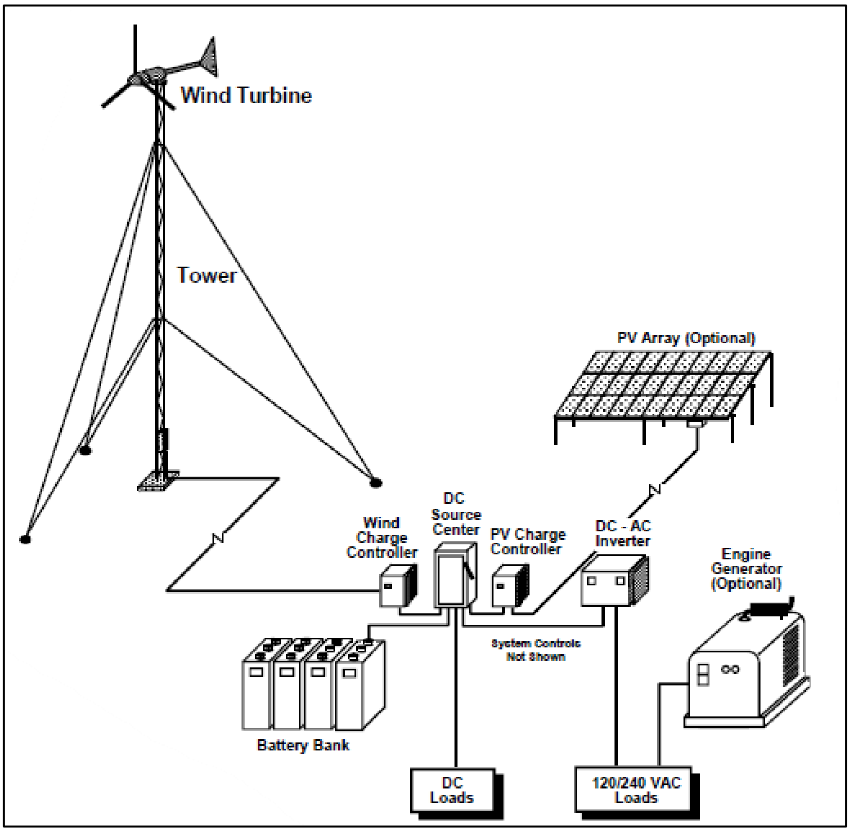


Figure 5-12: Layout of hybrid wind turbine energy system with storage (Van Dam *et al.*, 2008)

Two important aspects to evaluate when deciding if a small-scale wind energy system is feasible are to:

- check the regulations and
- perform energy production and economic analysis

This typically entails (Van Dam *et al.*, 2008):

- determining how windy it is and how much energy (kWh) is required
- configuration and sizing of the system
- estimating the energy production
- calculating the energy savings
- performing a cash flow analysis
- a wind resource assessment

The expected lifespan of all wind turbines is 20 to 25 years. An annual service is required for wind turbines to perform optimally. A service entails visual and noise inspection for possible failure of components or the rotor blade. If batteries are used for storage they should also be maintained and inspected regularly and replaced after a few years, depending on the technology used. Inverters typically need to be replaced after 10 years. It is important to verify the servicing costs and warranty periods of all system components with the installer (Schmidt, 2019).

On-site measured wind data remains the preferred option in terms of analysing if the wind resource at a specific site has enough potential to justify investing in a small wind turbine system. State or researched wind maps can be consulted as a preliminary analysis of the wind energy potential; however, the resolution of these maps isn't always good and local site features remain unrecognised. The height above ground indicated on the map is important as it relates directly to the tower height of the potential project. A potential source of error is added when trying to adjust the wind speed for the height difference between the turbine height and the map height depending on the selected wind shear exponent. Thirty to forty metres wind maps are far more useful than 10-, 60-, 80-, or 100-m wind maps for small wind generator applications. For map resolutions lower than the terrain features, adjustments are needed to account for local terrain effects (U.S. Department of Energy, 2021).

The type of wind flow, either laminar or turbulent, and wind shear need to be taken into consideration when deciding on the placement of a wind turbine. The effect of the ground and local obstructions on the wind speed can be determined by measuring the shear profile of the wind. Higher wind speeds are generally measured at greater elevations above the ground. This is illustrated in Figure 5-13.

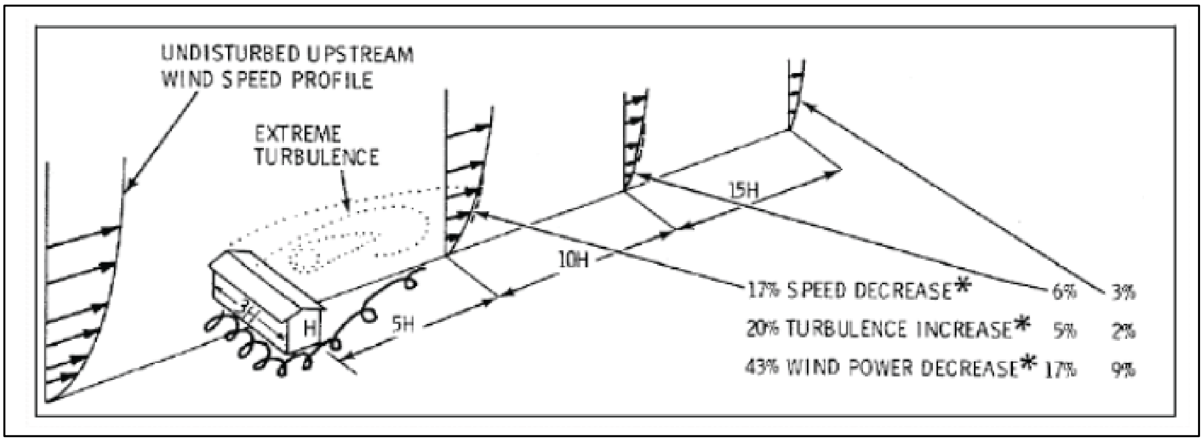


Figure 5-13: Turbulence effect due to building (Brosius, 2009)

The variation of wind speed at specific locations may be caused by seasonal differences or the effect of day and night due to a sea breeze for instance. These variation trends are well illustrated when plotting wind speeds on a time scale. Data needs to be collected at two different heights for calculating the wind shear exponent. With wind shear data an accurate analysis of the cost versus benefits of taller towers can be conducted. Additionally, analysis to determine wind distribution, the wind direction rose, turbulence intensity, vertical wind shear exponent, wind speed averages and extremes, Weibull parameters and associated uncertainties, must be performed.

5.7.3 *Estimating wind energy potential*

The electrical power output of a wind turbine at different wind speeds can be indicated with a power curve as shown in Figure 5-14. The wind speed at which wind turbines start to generate is referred to as the cut-in wind speed. The wind speed at which the wind turbine will stop generating is called the cut-out wind speed. The latter is necessary to prevent the turbine or its surroundings from getting damaged as a result of high wind speeds. The cut-out wind speed in Figure 5-14 is 10,5 $m.s^{-1}$ (Brosius, 2009).

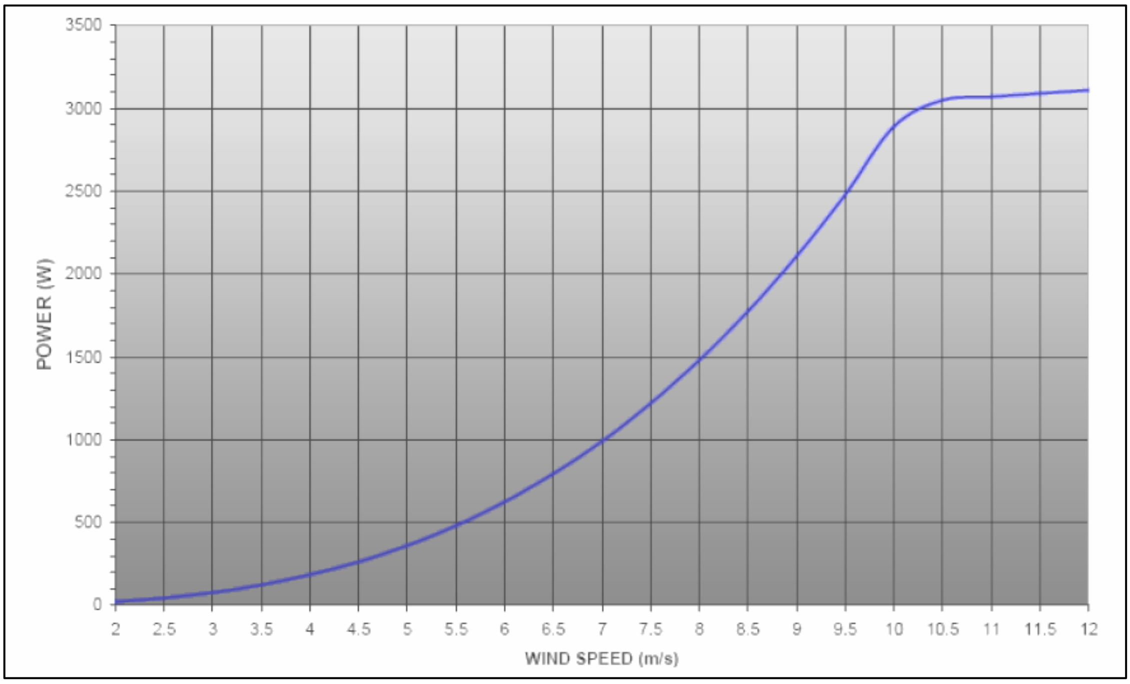


Figure 5-14: Wind turbine power curve (Brosius, 2009)

Figure 5-15 shows an example of Weibull curves illustrating the mean wind speed (x-axis) distribution based on the percentage frequency of occurrence (y-axis). On this particular graph the same mean wind speed with different shape factors is shown. A distribution with a shape factor of two is called a Raleigh distribution. The shortcoming of wind energy is that it is not constant and reliably available.

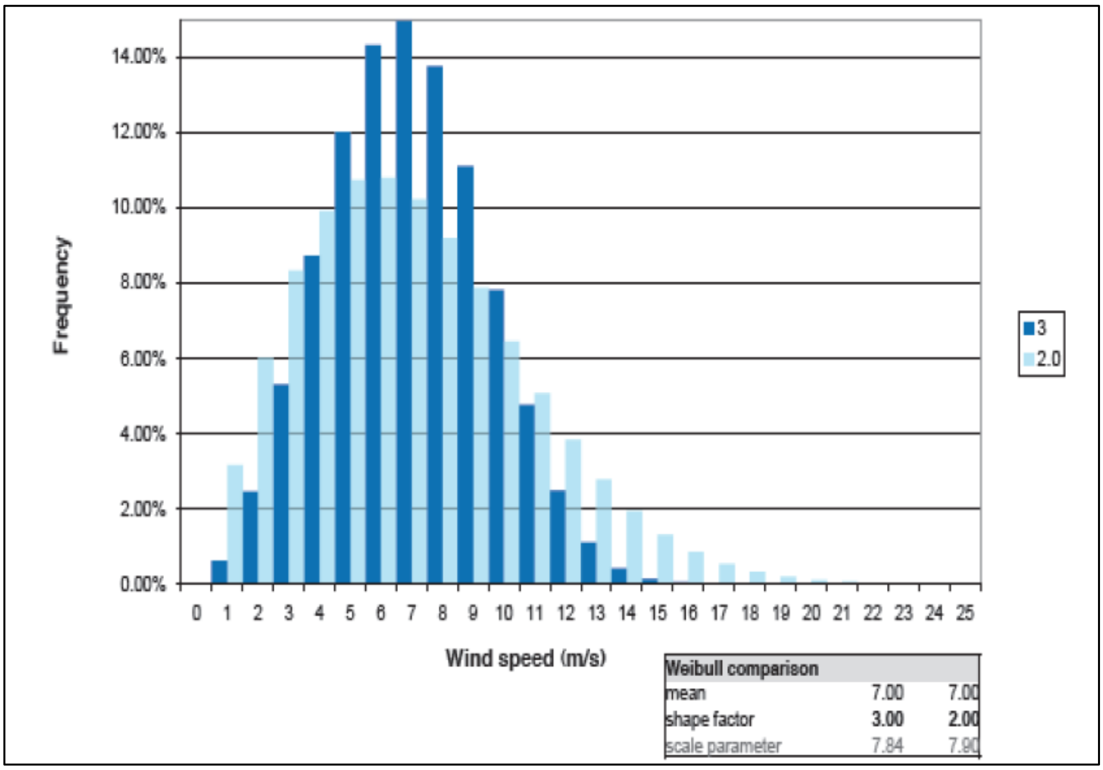


Figure 5-15: Weibull curve – mean wind speed distribution (Brosius, 2009)

The nominal wind turbine capacity is multiplied by the hours in a year to calculate the total annual maximum energy that can be produced. This is referred to as the total annual energy production (AEP) and is based on the available power. For each wind speed bin (u), the turbine puts out power, according to the power curve, for a certain number of hours per year. Energy (Eu) captured in that bin is the number of hours (tu) times the power output (Pu) in Watt per wind speed bin (u).

$$Eu = Pu \times tu \qquad (5\text{-}15)$$

Total energy captured (the total AEP) is sum of all wind speed bins, Equation 5-18.

$$AEP = \sum Eu \qquad (5\text{-}16)$$

Figure 5-16 shows the effect of the available power from a certain wind speed distribution in combination with a certain turbine's power curve. When overlapping these, one can see the available power underneath the intersection of the curves for each wind speed window as shown in Figure 5-17.

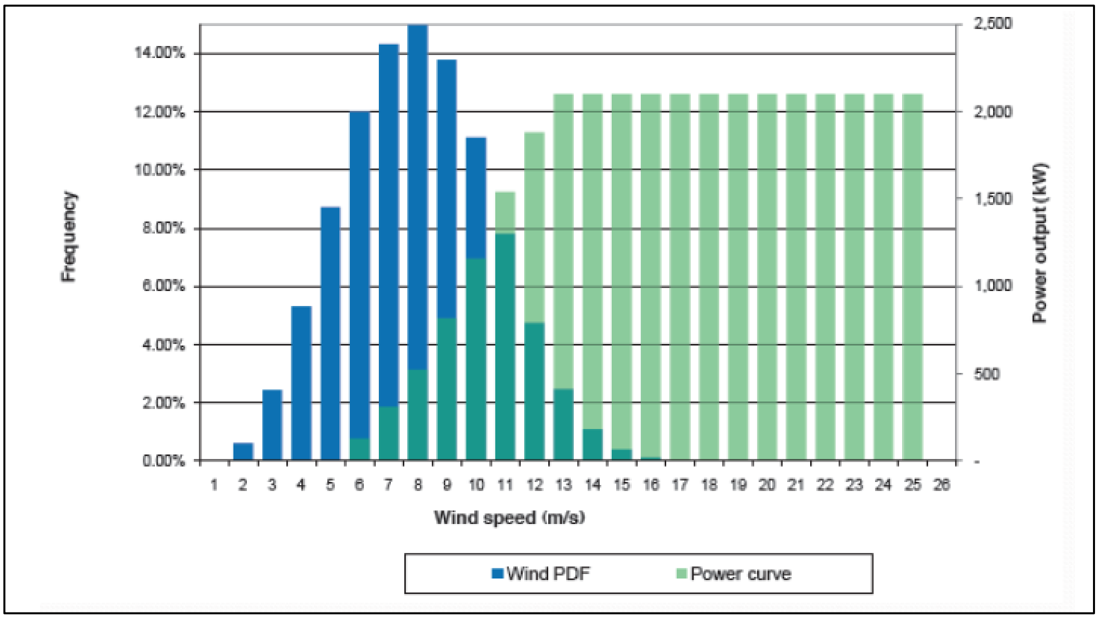


Figure 5-16: Wind speed distribution vs. power curve

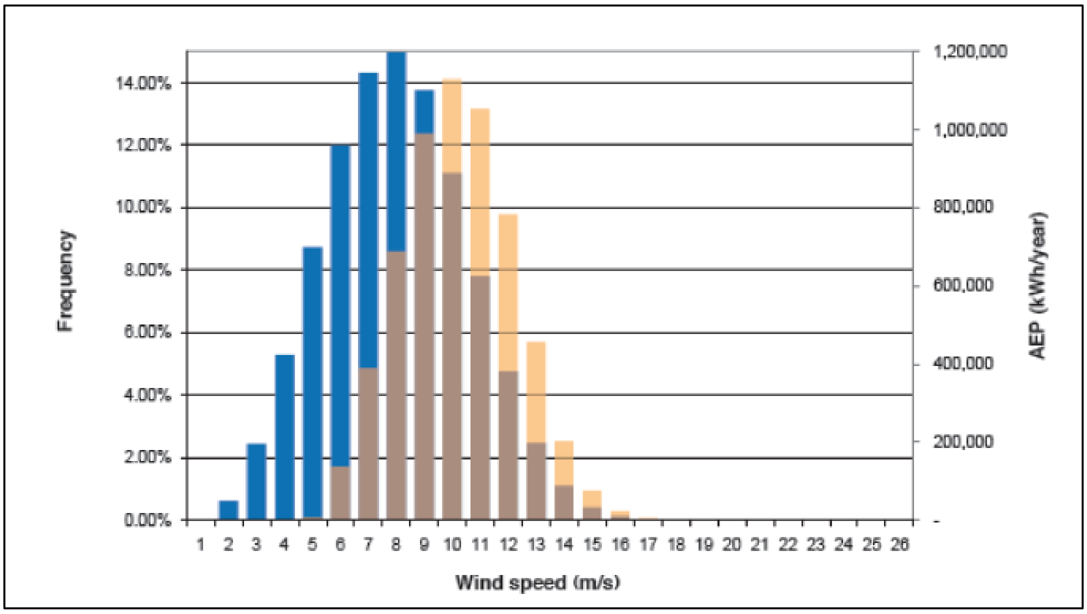


Figure 5-17: Wind speed, power and AEP (Brosius, 2009)

The Global Wind Atlas can be used for preliminary calculations to identify high-wind areas for wind power generation all across the globe. It is a free, web-based application developed to assist policymakers, planners, and investors.

It has a relatively friendly user interface with multiple tools and options to choose from. The mean wind speed and mean power density can be read from the graph for heights ranging from 10 to 200 m above ground, whichever is selected. Wherever the cursor points on the map, the co-ordinates and mean wind speed or mean power density can be read from the graph for the specific height selected. The default legend for the mean wind speed is scaled at a maximum of 10 $m.s^{-1}$. The highest wind speeds are indicated in red on the map and the lowest wind speeds are indicated in blue. There is also an option to select either the road map or satellite layer as backdrop allowing the user to clearly see the location. Users also have the option to see where on the map they are located.

The user has the option to select a country as well as a region within that country to display the mean wind speed. Another option is to draw a polygon or marker at the area on the map which the user wishes to analyse for wind energy potential.

For the country or region selected, the mean wind speed and power density for the 10% windiest areas in that region is given and can be read from a graph. There is also a wind frequency, wind speed and wind power rose for the selected area. Where the user draws a marker or polygon, the same area data is displayed and in addition temporal data is given for the annual, monthly and hourly wind speed distribution. The energy yield is also given but this feature is only available on desktop devices.

5.7.4 *Calculating the power output of a wind turbine*

The calculated total annual energy produced at an average wind speed of 5 metres per second can be referred to as the Rated Annual Energy of a wind turbine. The factors that are important to the performance of a wind turbine can be noted in formula 5-17. Wind speed (V) has an exponent of three applied to it which means that a small increase in wind speed can cause a large increase in power. By mounting wind turbines on taller towers, turbines are given access to higher wind speeds which subsequently increases its productivity (U.S. Department of Energy, 2021).

The formula for calculating the power from a wind turbine is:

$$P = Cp\, 1/2\, \rho\, A\, V^3 \tag{5-17}$$

Where:

P	Power output, watts
Cp	Maximum power coefficient, ranging from 0.25 to 0.45, dimension less (theoretical maximum = 0.59)
ρ	Air density, $kg.m^{-3}$
A	Rotor swept area, m^2 or $\pi\, D^2 / 4$ (D is the rotor diameter in m, π = 3.1416)
V	Wind speed, $m.s^{-1}$

With horizontal turbines, wind energy blows into the rotor-swept area. Larger rotors can therefore capture more energy. Standard conditions of 15°C at sea level apply for the ratings for wind turbines. An air density correction should be made for higher elevations since air density changes slightly with air temperature and with elevation. A prediction of the long-term performance of a wind turbine, typically does not require a correction for temperature (U.S. Department of Energy, 2021).

Unfortunately, there is a limit to the extraction of power in HAWTs. According to the Betz law, the maximum efficiency is 59.3%. This means that only 59.3% of the kinetic energy in the wind can be extracted to generate power. The German physicist, Albert Betz, developed this law in 1919. Essentially, the power which the rotor extracts from the wind is proportional to the product of the wind speed and the pressure drop across the rotor. The most well-designed modern turbines can however operate at efficiencies below the Betz limit. This can be due to engineering constraints, limited energy storage and transmission losses (Brosius, 2009).

Annual energy output ($kWh.year^{-1}$) remains the best measure of wind turbine performance. This can assist with determining if a specific wind turbine and tower produce enough energy to meet the demand. Wind turbine manufacturers, dealers or a site assessors can assist with estimating the expected energy production at a site by making use of:

- the particular wind turbine power curve,
- the average annual wind speed at the site,
- the height of the planned tower,
- micro-siting characteristics of the site and, if available,
- the frequency distribution of the wind (an estimate of the number of hours that the wind will blow at each speed during an average year).

The calculation should be adjusted accordingly for the elevation of the site (U.S. Department of Energy, 2021).

5.8 Assessing the feasibility of hydro energy sources

5.8.1 *Overview*

Hydropower systems have high initial capital costs. The largest part of the total cost consists of the costs of civil works. The plant size and infrastructure layout make up most of the capital costs which can be significantly increased by the cost of transmission and distribution of the generated electricity.

The location and site conditions contribute to approximately 75% of the development cost. Costs related to electromechanical equipment and manufacturing are relatively fixed and contribute to the remaining 25% of the development cost.

It is particularly important to carefully consider the economies of scale when hydro-electric projects are being developed. A general perception has been that the financial feasibility of facilities with capacities less than 5 MW are doubtful. Regulatory compliance and its associated costs and complexity are other barriers which increase project risk, and therefore inhibit the development of small and micro facilities. The importance of a comprehensive hydrological assessment was noted, as inaccuracies in this regard can affect the technical specifications of the project as well as the financial feasibility (PM and SANEDI, 2018).

The advantages of hydropower systems can be summarised as follow:
- require minimal operational costs (can be as little as 1% of capital cost per annum)
- have high efficiencies (75-85%)
- can serve more than one purpose (flood control, supply water for irrigation and/or consumption)
- require minimal maintenance
- no major overhauls over its lifespan
- minimal costs relating to the operation and maintenance of systems
- extended operational lifespan and robustness

The major cost components in a hydropower project are:
- Civil, e.g. earthworks, water conveyance infrastructure, powerhouse construction.
- Mechanical and electrical, e.g. turbine and generator.
- Electrical, e.g. grid connection and grid infrastructure.

The development process of a Hydro Kinetic system layout can typically entail:
- Site-selection and pre-feasibility study
- Turbine Selection (subject to the size and depth of the dam, maximum flow and head and availability of local maintenance and system components) (Schmidt, 2019).
- Grid integration
- Legislative assessments and approval
- Meeting with stakeholders
- Capital procurement
- Project implementation
- Operation and Maintenance
- Monitoring and evaluation

5.8.2 *General configuration of hydro energy systems*

The type of installation, grid-connected system or off-grid system will determine the required control equipment. A general layout for these configurations for HK systems is shown in Figure 5-18 followed by a list with a description of each item.

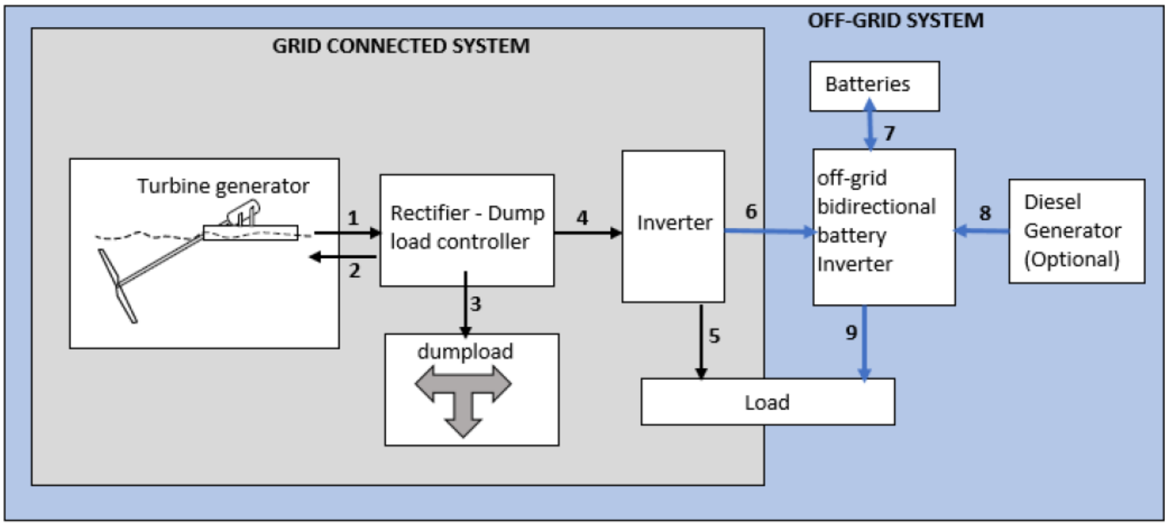


Figure 5-18: HK system layout (Niebuhr, 2018)

1. The turbine generator supplies power to the rectifier, along this connection a switch can be connected as the turbine break, simply as a safety feature.
2. This is the low voltage DC going back to the turbine, (safety mechanism) as long as power is supplied to the relay the turbine runs as normal, in the case where the cable is disconnected the relay will open, putting the turbine into open circuit and no power will be generated, also preventing stray power from leaking into the water.
3. Excess electricity is diverted to the dump-load to be dissipated (in most cases as heat, through heating elements) this will occur when:
   - Grid-connected and off-grid: to protect the grid tie inverter when the voltage exceeds 600 V.
   - Off-Grid: When the power produced is not utilised.
4. The rectifier converts the unstable current from the turbine generator to unstable DC current (if required) which is supplied to the grid tie inverter.
5. The inverter supplies AC as required (50 Hz in South Africa).
6. The inverter supplies AC as required to the off-grid inverter.
7. The off-grid inverter will use the batteries to stabilize the system, either by charging excess energy into the batteries or using energy from the batteries when insufficient power is supplied by the HK system.
8. A backup input may be used by connecting a diesel generator (or alternative back-up source) which will turn on automatically when enough energy is not supplied from the batteries and HK system.
9. The inverter supplies AC as required (50 Hz in South Africa).

Ram pumps can be used in remote areas and smaller streams. The fall of water necessary to for a ram pump to function may be as low as 500 mm and with such a fall, water may be raised to 18 m. With higher falls, such as from 2 m to 7 m and more, water can be raised to 300 m or more in height while the distance is more or less unlimited. Figure 5-19 shows a diagram of a basic ram pump installation.

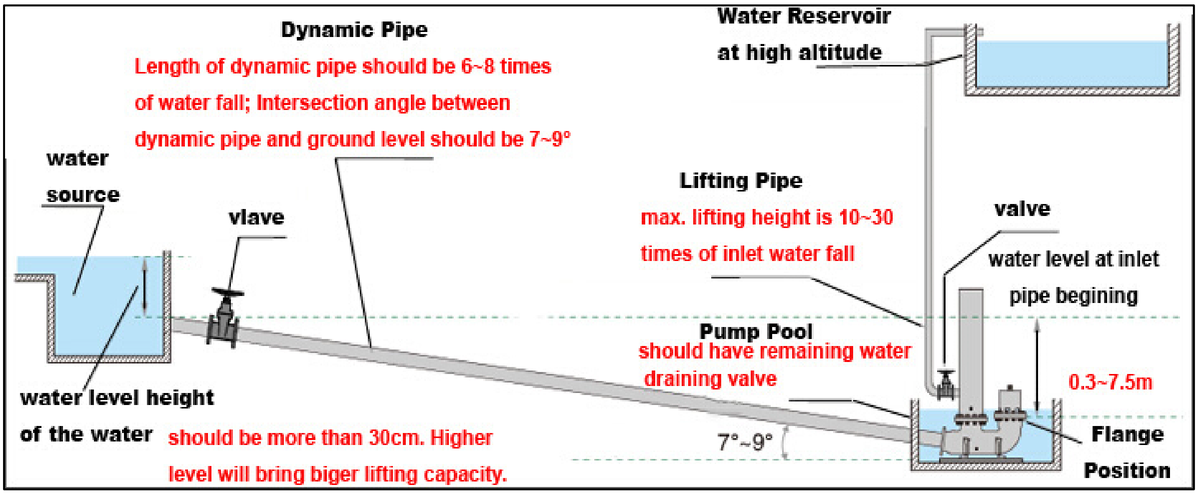


Figure 5-19: Diagram of basic ram pump installation

Before a calculation can be made to establish if the required volume of water can be supplied by the ram pump, the following information needs to be obtained:

1. Vertical fall: the difference in height between the water source and the pump site.
2. Lift: the difference in height between the pump site and the point of storage or use.
3. The quantity of flow available from the source.
4. The quantity of water required.
5. The length of pipe from the source to the pump site (called the drive pipe).
6. The length of pipe from the pump to the storage site (called the delivery pipe).

$$D = QFE/L \tag{5-18}$$

Where:

D	Volume delivered, $m^3.h^{-1}$
Q	Quantity of water supplied from the source, $m^3.h^{-1}$
F	Fall or height of the source above the ram, m
E	Efficiency of the ram (for Derkor models use 0.6)
L	Lift height of the point of use above the ram, m

5.8.3 *Estimating Hydro energy potential*

Water resource related information and data is available from the Department of Human Settlements, Water and Sanitation's (DWS) website. Data for a flow measurement gauging station can be accessed from the DWS website. The user can choose to access either the monthly volume of flow, the daily average flow or the primary data. The average daily or monthly flow data for the record period can then be ranked from high to low to establish the percentage reliability of supply/flow in the river for the specific demand/requirement. See Figure 5-20.

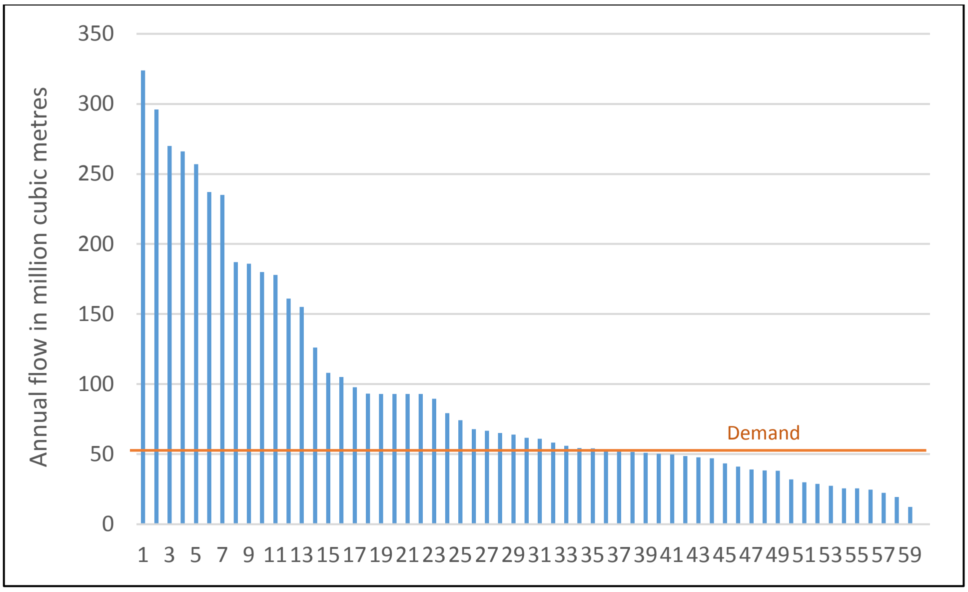


Figure 5-20: Ranked annual flow data measured at flow gauge

It is important to note that observed flows can in some cases be misleading, in particular when significant development has taken place upstream of the flow gauge. Depending on the significance and type of upstream development that took place over time, the flow, as measured at the gauge, can decrease over time or in some instances even increase if significant return flows from urban or industrial areas enter the river system. These decreasing or increasing trends of the originally natural flows (flows before upstream development occurs) will lead to the over- and underestimating of the capacity of the required turbine and related generation capacity respectively.

If such developments are evident in the catchment under consideration, further detail work is recommended. Water resource models can be applied for detail analysis of water resource availability and assurance of supply. These models are used to generate the natural flow at any specific site in a catchment, and then add the impacts of any upstream developments impacting on the river flow. These models can be used for example to keep the impact of the developments constant over the analysis period as it is at current development level or at any future development level. One can then at current development level determine what the available flow and the reliability of the flow currently are, or at a selected future development level (M Maré 2022, personal communication, 21 January).

Hydrology is the main factor influencing the resulting yields and estimated risk of failure of a system. Therefore, reliable hydrological data sets are important for undertaking reliable water resource analysis. Data validation and verification is important throughout the process of hydrological analysis. Rainfall data sets need to be patched and filled as necessary enabling the naturalisation of the historical streamflow sequences and rainfall-runoff modelling. The WRSM2005 Model is used to undertake the rainfall-runoff modelling and stochastic streamflow sequences can be generated with the STOMSA Model. This is a probabilistic analysis approach. Figure 5-21 shows the overall linkages between the hydrology and the water resource analyses.

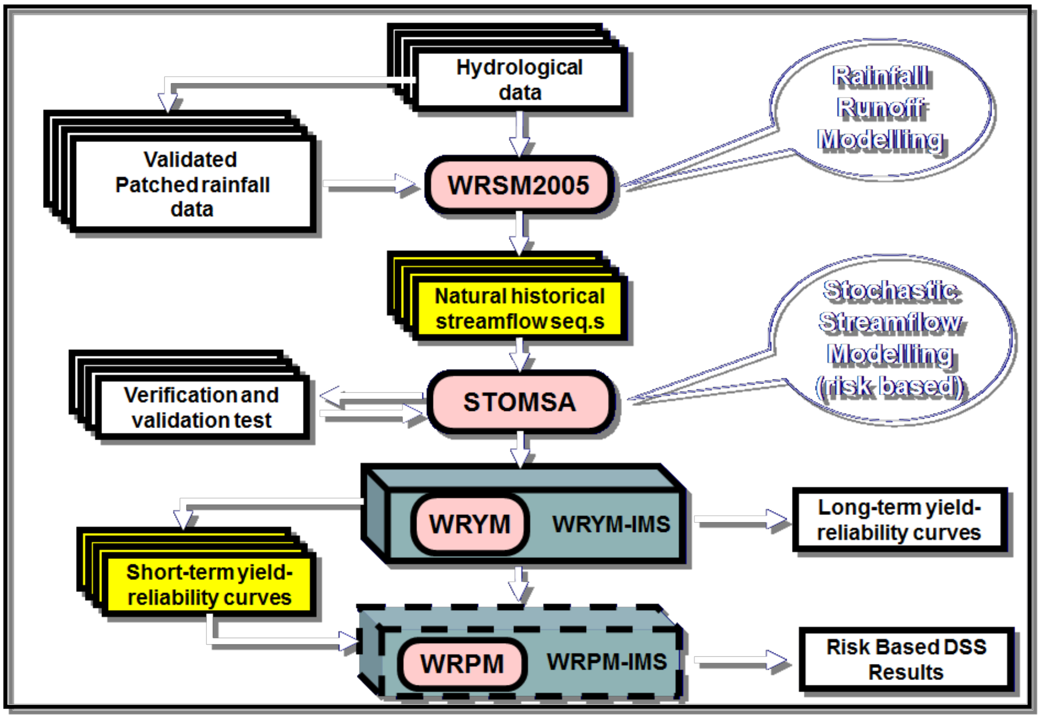


Figure 5-21: Links between hydrology and system analyses (Mckenzie, 2017)

The two water resource models, namely the WRYM and WRPM, can be considered as a single model with an initial function to establish the existing yield capability of a specific system based on a set of operating rules. During this process, the naturalised historical streamflow record with current day development demands in place is used and supported by 100 to 1 000 stochastically generated streamflow sequences.

These models and the related processes to achieve the end results involve quite a lot of detailed and specialised work that can be time consuming and expensive to carry out, in particular when considering large systems. Configuration and execution of these models require someone that specialises in this field. These models were already setup and used for analysis for most parts of the RSA by the DWS. Without working through all these processes, running, and validating of these models, one can use any of the already setup and approved models to assist with the modelling of flows at a specific point in a river system or even an existing scheme. Most of the WRPM and WRYM models are used by DWS to advise them on the annual operating requirements for water resource schemes all over the country. These models are updated on an annual basis and used for operational purposes. If there is a need for analysis by using the WRYM and or WRPM to determine the flows at the required site, it will require a discussion with DWS and a model specialist before this analysis can be undertaken (M Maré 2022, personal communication, 21 January).

5.8.4 *Calculating the power output of a hydro system*

The available power that can be sourced from either potential energy driven or kinetic energy driven hydro energy systems can be calculated as indicated in Table 5-8.

Table 5-8: Calculation of hydro energy output

Potential energy Output of the system is directly proportional to the flow and pressure: $P = \rho g Q H \eta$ (5-19)		**Kinetic energy** Power depends on velocity of water: $P_{HK} = E \times \frac{\rho}{2} \times v^3$ (5-20)	
P	Mechanical power output (W)	P_{HK}	Mechanical power output ($W.m^{-2}$)
ρ	Density of water ($kg.m^{-3}$)	E	Device efficiency (%)
g	gravitational acceleration (9,81 $m.s^{-2}$)	v	Fluid velocity ($m.s^{-1}$)
Q	flow rate through the turbine ($m^3.s^{-1}$)	ρ	Fluid density ($kg.m^{-3}$)
H	effective pressure head across the turbine (m)		
η	hydraulic efficiency of the turbine (%)		

Selecting the location and spacing for the installation of multiple HK turbines within a canal/river section can be a complex process. The decision is site dependent and subject to the type of turbine used, the rotor blades and the velocity. Complete laminar flow needn't be regained in a canal where these turbines are installed. The velocity however is the driving factor behind the power production. An example of a power curve of a HK turbine is shown in Figure 5-22.

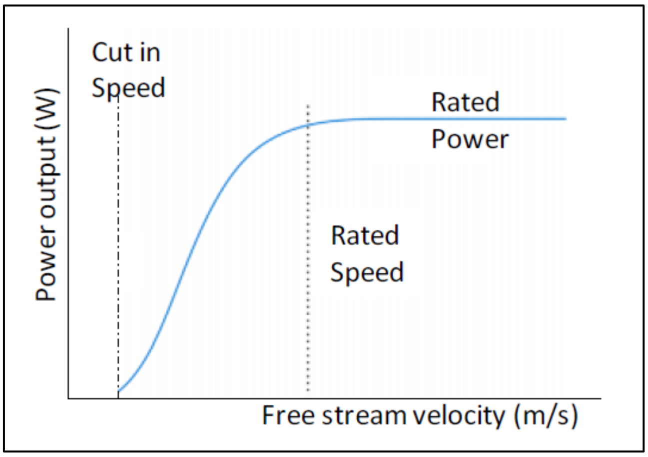


Figure 5-22: Power curve of HK device (Neibuhr, 2018)

If multiple turbines are spaced close to one another, it is important to allow enough wake length for the velocity of the water to recover to conditions prior to installation. Research has shown that it takes a distance of 20 diameters downstream of the rotor of an axial flow turbine (similar to wind turbine) to recover 90% of its velocity (Figure 5-23). A wake recovery of 85% is considered sufficient (Laws and Epps, 2016).

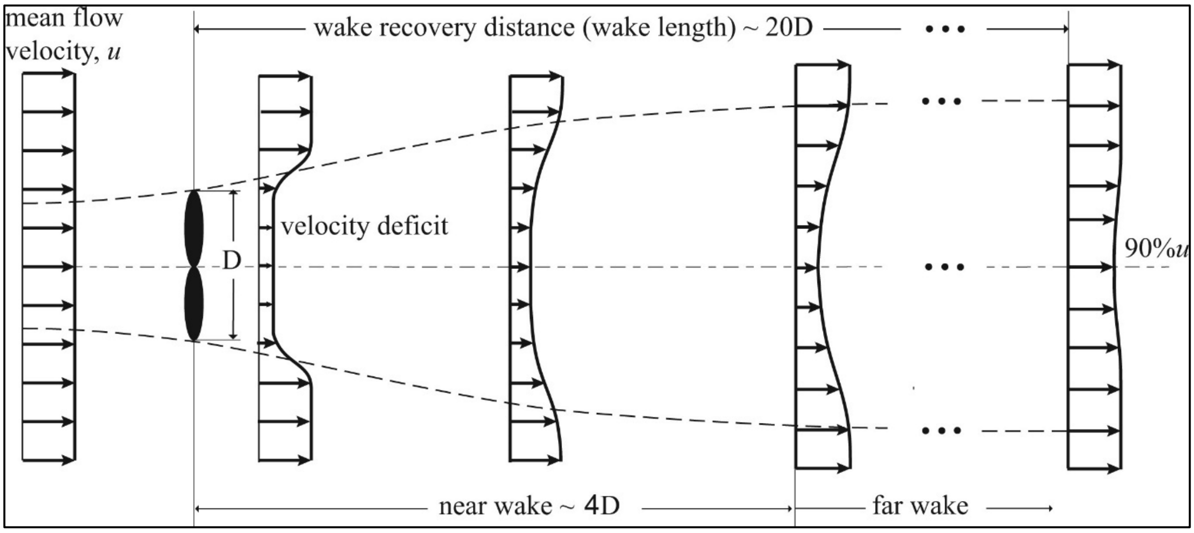


Figure 5-23: Definition of wake characteristics (Laws & Epps, 2016)

5.9 Summary

It is important to evaluate the viability of irrigation systems with a renewable energy source combination. The general framework presented to evaluate the techno-economic feasibility of RES emphasises the importance of a preliminary feasibility study. Careful consideration should be given to this phase of evaluation of a RES. During the preliminary feasibility phase, it is important to devote enough effort towards understanding the dynamics of the EDL and the operational requirements of the system. Failure to acknowledge the dynamic aspects of EDL may stem the development of a RES infeasible from an operational perspective with relation to supply of RE. The importance of conducting a sensitivity analysis is emphasised, however, a proper risk analysis should be conducted to evaluate the reliability of the system with respect to the probability of failure. Once the energy requirement of the specific irrigation pumping system has been established, the energy potential of the RE source at the specific location needs to be determined. Various maps and tools are available to assist with the spatial assessment of the feasibility of renewable energy sources. Once this is known, the power output of the RES can be calculated and the size of the RES can be planned. At this point installation costs can be reviewed.

The RES is deemed economically feasible if the LCOE is less than the known tariff currently paid for electricity. The breakeven life cycle cost of the renewable energy source can be determined since it is free from product specific data regarding the investment costs, maintenance and operation. Energy will be generated with an economically feasible investment if the LCC of the investment is less than BLCC.

6 CONCLUSION

In the irrigated agriculture sector, the technical feasibility of a renewable energy system is defined as the ability to design an energy system with existing technologies that will satisfy the electricity demand load EDL necessary to irrigate crops economically. From the available and derived feasibility maps, it can be seen that the application of renewable energy sources including solar, wind and hydro can be technically feasible in the irrigated agriculture sector. However, each application is site specific.

The techno-economic viability of PV systems and subsequently all alternative RE systems is influenced by numerous factors such as: the available space and design of the system, installation costs, operational and maintenance costs, financing options, electricity usage profile of the site, the generation profile of the plant, how often the system will be offline and the applicable electricity tariffs.

The current cost of electricity in $R.kWh^{-1}$ is important to determine the breakeven levelized cost of the investment in the RE system. This is to establish if the energy cost for the alternative renewable energy system is equal to the energy cost of the currently installed system. The breakeven approach was followed to steer away from detail. The economic feasibility of the system could be enhanced if the excess energy generated can be sold, stored or consumed. Once energy is stored, it can be applied during times of limited availability.

Technological progression increases the viability of using RE as energy source for irrigation. The South African irrigated agriculture sector will benefit most from innovations with respect to PV systems and localised hydro energy schemes. Hydro power is definitely an option as renewable energy if there is a drop in elevation and security of water supply. The adoption of RE solely for irrigation purpose on a commercial scale is, however, still relatively low which raises the question whether potential users of RE are aware of recent technological developments and legislation.

Legislation is changing to allow RE users with small generating capacity to be grid-tied. These systems might help overcome the seasonality of peak electricity demand since they allow for banking and offset of electricity usage. Managing grid-tied systems economically is a function of the size of the RE generating plant in relation to the electricity demand as well as the specific regulations governing the banking and offset of electricity with ESKOM. This option purely serves as an energy security option to store energy and does not entail selling electricity to ESKOM.

No specific incentive scheme, other than the normal investment tax deduction, exists to incentivise irrigators to adopt RE. There is need for the government to play a more active role in the adoption of RE sources.

For solar energy systems for example, the ideal is to pump water during daytime if the potential for elevated storage exists, such as a mountain or a hill. If water is available from either a stream or a borehole, it can be pumped for seven to eight hours to the elevated storage to have enough water for a 24-hour irrigation cycle. Alternatively, smaller centre pivots can be installed to irrigate directly for eight hours a day. This is a more cost-effective solution. It becomes expensive when water resources are limited and the need to pump continuously cannot be met due to the unavailability of elevated storage.

The cost of the solar energy systems in irrigated agriculture is largely influenced by the number of hours per day irrigation is required, the size of the dam and the centre pivot. All of this is considered to determine the most cost-effective way to proceed. The suppliers tend to know from experience what region yields what energy; and a certain amount of $kWh.kWp^{-1}$ for a certain type of installation is required. For normal north facing systems, they work with 1 600 $kWh.kWp^{-1}$ in Pretoria, 1 800 $kWh.kWp^{-1}$ in Northern Limpopo and 2 000 $kWh.kWp^{-1}$ in Northern Cape. Solar radiation in RSA isn't that much different from region to region except perhaps in the Western and Eastern Cape where there are more overcast days. Solar radiation isn't really a cost driver. There are other factors that are substantially more significant if a sensitivity analysis is undertaken.

A bigger impact on costing, is the size of battery and size of the pump. Not so much the size of the solar system and region. If solar tracking systems are installed, it can give up to two hours more pumping hours per day. Costs are pushed up substantially with these systems, however the smaller size of the system, allows the application to become cost effective. Soiling, dirt on panels and maintenance are more important factors to consider than solar radiation. The production curve of a solar system is more important than the amount of energy the system yields. When water is pumped with solar energy, it is good practice to design the system larger than is required. A system design can be up to 2,5 times more than the pump/motor size. The cost of the production of water ($R.m^{-3}$) is an alternative method to determine if the installation of a solar system on a specific surface area will be viable.

It can be concluded that RE is feasible everywhere in RSA, however, it depends on the point of reference and legislation. Electricity Regulation Act (Act No. 4 of 2006) exempts the requirement for a generation licence when installing a renewable energy system if the installed capacity is less than 1 MW and permission has been received from the relevant network owner (municipality or ESKOM).

To decide between off-grid or grid-tied systems mainly depends on the capacity of the plant as well as the energy provider in the area. One of the major factors influencing the viability of solar irrigation systems is if a system can attain up to 10 hours and more effective irrigation during summer. The growth and demand of crops influence the payback period of the project. The investment in solar panels is a viable means of renewable energy generation. It is important however to consider the implementation of a hybrid renewable energy system to go completely off-grid as an investment in battery banks to meet a full off-grid capacity, required to run a farm, is usually not financially feasible.

Renewable energy pumping systems, especially photovoltaic systems, are well developed. The operations and maintenance cost of these systems are very low. On the contrary, the investment costs may be significant. The general framework presented to evaluate the techno-economic feasibility of RES emphasises a preliminary feasibility study. Careful consideration should be given to this phase of evaluating a RES. The importance of conducting a sensitivity analysis is emphasized, however, a proper risk analysis should be conducted to evaluate the reliability of the system with respect to the probability of failure.

The RES is deemed economically feasible if the LCOE is less than the known tariff currently paid for electricity. The breakeven life cycle cost of the renewable energy source can be determined since it is free from product specific data regarding the investment costs, maintenance and operation. Energy will be generated with an economically feasible investment if the LCC of the investment is less than BLCC. The electricity tariff used in the breakeven analysis is highly dependent on the management factors. Ruraflex, for example, allows their users to change the average tariff that they pay for electricity based on their energy consumption patterns.

There are many possibilities for renewable energy for irrigation. It was found that these resources are feasible, but there is still scope to improve management with reference to size of alternative energy plants. Not all the detail regarding the feasibility of alternative renewable energy sources in the irrigated agricultural sector is known since these applications are site specific. The idea of how to harness the energy from these resources (solar, wind and water) has been outlined. It is not always possible to use all the energy that is generated and therefore it can be recommend looking into energy storage options such as batteries and elevated storage.

From the available and derived feasibility maps, it can be seen that the application of renewable energy sources including solar, wind and hydro can be technically feasible in the irrigated agriculture sector. However, each application is site specific. This finding forms part of the new knowledge created by this project. The gaps filled or addressed by the new knowledge include the uncertainty and the lack of knowledge that used to exist about the feasibility of alternative renewable energy sources for irrigation.

New products produced from this research include:

- Scoping report summarising existing information and tools to determine feasibility of small-scale renewable energy application
- Map and list with currently installed renewable energy systems related to irrigation
- General framework to determine feasibility of renewable energy in irrigated agriculture
- Database with suppliers and technologies
- Solar feasibility maps for South Africa.

The scoping report gives a good summary of the different renewable energy systems and technologies, its potential and application related to irrigation. Some maps in terms of the availability of renewable resources already exist for utility level application. The innovation of the products lies in their applicability to small scale systems and irrigation.

The users and beneficiaries of the products and outputs from this study include suppliers, irrigation designers and farmers. Many users are not aware of the information sources available for assessing the feasibility of RES for irrigation. The number of currently implemented RES is small compared to the potential for RES in irrigated agriculture.

Solar energy is probably the one alternative energy option that can be utilised most in South Africa. In KwaZulu-Natal and the Eastern Cape the solar radiation might be lower resulting in the solar investment having to be bigger. The risk of overcasting and thunderstorms are part of the detail. Grid-tied systems might be a better option in these regions. These questions need another framework to be analysed. It is worthwhile to go into more detail and there is potential to use solar energy to generate electricity, but a cost-effective design should be developed to provide the amount of water required.

7 RECOMMENDATIONS FOR FUTURE RESEARCH

The recent bout of load shedding which coincides with the planting season has served as an uncomfortable reminder of how vulnerable the irrigated agricultural sector is in terms of a reliable source of energy and will definitely create renewed interest in the use of alternative sources. This emphasizes the importance and timing of this WRC study and acts as motivation for developing practical tools for the industry.

Sustainable access to energy in future will require adjustments in both supply and demand design approaches. In the case of irrigation, utilising an alternative energy source will not only require new knowledge and skills in the industry on designing, installing and managing "on-farm" electricity generating infrastructure but also adapted approaches to planning and designing the irrigation system in terms of operating hours available per day and strategic placement of water storages.

An integrated approach to RE development is necessary to ensure that interrelation between the size of the system, energy demand and the rules governing banking and offset of electricity with ESKOM results in the most profitable system. A clear need exists for improved decision support with respect to the management and development of grid-tied systems as an energy security option. The development of a decision support system for irrigated agriculture will fill the gap in financial and economic assessment skills farmers may lack in determining risk and viability of RE projects.

Solar energy is probably the one alternative energy option that can be utilised most in South Africa. There is scope for a follow up study where solar is definitely an option as alternative renewable energy for irrigation. The detail factors to be considered need to be identified in such a study and the different system configuration options such as elevated storage, grid-tied, not grid-tied, etc. need to be considered. All the intricacies and detailed analysis in terms of what the feasible alternatives are, should be evaluated. There is potential for developing a framework for evaluating different type of systems in more detail and develop a calculation procedure or model that will assist users to undertake a detail analysis in terms of feasibility.

The WRC should consider financing a new project perhaps in collaboration with local suppliers of alternative renewable energy sources to develop a framework for evaluating different type of systems in more detail and develop a calculation procedure or model that will assist users to take the detail into account.

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APPENDIX A – DATABASE WITH SUPPLIERS AND TECHNOLOGIES

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Sonvrucht & Carg-trust Kakamas Dr. Tokka van den Hever 054 431 0302	Kakamas (NC)	80% table grapes; 20% raisins	Solar grid-tie	Y	There are two MV-systems (500 kVa and 340 kVa) installed on this user's farms. An LV-systems is also being considered since it is easier to get permission to install these systems. Water is abstracted from the Orange River to irrigate table grapes (80%) and raisins (20%). Pumps and cold storage use the most electricity between May and September. The farm does not use a lot of electricity in the winter while ESKOM does. ESKOM will therefore take electricity from the farm's "reserve" during the winter and the contrary will realise during the summer. The total installation cost on both farms was R19,2 million. The internal connection of power lines with transformers cost an additional R1,265 million. With the tax benefit, the system can be paid off within six years. The system at Chargo-Trust (500 kWp) generates 254 134 kWh in 80 days of which 97 084 kWh is used by the farm and 157 050 kWh goes to the ESKOM grid. This farm has already saved R205 214 (2020 rates) with R27 088 worth of electricity banked that should be utilised before April. The system at Sonvrucht (340 kWp) generates 171 010 kWh of which 78 153 kWh is used by the farm and 92 857 kWh goes to the Eskom grid which equates to R125 604 saving and R31 424 worth of electricity "banked". Other savings achieved by these farms include the cancellation of many existing ESKOM transformers eventually to only make use of one. The user, Dr. Van den Hever, said that big capital expenditure was worth it (Du Preez, 2020).
Supplier	Sonfin - 'http://sonfin.co.za/ Chris Schutte: 072 102 6979 IG Du Plessis: 083 675 3034 info@sonfin.co.za ig@sonfin.co.za	Pretoria (GAU)	n/a	Solar PV grid-tie, interactive & off-grid	Y	Cater for 300 - 999 kW. 2 Prieska & 3 in Augrabies; Swartwater & Thabaz (1 x 240 Kw, 1 x 1 MW, 3 x 500 kW) mainly < 350 kW Not many installations in the irrigation sector. A few in agriculture for cold rooms. Solar systems are less involved; not lot of maintenance required. Too many moving part in wind systems. High maintenance. Not really water in SA for hydro.
Supplier	Alex Solar - Terry Moss/ Sarel Botha https://www.allpowersolar.co.za/ 046 654 0109 083 947 1260 041 451 3936 hhelec@vodamail.co.za info@allpower.co.za solar@allpower.co.za	Port Elizabeth (EC)	n/a	All	Y	In the event that no ESKOM power is available , or the strong prospect of power failing or disappearing for good , alternative energy is always a viable option, as fossil fuels cannot compete. In the event of Eskom being available for farming and agriculture – and it would be desired to reduce the power bills , this pay back will vary from 3.5 years to 7 years , depending on scale and type of usage and annual rate increments. We have a number of standalone systems , all of which are evidence of viability , however only viable if these can obtain up to 10 hours and more effective irrigation during summer. To achieve this , it's necessary to have the technology , something we have developed over the past 30 years. Type of RE systems include: High volume solar water pumps (no batteries, three-phase). Solar powered irrigation systems of any nature. (No batteries, three-phase). Center Pivot irrigation systems directly of the sun. (No batteries, three-phase).
		Kimberley (NC)	n/a		Y	30 ha centre pivot
		Baltimore (LIM)	n/a	Solar PV off-grid	Y	15 hectare pivot and has had numerous crops – that has 11 boreholes – reservoir – booster pump and 15 hectare pivot- standalone (no ESKOM)
		East London (EC)	n/a	Solar PV grid-tied	N	we have a 400 kW system , recently completed – and I believe it will have a 4 year full payback , less when the tax incentives are taken into account – connected to ESKOM
		Humansdorp (EC)	n/a		N	260 kW—connected to ESKOM
		Cradock (EC)	n/a	Solar PV grid-tied and off-grid	Y	no ESKOM at all , whilst there are others in Cradock that work in tandem with ESKOM (power saving)
		Balfour (EC)	n/a	Solar PV off-grid	N	(Katbreg) where I farm, I have a solar system that runs the farm workshops and houses - battery system, whilst I pump water 300 m to top of a mountain with solar directly off the sun (no batteries), the entire farm operates on solar – no power bills whatsoever, as I also hate the site of a power line.
Supplier	Van Heerden Solar Power http://www.vanheerdensolarpower.co.za/ Ludwig van Heerden: 082 574 0005 lvhsolar@gmail.com		n/a	Solar & Wind	Y	Sells 100 W PV panels @ R1 100 + VAT Sells 320 W PV panels @ R2 700 + VAT wind chargers: AN 400 W Land 12 V @ R 9 800 + VAT AN 600 W Land 24 V @ R 12 800 + VAT
Supplier	SAW Africa (Grundfos) https://www.sawafrica.co.za/ Hannes van Niekerk: 083 264 1272 hannes@sawafrica.co.za	KBY, CPT, KZN, GE, JHB	n/a	Solar with Grundfos pumps (mostly off-grid)	Y	Hannes van Niekerk of SAW Africa says that almost 99% of all their installations, or what they have assisted with, are independent (of ESKOM). At many of these installations there are not any ESKOM supply points. He was not allowed to disclose any further information regarding these installations due the restrictions on Intellectual Property. His opinion is that RE is feasible everywhere in RSA. Depending on the growth and demand of crops, the project can potentially be paid off over a shorter term. Each installation is unique and not necessarily based on basic principles. If the potential of solar energy for irrigation is compared to that of wind energy, it is important to note that that wind is a very localised phenomena and not all irrigation regions in RSA have sufficient wind to generate electricity. For example, a region might be classified as a wind still region, yet still have mountain winds.
Supplier	Ultimate Solar https://www.ultimatesolar.co.za/ Darryl Claassen: 083 321 6076 017 773 0098 darryl@ultimatesolar.co.za info@ultimatesolar.co.za	Balfour (MP)	n/a	Solar & water (Prieska)	Y	No feedback.
Senior Engineer	Nelson Mandela University Riaan Opperman: 073 338 6453 Riaan.Opperman@mandela.ac.za	Port Elizabeth (EC)	n/a	Solar & hydro	Y	I know off two hydro systems running for agricultural use here in the Eastern Cape as well as a solar pivot.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
Consultant Pr Eng	MBB Consulting Nelspruit https://www.mbb.co.za/operation-and-maintenance/ Koos Van Rensburg: 083 626 5767 jvr@mbbnel.co.za	Mbombela (MP)	n/a	Hydro	Y	Hydro Power is a Definate option if there is a drop available and water supply secured. Unfortunately SA is a water scarce country with first world regulations difficult to overcome in the past. Energy is the product of flow rate and head. i.e. in simple terms energy of High flow low head = low flow high head. Various infrastructure requirements however. Sites were identified. We have experience in run of river systems since 1987. Not aware of other substantial use of renewable energy in the agricultural sector. The system we are involved in generates about 12 gWh /annum, but it has a drop of 64 meter and fairly stable supply of water in relation to the plant system capacity of 2 MW. MBB is also providing hydropower to Densa sawmill and Badplaas Avontura Resort. There is also a Hydro plant close to Kaap Muiden and one at Riverside Farm using water from the Crocodile River.
Supplier	SPS https://sps.africa/solar-projects/ Axel Scholle: 083 282 3903 axel@sps.africa	Somerset West (WC)	n/a	Solar	N	We are not involved in the irrigated agriculture sector – we do mostly roof top solar systems for shopping malls and some industry, as well as off-grid systems in East Africa and for Island States. I can only imagine that this could be very interesting for the agricultural sector in terms of cost when it comes to long grid electricity lines or even off-grid power supply.
User	Villiera Wine Estate http://www.villiera.com/Page.aspx?PAGEID=2696&CLIENTID=3484 021 865 2002 wine@villiera.com	Stellenbosch (WC)	Grapes Wine	Solar	Y	The wine estate spans a 400 ha property with 180 ha planted vineyards and 200 ha set aside as a wildlife sanctuary. Villiera is well known for their distinctive high quality wines and sparkling wines. They are suppliers to the UK retailer M&S and the South African retailer Woolworths. 70% of their wines are produced for the local market and 30 % for the international market. The average annual output is 1.3 million bottles of wine. The associated electricity consumption for the year 2013 was for example 589 701 kWh. With life spans of about 25 years, solar panels are expected to 'pay for themselves' over the next seven to eight years. 900m² of solar panels & 539 solar modules in total mounted across cellar roofs. This capacity is producing a total of 726 kWh a day - around five hours at 140 kW. Valliera produces 240 000 kwh of solar and saves a further 360 000 kwh through energy efficiencies per year. They rely on ESKOM during night and peak times (harvesting). Electrical energy reduction results in a 600t carbon footprint saving. enerGworx, a Cape Town- MLT Drives supplied the inverters, and two AfriSun70 systems polycrystalline photovoltaic modules were procured from Solaire Technologies.
User	Neil Wheeler: 072 516 3036 neil@wheelergame.co.za	Brits (NW)	Citrus & Peppers	Hydro (ram pump)	Y	Water is constantly pumped from a non-perennial stream in the Magaliesberg mountain to a 75 m3 storage dam at an elevation 45 m higher by use of a ram-pump. This water is used to irrigate 1 200 lemon trees with drip irrigation by means of gravitation at a 60 m lower elevation.
Supplier	Energyneering Jan Esterhuysen: 082 452 3759 jan@energyneering.co.za	Pretoria (GAU)	Potatoes	Solar PV grid-tied	Y	One of the projects that we are busy with include a project between Brits and Thabazimbi: - 4 MW ESKOM connection - 2,6 MW hydro pump storage with 4,9 MW pumps to utilise peak of the PV. - 3 MVA diesel standby - 2 500 ha irrigated - 3,5 MWp PV Phase 1 - Total PV equals 8 MW Another project we are busy with is in the Tugela river: - Pump water from the river over a distance of 5,5 km and over a mountain with at an elevation of 180 m. - Water is stored on top of the mountain. - On the other side, a turbine is used to generate electricity. - 5 000 000 m3 water per year.
User	Becker farms Pieter Becker: 083 602 1413	Tolwe (LIM)	Potatoes	Solar PV grid-tied	Y	The solar energy plant is an Agri PV ground mounted grid tied 3-phase system with 768 x 325 W solar panels giving it a design capacity of 240 kWp that can yield 1 200 kWh/day or 420 000 kWh per annum. The processing of 12 months' historic data was used to size the plant. Nine transformers with 1 MVA total capacity was installed and the system is amalgamated with the existing ESKOM grid using eight step-up step-down CL 25 Optimum Plus Inverters. The installation includes a 5,5 km 3 300 V private medium voltage powerline which has resulted in the elimination of five ESKOM transition points ensuring more economic operation in the long term. Reversed power protection is part of the installation and a smart controller system balances the solar system with the load ensuring optimum output energy from the solar plant to pumps and equipment. A Power factor correction unit is installed on the grid supply side to mitigate kVA fluctuations and line instability.
User	L'Ormarins Gary Baumgarten: 021 874 9052 garyb@rupertwines.com	Franschhoek (WC)	Grapes	Hydro	N	No irrigation from this system.
Supplier	I & F Engineering https://ifengineering.co.za/projects/ Ian de Jager: 082 577 0677 ian@ifengineering.co.za	Botrivier (WC)			Y	To decide between off grid or connected to the grid mainly depends on the capacity of the plant as well as the energy provider in the area. Energy cost, availability and service of the provider can sometimes be the main problem. If you generate off grid you must be able to supply the maximum demand when needed and the water and head availability will determine if this could be met. Further is it a financial decision to store energy in the grid or not. The best site for a connected to grid is the L'Ormarins hydro near Franschhoek and the best off grid is at Klipfontein near Cookhouse if you would like to visit.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Marlenique Estate https://www.newsouthernenergy.com/ Mike Pritchard: 021 276 2290 mike@newsouthernenergy.com	Western Cape	Apples, pears, citrus & peaches	Solar PV grid-tied	Y	The site produces fruit for the commercial market and is heavily reliant on a consistent supply of energy to power pumps for irrigation and cold room storage units. Solar PV was a financially attractive, reliable solution which best met the client's needs. Being a farm, this is a large site with multiple utility connection points existing . Apart from providing a consistent energy supply, the focus was to reduce the amount of utility connections to a single point into which the solar tied in to. Thereafter power is distributed to various points across the site via a microgrid which was installed in conjunction with energy generation component. A backup generator was also installed.Nedbank Agriculture financed system.
User	Gerrie Scholtz (SP) Genade Boerdery - Hannes Bruwer	Northern Cape		Solar PV	Y	
User	Michael Vermaak (contact Ian de Jager)	Cradock		Hydro off-grid	Y	Ossberger hydro-electric plant of 280 kW off-grid using reserve flow of river. Private electrical network suplying pump stations and workshop. Dam is used as storage to gravity feed centre pivot irrigation.
SWITCH AFRICA GREEN SANEDI REEED RESEARCH REPORT						
Supplier	Biogas Consulting SA http://www.biogassa.co.za/ Mark Tiepelt: 072 445 4739 mark@biogassa.co.za	-	n/a	Biogas	Y/N	There are a number of biogas plants established in the agricultural sector generating electricity – I am however not sure if the electricity is utilised specifically used for irrigation purposes. It is however a practical option to do so. **<u>BiogasSA</u>** offers two anaerobic digestion technology solutions targeted at the farming sector, i.e., the large Biobag and the Floating Digester. customised **<u>Biobags</u>** of up to 50m² in size, costing around R14 000 to R42 000 per kit, with an estimated payback period of between two and three years, if the technology is self-installed by the farmer. The Biobag Kit comes complete with the actual PVC digester, gas pipes and fittings, in-line gas pressure pump, desulfuriser, safety valve, moisture trap and complete installation and operation manual. It is important to note that there are no generic solutions for these biobags as well as other digester solutions since there are too many variables to consider before installations, e.g., type of feedstock, quantity, temperature, mixing, heating, geographical location, etc. <u>As</u> a rough estimate, a 50m3 biobag digester could potentially produce 25m3 of biogas from the daily manure production from: • 200 grown pigs • 35 cattle • 3500 chickens • 700kg vegetable waste <u>Also</u>, as a rough estimate for indication purposes, 1m3 of biogas could provide the following energy support: • One-hour cooking time on a 2-plate biogas stove • 20min hot water from a 6l/min biogas geyser • 15 hours lighting on single biogas light • 1.5kWh of electricity by running a biogas generator
						Floating Plug Flow Digester This medium sized anaerobic digestion solution is currently being developed. It is built from either concrete or brick & mortar, covered by a 'floating' type gas dome. It is designed to allow for selfinstallation by the farmer in order keep the costs as low as possible. The main digester is a rectangular construction with an inlet and outlet manhole very similar to those of the above mentioned Biobag installation, just on a much larger scale. The edge of the dome is anchored in a water channel that runs around the structure, which also serves as gas trap. <u>Feasibility/Challenges</u> • The solution is feasible for abattoirs in particular as waste management regulations for landfill waste is becoming stricter • Biogas SA states they struggle with financial assistance for biogas plants • No generic solution for biogas as there are a lot of variables which determine the amount of biogas produced <u>Financial</u> A biogas plant becomes financially viable after a 350kWe plant upward, in addition the cost of setting up a biogas plant is expensive due to the electricity tariffs, operating costs and capital costs (Biogas SA , 2016). Benefits • Biogas can be used as a fuel to run generators (Biogas SA , 2016) • Floating Digeste and Biobags can be installed and constructed by a farmer themselves, thus lowering the cost <u>Payback Period</u> <u>According to Biogas SA , (2016), the payback period for a biogas plant is 5-8 years. The payback period for a large Biobag is 2-3 years.</u>
						Plant cost is normally divided into 3 components: the digester itself, the biogas generator and the balance made up of civil, mechanical and electrical installations. Based on the current factors such as capital cost of the plant, operating costs, electricity tariffs (Eskom and municipal), biogas plants in South Africa only starts showing financial viability from a 350kWe plant upwards. This means that most farming operations in SA would not be able to establish a financially viable biogas project. BiogasSA is actively developing a biogas solution specific for the farmer which is practical and cost effective, allowing the farmer to participate in the actual construction of the plant, thus reducing costs considerably. BiogasSA is also developing a locally produced dual fuel generator that can run on diesel and biogas, thus eliminating the need to buy and operate 2 separate generators.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	SASA/ Farmer along Northern Coast https://sasa.org.za/ 031 508 7000 info@sasa.org.za	KZN	Cane	Biogas	Y/N	SASA encourages farmers to invest in biogas plants and utilise cane leaves to create methane gas that can be used to run tractors. Feasibility/Challenges • SASA assists members looking to save energy by potentially implementing renewable energy and energy efficiency projects. • Changing the behaviour and mindsets of farmers from conventional agricultural views to transitioning to sustainable agriculture is a challenge for SASA. • Sourcing of funding is another constraint farmers experience with implementing these projects and cash flow. • The impact of the drought has created resistance from farmers, it will take 5 years for farmers to get past the negative financial impact the drought has had on their supply, their primary focus is on supply at the moment. Financial Implications According to SASA, the majority of the farmers are not aware of financial incentives and how to access it. SASA is only aware of one funding opportunity, which was offered by Dragons Den. Benefits • Reduces the carbon footprint of cane growers by preventing the release of GHG emissions, promotion of methane gas for fuel and electricity is a much cleaner alternative • SASA is focused on helping farmers save costs through sustainable farming practices • SASA assists in the implementation of projects and helps minimize the costs of implementation Payback Period SASA can assist in working out the payback period for farmers.
User	Rustica Olive farm https://derustica.co.za/farm/ 044 241 2177 info@derustica.co.za	Oudtshoorn	Olives	Solar PV for cooling	Y	De Rustica Farm has invested in Solar PV panels to meet the electricity demand required for the cooling of their olive storage rooms and provide electricity for their irrigation pumps. In addition, De Rustica Farm is looking at installing VSD's on their irrigation pumps to save electricity. The Solar PV panels host a capacity of 20kwh. Feasibility/Challenges The Solar PV panels meets peak demands through summer. De Rustica's total monthly electricity bill is R60,000-R70,000, using Solar PV to generate energy provides a minor monthly saving of R3,000 per a month thus the need to implement additional energy efficient practices in conjunction with Solar to reduce their monthly electricity bill further. Hence, De Rustica's potential installation of VSD's. Financial Implications The Solar PV panels costed R450,000 and were installed by contactors in the area. De Rustica Farm paid for this themselves, and did not look to banks or financial incentives for funding. Benefits • Installing Solar PV panels on the farm has generated savings of R3,000 a month on their electricity bills • The Solar PV panels meet the peak demand times in summer Payback Period The payback period is 4-5 years as stated by De Rustica farm.
User	Rooibos Ltd https://rooibosltd.co.za/ 027 482 2155 027 482 8100 info@rooibosltd.co.za	Clanwilliam	Rooibos Tea Farm	Solar PV	N	Rooibos Ltd. has installed 2088 solar 245W modules on the roof of their storage facilities to generate 875 000 kWh of energy per a year and supplies 40% of the electricity needs (Colthorpe, 2013). Feasibility/Challenges One of the requirements for Rooibos to supply the USA and the EU is that they reduce their GHG emissions to mitigate the effects of climate change (Colthorpe, 2013). Implementation of rooftop Solar PV system has an expected reduction of 840.5 tonnes in their carbon dioxide emissions (Colthorpe, 2013). Financial Implications Cost of the investment was not provided. Benefits • Lowers Rooibos's carbon footprint and improves their image as a low-carbon footprint supplier • SolarWorld guarantees system performance for 25 years, mitigating maintenance and repair costs associated with poorly installed panels • Reduces exposure to rising Eskom electricity tariffs Payback Period The payback period was not identified.
User	Klipopmekaar Rooibos Farm http://www.klipopmekaar.co.za/ Paul Schlechter: 027 470 0070 paul@klipopmekaar.co.za	Cederberge	Rooibos Tea Farm	Solar thermal water heaters and Solar PV for irrigation	Y	High input costs in crop production are a result of extensive crop irrigation required in the sector (Sunworx 2016). Klipopmekaar Farm has invested in Solar PV panels to power their 3kwh water pump. (solar thermal for houses). Feasibility/Challenges Solar has been a feasible solution for Klipopmekaar Farm, as a result they are considering investing in additional Solar PV panels so they can feed electricity into the grid. However, this will only be done once Eskom provides a rebate for them to do so. Financial Implications Klipopmekaar Farm funded the panels themselves, they did receive non-financial assistance with the project from the Green Alliance. Benefits Savings on their electricity bill was the biggest benefit Klipopmekaar Farm indicated Payback Period The payback period is 3-4 years.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Murludi Farm www.murludi.co.za Kobus van der Westhuizen: 023 230 0732 murludi@mb-net.co.za	Witzenberg/Tulbagh (WC)	Fruit	Hydro-electric turbines	Y	At the end of 2013, he decided to install a hydro-electric turbines consisting of 4 units as a solution to his problems (power failures). <u>Feasibility/Challenges</u> Kobus 's Murludi farm is located below the springs in the Witzenberg mountain range. Using water from the spring to generate electricity was feasible for alternative energy production. Furthermore, it also promotes minimum water waste as the excess water after going through the hydro-electric turbine is then returned back into the spring. <u>Financial Implications</u> An additional investment was required to mitigate the risk of electricity fluctuations caused by variations in the water flow supply. Battery banks were purchased by Kobus to prevent machinery getting damaged, it prevents the costly replacement and repairing of equipment (Kriel, 2015). <u>Benefits</u> • Kobus saved over 50% on his electricity bills during the fruit season, this is because his operations are heavily reliant on electricity, particularly the cooling and drying systems which uses 80% of the total electricity usage for the cooling and drying of fruit crops (Kriel, 2015) • The turbines can meet the demand of up to 124kWh during fruit season and the unit can deliver 29kWh in total • Kobus also managed to reduce his Eskom electricity consumption by 22 000kWh in 2015 (Kriel, 2015) • Savings maintenance of his equipment are benefits he has gained • In 2013, Kobus's electricity bill was R360,00 because of power outages; when he installed the hydroelectric turbines his electricity bill reduced by half in 2014 (Kriel, 2015). <u>Payback Period</u> The payback period is indicated to be 5 years; this will come from energy savings and savings on maintenance and repair costs (Kriel, 2015)
User	Suptrop https://www.subtrop.co.za/contact-us/ 015 307 3676	Tzaneen (LIM)	Fruit		Y/N	Subtrop promotes sustainable agricultural practices and renewable energy practices amongst its members. They promote organic farming, cover cropping, biological/ eco-friendly pesticides, compost tea fertilisation, mulching, solar power generation, Eskom energy saving initiatives for the agricultural sector and macadamia husks for heat-drying in processing plants. Subtrop discusses the benefits of transitioning to renewable energy and energy efficiency solutions through study groups and farmer days which target their members and they enlist energy experts to explain the benefits and the technology. Avocado and macadamia growers have implemented macadamia husk heat generation and solar power for electricity generation in avocado pack houses. <u>Feasibility/Challenges</u> • Associations have limited awareness of incentives available • One of the challenges faced by members has been identified as lack of knowledge of funding or incentive programmes • Associations experience difficulties persuading growers of the benefits of transiting to sustainable agriculture Financial Implications Information on the financial implications involved was not provided by Subtrop; however, Subtrop did acknowledge sourcing funding for renewable energy and energy efficiency projects was difficult for the members. <u>Benefits</u> • Better pest control • Irrigation water savings • Better soil health • Cost savings and avoidance of being impacted by load shedding and electricity tariff hikes • Reduction in cable theft
User	Harvest Fresh George: 016 590 1236 george@harvestfresh.co.za	Meyerton	Vegetables	Solar	N	Cannot rely on ESKOM. <u>Feasibility/challenges</u> An energy audit will possibly be conducted to determine energy savings and identify whether Solar would provide adequate electricity generation for the farm. <u>Financial Implications tbc</u> <u>Benefits</u> Harvestfresh expressed the following potential benefits that led to the potential implementation of Solar PV technology on their farm: • Harvestfresh is a part of Woolworths Holding Limited. Woolworth's promotes the Farming for the Future approach, which is centred around growing food sustainably (reference) • Renewable energy will reduce their carbon footprint • Harvestfresh's reliance on Eskom will decrease • Mitigation of price hike sensitivity
Supplier	Soventix https://www.soventix.co.za/ 021 852 7333 info@soventix.co.za	Somerset West (WC)	n/a	Solar PV	Y	Installations for: Oldenburg Vineyards - Ground mounted solar plant of 44,65 kWp on wine farm with Soventix 235W modules and SMA STP 17000TL inverter. Completed May 2013 generating 71,837 kWh p.a. and saving 71 tons p.a. CO^2. Lifetime benifit of R 4.2 Million. Cavalli Wine & Stud - Roof mounted solar plant of 51 kWp on wine farm with Jinko Solar JKM250P-60 modules and SMA STP 17000TL inverter. Completed Dec 2013 generating 75,454 kWh p.a. and saving 74,7 tons p.a. CO^2.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Oldenburg Vineyards http://oldenburgvineyards.com/ 087 057 4515 homestead@oldenburgvineyards.com	Stellenbosch	Grapes Wine	Solar PV grid-tied	Y	Oldenburg Vineyards use Solar PV panels to generate energy in which they use for lighting, offices, wine tasting centre, guesthouses and irrigation pumps. In addition, they feed electricity generated into the grid. They have 119 panels in which they have invested in. They are looking at investing in more Solar PV panels for their new wine vineyard, which will be covered in Solar PV panels. <u>Feasibility/Challenges</u> • One of the challenges expressed was theft of the panels, preventable measures had to be taken to ensure panels do not get stolen • The Solar PV panels are still linked to the grid so when Eskom is offline it still creates challenges • Oldenburg Vineyards have not invested in batteries as they are too expensive at this stage, they cannot store electricity generated from the panels due to this <u>Financial Implications</u> Eskom was supposed to provide a rebate for the installation of the Solar panels; however, Oldenburg Vineyards have been waiting 4 years for this and still have not received any form of rebate. <u>Benefits</u> • They generate 73,948 kwh from the unit, Eskom power can generate 95,000 kwh • Eskom electricity costed R173, oo0 per an annum, with Solar panels they are now saving on that cost • During midday, the Solar panels can accommodate 85% of the electricity demand <u>Payback Period</u> The payback period is unknown at this stage.
User	Cavalli Wine & Stud 021 855 3218 info@cavalliestate.com	Somerset West (WC)	Grapes Wine	Solar PV	Unverified	
User	Greenway Farms Vincent Sequeira 082 554 9662 vincent@greenwayfarm.co.za	Tarlton	Carrots	Bio digester	N	Greenway Farms is focused on sustainable agriculture and nature conservation; they apply sustainable practices in their carrot production. They have a biogas plant on their farm, they feed carrot pulp waste into their bio-digester and use the methane gas to fuel their boilers in their carrot juice factory. They are considering implementing a second bio-digester to cogenerate. <u>Feasibility/Challenges</u> The biggest challenge Greenway Farms faced was the regulatory requirements that came with implementing a methane plant. Before setting up the bio-digester, an economic impact assessment had to be conducted, engineering certificates produced and government laws adhered to. Greenway Farms say that their experience in implementing a methane gas plant was difficult because the government offered little support, instead over regulated requirements and restrictions made the process timeous and costly. <u>Financial Implications</u> Greenway Farms also experienced difficulties with funding, the financial proposal was completed by the Industrial Development Corporation (IDC). They applied for loans but opted out of this route and the security perquisites were higher than what most other loans asked for. In addition, there were a lot of additional audit requirements and costs involved. <u>Benefits</u> The initial start-up costs of a bio-digester are expensive; however, the long-term benefits are electricity savings. <u>Payback Period</u> The payback period is indicated by Greenway Farms to be between 8-10 years
User	Southern Farms Louis Hannekom COO 054 453 3006/7 info@southernfarms.co.za	Northern Cape	Grape Table	Solar PV	Unverified	Southern Farms are grape producers looking at implementing Solar PV panels. At this stage, the project is still in the planning stage and they're conducting energy audits to determine feasibility, energy usage and potential savings. They are looking to use solar power for electricity generation to run irrigation operations, pack houses, pumps and labour houses. <u>Feasibility/Challenges</u> Southern Farms see Solar PV panels to be a feasible solution over other renewable energy means given their location in the Northern Cape and the high sun density. However, one challenge identified that Solar would provide a solution for electricity costs but would not provide a solution for fuel. <u>Financial Implications</u> Funding sources and financial implications will be looked at after the energy audit is completed; however, they will look into incentives as possible means for funding. <u>Benefits</u> • Reduces their carbon footprint • Savings on their electricity bill • Greener image <u>Payback Period</u> No payback period has been identified as yet.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Ceres Fruit Growers http://www.cfg.co.za/sustainability/ 023 316 9400 growers@cfg.co.za	Ceres (WC)	Fruit	Solar for cooling	N	Ceres Fruit Growers boasts one of the largest agricultural rooftop Solar PV system within South Africa. The large fruit producer invested in 4,060 SW250 polycrystalline panels (Colthorpe, 2013). The area of Ceres Fruit Growers is 54 hectares which has 100 cold storage units. Feasibility/Challenges No challenges were identified in the article. The implementation of the Solar PV is helping many farms reduce their carbon footprint before the Carbon Tax Bill comes into effect. Financial Implications The financial implications were not indicated. Benefits • The Solar technology contributes to 6% of Ceres's annual electricity consumption (Colthorpe, 2013) • Reduces the impact of rising electricity tariffs • Reduces the carbon footprint of Ceres by over 1,622 tonnes each year for the next 25 years (Colthorpe, 2013) Payback Period No payback period was identified in the article.
User	SAMGA https://www.angoras.co.za/ Sanmarie Vermaak: 079 236 7823 samga@angoras.co.za	Jansenville (NC)	Angora Goats	Solar for pumping	Y/N	SAMGA promotes the use of solar technology amongst its members because as they believe it is a viable source of alternative electricity generation, in addition they promote other sustainable agricultural practices such as zero waste. On-farm assessments are provided to educate their members on solar technology and encourage them to use it. Feasibility/Challenges • SAMGA is not aware of incentives or financial assistance available for their members • A challenge identified by Mohair was theft of equipment • About 50% of members in the association have invested in renewable energy and energy efficiency solutions • Angora goat farmers are said to be very conservative farmers making it difficult to change their view on conventional farming practices Financial Implications No specific information is given on the cost; however, it is expressed by the association that the cost of solar technology is relatively low with a reasonable payback period. Benefits • Solar electricity generation is an alternative to avoid reliance on the grid • SAMGA sees solar power as a more cost effective option • SAMGA states solar is easy to install • Reduces the dependency on labour Payback Period SAMGA identifies the payback period for investing in solar to be 3-5 years; that is why it is promoted amongst their members because the payback time frame works.
User/Supplier	Humpheries Piggery / Cape Advanced Engineering Andre Taylor: 082 775 1001 andrewtaylor@cae.co.za	Roodeplaat Pta	Pig farm	Solar for heating and irrigation	Y	Solar panels are used for electricity generation, heating and on irrigation pumps on Humpheries Boerdery Piggery farm. Feasibility/Challenges Piggery farms require heating at night, particularly in winter. With the amount of batteries that Humpheries Boerdery Piggery farm, have their capacity only allows for storage of electricity for up to 2-3 hours at night, which they use for heating on their breeding site. When load shedding occurs, it is just as expensive because it takes a lot of electricity to charge the batteries. Solar power is feasible for use during the day, if there are large amounts of electricity required throughout the night it maybe not be suitable if the storage capacity of the batteries is limited. Financial Implications Investment in batteries is required to store electricity. To run electricity throughout the whole night and solely rely on solar for electricity generation it would require a lot of batteries; therefore, for it would be expensive and charging the batteries would increase electricity bills. Benefits • Capacity of electricity in the evenings is 60-70kWh at night • Solar PV panels are used to generate electricity for multiple uses on the piggery farm The payback period was not indicated.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Humpheries Piggery	Roodeplaat Pta	Pig farm	Bio digester	N	Humpheries Boerdery Piggery had a bio-digester in which they fed pig manure, washed water and solids and used the methane gas as fuel for the generator. This has been stopped due to the methane gas affecting the generator's engine. After the waste has been put into the digester, the water is reused on the farm. They are currently looking at investing in a bio-digester again to use the gas emitted for fuel and electricity again; however, they have acknowledged it will take time as an impact assessment will first need to be conducted so the digester is successful this time. Feasibility/Challenges Before Humpheries Boerdery Piggery makes use of a bio-digester to generate energy again, they have indicated that they need to ensure the correct process is followed so the methane gas does not affect the engine. Financial Implications The financial implications for installing a bio-digester was not indicated. Although when speaking to Humpheries Boerdery Piggery incentives were discussed; however, there were concerns raised as to whether or not funding would be provided for the full cost. Benefits The generator ran on methane gas from the bio-digester and was able to generate 60kwh in the day and 20kwh at night. The overall capacity was 70kwh The payback period was not shared.
User	Camphill Village farm https://www.camphill.org.za/ Katriena Ntlayi: 021 571 8600 info@camphill.org.za	West Coast	Vegetable and dairy	PV thin film for heating and machinery	N	Camphill Village Farm has been using solar technology for the past 2 years to run their operations, although they still rely on Eskom the idea is to go completely off grid. They use solar power for their pasteurizers, heating of water, milking machines and pumping of water. Initially the solar plant was a 20kwh plant it now has a capacity of 60kwh. Phase 2 of the Solar PV plant allowed for the dairy operations to be completely offgrid through the use of 732 PV modules was installed when the project started. Feasibility/Challenges Using a new thin film technology allows for the production of energy to be steady even during overcast days. The overall long-term goal of Camphill Village is to be completely off-grid, in the interim dependency on Eskom still remains a challenge. An energy audit was conducted for the project to determine feasibility and savings. Financial Implications Camphill Village Farm did receive funding for the solar project implementation, they do not want to disclose the beneficiary. Although, their website does indicate that phase one of the project was supported by German based Rays of Hope Foundation who sourced funding for components and technology from BAE, Dehn, First Solar, Hanel Projects, Lahmeyer International, Leschaco, Q3, Schletter, Sieckmann Engineering, SMA Solar Technology, Solardura, Southern Sun Solar and UFE (Camphill Village West Cost, 2015). Benefits • In summer they save R14,000 a month as a result for solar electricity generation • R8,000 a month is saved in winter as a result for solar electricity generation • Over the next 20 years the anticipated savings on electricity costs are R1.44 million (Camphill Village West Cost, 2015) • Reduction in Camphill Village Farm's carbon footprint • Capacity to produce 28 000 litres of dairy products from the Solar PV plant Payback Period The anticipated payback period is 5 years for the implementation of the Solar PV panels.
User	Red Barn Free Range Chickens George: 044 876 0014 info@redbarn.co.za		Poultry	Solar for borehole pumps and LED lights	N	Red Barn Free Range Chickens installed 32 Solar PV panels on the roof of their processing area as a result of the pressure faced from electricity price hikes. The Solar PV panels provide electricity to run all of the fridges and provide electricity for the borehole pumps. In addition, they have invested in LED lighting throughout the whole farm. There are plans to install additional Solar PV panels to provide electricity for the additional pumps and geysers on the farm. Feasibility/Challenges One of the challenges faced by Red Barn Free Range Chickens was finding an experienced Solar PV installer in George who could install a 3 phase system. Financial Implications Red Barn Free Range Chickens paid for the solar panels themselves and were not aware of incentives offered. For future installation of additional panels, they are eager to look at incentives that are available. Benefits • Investing in a battery bank enables Red Barn Free Range Chickens to consume electricity from the panels in peak and off peak times throughout the day and night • Long-term savings are 20-25% savings on their electricity bills as they hope to go completely off grid Payback Period = 10 years Red Barn Free Range Chickens sees this project as a long-term project and the payback period is anticipated to be 10 years.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Uilenkraal Farm 022 492 2950	Western Cape (Darling)	Dairy	Anaerobic digestion from cattle manure (bio-digester)	Unverified	Uiklenkraal farm has implemented a bio-digester which use cattle manure as fuel to generate electricity for their farm (Claassen, 2015). Inspired by the European implementation of biogas plants fuelled from cow manure, Uiklenkraal farm sort to a local engineering company in the Western Cape South Africa to design a low-cost rectangular tent-like structure suitable for the specific needs of their farm (Claassen, 2015). The biogas fuels their 2 generators, resulting in a production capacity of 200kWh a day for each generator. Feasibility/Challenges The bio-digester is a feasible long-term solution as the bio-digester has a 30-year lifespan due to its design. A key challenge identified by Uiklenkraal farm, was that there are not many farmers who produced a sufficient amount of biogas and have a large enough electricity demand to justify investing in a biogas plant, a solution in which he believes will motivate biogas is compensation from Eskom to feed electricity into the grid (Claassen, 2015). Uiklenkraal farm produces double the amount of biogas needed daily, as a result the excess biogas is burnt off from a flare stack, in essence is wasted (Claassen, 2015). Another challenge commonly associated with biodigesters are the controlling of variables, parameters and inputs in order to ensure quality and stability. Financial Implications Investment in the plant costed R10 million (Claassen, 2015). Benefits • Potential use of compost from the bio-digester for on farm crops • The farm experienced a 90% reduction in their electricity bill, firstly it decreased from R110,000 to R45,000, it then dropped drastically again to R12,000 as a result of the 2 generators coming into effect (Claassen, 2015) • No moving parts in the bio-digester allows for simplistic maintenance Payback Period = 10 years The payback period is 10 years.
AREP Database						
Supplier	1Son Dylan Reeves: 021 883 8444 dylan@1son.co.za	Die Boord (WC)		Solar PV	Y	
User	Genesis Farm 072 125 1539 admin@genesisfarm.co.za	Raithby (WC)	Organic vegetables	Solar PV grid-tied	Y	1Son was responsible for the project management of a 15.925kWp Grid Tied Solar power installation for Genesis Farm using SMA inverters, Canadian solar modules and a Romano mounting structure. Romano acted as installer & Designer for this project.
Supplier	Perpetual Solar 0861 777 877 jhb@perpetualsolar.co.za	GAU, WC, KZN		Solar PV	Y	Our reputation rests on the quality and durability of the products we use, and we source our solar components from leading international manufacturers for all our installations. Large and small.
User	Estramadura Farm 086 177 7877	Makgodu river, Dendron		Solar PV grid-tied	Y	Estramadura farm, based on the banks of the Makgodu river, final installation consists of Solar-world mono black protect panels, SMA STP25000TL inverters, SMA Monitoring, Solar-world Frame structures, Electrical Reticulation and infrastructure. A grid tied ground mount PV Installation, to assist the farmer with his monthly electrical bill, for centre pivots and numerous 30KW pumps. Total 120 kWp.
Supplier	Solarworld https://www.solarworld.co.za/ 021 421 80 01 service@solarworld.co.za	Cape Town (WC)		Solar PV	Y	Supply variety of solar PV products. Agriculture related clients include Rooibos Ltd., Ceres Koelkamers and Holden Manz Winery.
User		Klawer (WC)			Unverified	40 kWp Max Yield Energy – EPC, Solar MD – installer, ABB inverters Canadian solar modules Valsa Mounting structure
Supplier	Solar MD 021 555 2181 info@solarmd.co.za	Cape Town (WC)				Leaders in energy storage products in Africa
User	Ceres OAST Farm Kobus 023 312 1497 087 820 2305	Ceres	Fruit Farmers	Solar PV grid-tied	Y	On top of roof - not used goes to grid. Municipality. Monitor wat plant uses and what goes back to grid. 100kWp SSEG Ceres, Modules used were BYD 250Wp x 400, Inverters on site: ABB TRIO-20-TL-S2X x 5 Mounting Structure: Valsa (https://directory.areprac.org/pv_installations/south-africa/western-cape/ceres/solar_md/oast-farm-solar/)
User	Blue Jay 021 889 5013 info@tftrust.co.za	Stellenbosch (WC)	Apples	Solar PV	N	A 3 million Rand solar pv project now subsidises 30 per cent of Timberlea's total electrical consumption. Usage is carefully controlled and monitored and methods such as timers in the cold rooms are allowing the farm to achieve a 1KWH reduction per kilogram packed year on year.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Paul Cluver Wines Paul Cluver: 021 844 0605 info@cluver.com	Grabouw (WC)	Wine Grapes	Solar PV	Unverified	Reduce electricity consumption by using solar panels since 2015
PQRS Database < 10 Kw						
Supplier	Southern Sun Solar https://www.southernsunsolar.co.za/ 021 832 0932	Cape Town (WC)	n/a	Solar PV	Y	We installed a 10Kw system at Stellekaya win farm to power the main house on the farm. This system is completely off grid which means that is doesn't rely on Eskom power from the grid at all, it is completely independent.
User	Stellekaya Wine Farm 021 883 3873 066 549 6015 wine@stellekaya.com	Stellenbosch (WC)	Wine Grapes	Solar PV grid-tied	Unverified	
Supplier	Solsquare https://www.solsquare.com/ 061 211675	Windhoek (Namibia)	n/a	Solar PV	Unverified	Grid-tied & off-grid solutions: Khaais farming - 77,92 kWp, 2 x pump drives @ 37 kVa and 250 kVa generator. Includes remote monitoring. Andre Louw Farm - 24,3 kWp, 4 x 5 kVa AC inverters, 2 x 130 A solar chargers, 2 x 8 kVa battery inverters, 43,2 kWh Lion battery storage.
PQRS Database > 10 kW < 100 kW						
User	JC Bosman & Groenfontein & Lelienfontein PD Bosman: 083 632 2754 pd@bosmanadama.co.za	Wellington (WC)		Solar PV grid-tied	Y	88 kWp & 35 kWp
Supplier	Emergent Energy 021 828 4202 011 028 8060	Woodstock (WC) Sandton (GAU)		Solar PV	Y	They have 24 agriculture related installation indicated on a map on their website. Some of them include: Rupert & Rothschild (253kWp), El Rio Boerdery (179kWp), Winterhoek Winery (60kWp), Elgin Orchards (600kWp), De Grendel Winery (210kWp) & Groot Constantia (50kWp).
User	La Motte & Leopard's Leap Isabel Mwale: 021 828 4202 011 254-6400 isabel.mwale@schneider-electric.com info@emergentenergy.co.za	Franschhoek (WC)		Solar PV	Unverified	104 & 54,9 kWp
User	Klein Constantia 021 794 5188 info@kleinconstantia.com	Constantia (WC)		Solar PV	Unverified	Recently we installed a Solar Photovoltaic system on the roof of our winery. The system will generate almost 90 000 kWh a year. EmergentEnergy who ran this project, had this to say about the installment: "With over 220 solar modules delivering 90MWh per year, Klein Constantia have reduced their exposure to rising electricity prices, while investing in a cleaner and more sustainable energy supply."
User	Kleinood 021 880 2527	Stellenbosch (WC)			N	Installed solar panels on the roof of the wine cellar a few years ago to be able to use renewable energies. Irrigates from fountain 3.5 bar
User	Solar irrigation system Montagu			Solar PV	Unverified	Unverified
User	Haakdoringduin	Kalahari-West			Y	The solar pump system consists of three Lorentz type PS21k surface pumps each powered by about 17.5KW-peak solar PV arrays, yielding a nominal performance of up to 115cum/hour at 70m total head. The client is the Kalahari-Wes Users Association and purpose of the solar pump system is to largely replace the current Diesel driven pumps at Haakdoringduin, which supply water to a community of about 83 farmers via 3 main lines. It is envisaged that the operation of the existing diesel pumps will be largely curtailed, acting as a "top-up" in the evenings and acting as standby. This project has been under consideration for more than 2 years and given the improved price/performance ratio of PV technology and the coming to market of reliable larger solar pumps, as well as rapidly increasing diesel costs, it was decided to implement it now. With some further demand side management it should be possible to achieve a payback period of under 6 years. A fourth pump is expected to be added to the system in 2014.
User/Supplier	Stephan van Zyl	Groblershoop (NC)	Grapes	Solar PV	Y	30 kW pump station abstracting from Orange River for irrigation
Supplier	Agri-solar 054 331 0074	Stampriet Namibia	Unknown	Centre Pivot	Y	(1 x7,5kW submersible pump driven by a 11kW solar vsd 3phase drive with 12kW solar panels. 1 x 5,5kW submersible pump with a 7,5 solar vsd 3 phase drive with 10kW solar panels and a 4kVa 3phase offgrid system to drive pivot.)
Supplier	KGE Solar 010 593 8058 info@kgesolar.co.za	Boksburg (GAU)	n/a	Solar PV	Y	KGE Solar specialises in solar photo voltaic energy and solar pump solutions in South Africa; They offer a wide range of solar pump products, experience and after sales service support in the field of submersible solar borehole pumps, solar irrigation systems.
Supplier	Summit Renewables https://summitrenewables.co.za/projects.htm l Tony Visser: 083 293 9048	Centurion (GAU)	n/a	Solar PV	Y	Partnering with DEGER Energie we bring our clients solar tracking systems with the unique, patented "Maximum Light Detection" or MLD technology. The MLD-sensor constantly aligns the connected solar modules to the point that provides the greatest energy and achieves a 42,9% greater yield on average than fixed systems.
User	Disselfontein	Hopetown (NC)	Unknown	Solar PV grid-tied	Y	DISSELFONTEIN Grid tied Solution with Eskom wheeling. The plant was designed to support an irrigation farmer at Disselfontein close to Hopetown. The farmer had a 75kw pump that irrigated via a Pivot on a pre-scheduled program due to insufficient Eskom power. The plant was over-designed with a wheeling agreement with Eskom. The 181kwp plant was built in 6 weeks and is delivering 1,3Mwh and 1.7Mwh per day. The farmer irrigates between 8-11hrs per day with this system.

Supplier/User	Name, number, email	Location	Type of farming	Type of RE system	Irrigation	Comments
User	Suurberg	Suurberg (EC)	Unknown	Solar PV off-grid	N	SUURBERG Off Grid Solution with battery and generator backup. The system consists of 2 x 5000TL sunnyboys, 2 x S60H single axis trackers, 1 x 8.0H Sunny island, 52 x 255 Watt Multicrystalline solar modules, 80KW battery bank, 5Kw backup generator with all the communication products. Yield and performance: 13,6kWp, 106 - 135kWh per day
User	De Bron	De Bron (WC)	Unknown	Solar PV grid-tied	Y	Grid tied solution with net-metering designed to sustain water supply to the pivot station. The system consists of 9 x S100-PF-SR single-axis Deger with MLD trackers with 62 x Canadian Solar 375W modules fitted on each tracker. SMA Core 1 inverters where installed on the AC side. The plant design is around 209kW DC. The average yield calculated for the site is 1504kWh/day.
User	Waschbank	Waschbank (FS)	Unknown	Solar PV grid-tied	Y	WASCHBANK The system is grid tied with net metering designed to sustain pumping operation from the river. The system consists of 9 x S100-PF-SR Deger single-axis with MLD trackers fitted with 62 x Canadian Solar 380W modules per tracker. SMA Core 1 inverters was installed. Yield & Performance: 1 562kWh/day
User	Kroonstad	Kroonstad (FS)	Unknown	Solar PV grid-tied	Y	The system is grid tied with a step up/down, replacing two additional feed-in points. The plant sustains the farm operation. The system consists of 4 x S100-PF-SR Deger single-axis with MLD trackers fitted with 62 x Longi LR6-72PE-370W modules each. SMA Core 1 inverters was installed. Yield & Performance: 660kWh/day
User	Berg River WUA Etienne Weidemann etwowater@gmail.com	Paarl (WC)	Various	n/a	N	We currently do not have projects that focus on the generation of renewable energy. It is a interesting concept but for a Water User Association the market for buyers of electricity is limited and Eskom and the Municipalities, very unreliable partners. The alternative is that the beneficiaries should be the farming community but without the necessary capital expenditure the dream of renewal energy from our water works becomes a pipe dream for now.
Funder	SEFA (Sustainable Energy Fund for Africa) Rahul Bahua r.barua@afdb.org				N	SEFA has to date not funded sustainable energy-irrigation projects in South Africa. However, we did provide a project preparation grant to the solar PV mini-grid developer JUMEME in Tanzania, who has since run a trial of powering irrigation in the villages they have electrified. We have also incubated and funded the Facility for Energy Inclusion Off-Grid Energy Access Fund. This is an investment fund that is independent of SEFA and the AfDB, and which is managed by Lion's Head Global Partners. The FEI OGEF has made three investments to date, one of which was made in SunCulture - a Kenya-based solar irrigation product and services provider. I hope this information is helpful and kindly keep us updated with the final outcome of your work.
Funder	Inspired Evolution Investment Management (Pty) Ltd Omid Alimia: 021 180 4321 omid@inspiredevolution.co.za				N	Regarding your interest in information on our projects, the Evolution I and II funds have historically not invested directly in renewable energy sources for agricultural irrigation systems. We have focused primarily on utility scale renewable energy projects and have more recently moved into distributed generation.
Procurer	IPP Procurement Programme Project Officer query@ipp-renewables.co.za				N	The IPP Office on behalf of the Department of Mineral Resources and Energy is mandated as the procurer of energy. As such the IPPO only procures fully structured projects that comply with the Qualification Criteria as set out in the Request for Proposal (RFP). One of these criteria is a fully funded project with both equity and debt in place. The IPPO / DMRE therefore does not get involved in the financial structuring of any project. We suggest you approach the DBSA and the IDC as development finance institutions who could possible assist.

APPENDIX B – CASE STUDIES

Becker Farm Limpopo

GENERAL DESCRIPTION			
Renewable Energy System	Solar PV	**Location**	Tolwe
Type of farming (crop)	Potatoes, onions, lucerne, pecan nuts	**Extent**	200 ha
Irrigation system	Centre pivots	**Service provider**	Energyneering
Water Use Authority	Mogalakwena IB	**Electricity service provider**	ESKOM
Sun hr: 200-400 hr.month^{-1}	**Temperature:** 20,6°C	**Wind:** 5-20 km.h^{-1}	**Rain:** 423 mm.a^{-1}

DRIVERS FOR ADOPTING RENEWABLE ENERGY SOURCE	
Cost of electricity:	R120 000-R150 000 per month
Reliability of ESKOM power supply:	Poor
Economic Incentives:	Savings (might sell to ESKOM in future)
Financial feasibility:	Good
SYSTEM CLASSIFICATION/CHARACTERISTICS	
Purpose:	Direct irrigation, pump water to storage dam, sell electricity to grid (possibility)
Configuration:	Grid-tied, Storage dam (pump surplus)
Tracking:	Static
Size of system:	240 kWp (200 kVA)
Power:	AC
Proximity:	3,3 kV ring feed
SYSTEM SIZE	
DC system size:	250 kWp
AC system size:	200 kVA
Type and number of panels:	PV Modules Trina Solar 325 Wp @ 768 panels
Type and number of inverters:	Schneider Electric CL 25 kVA @ 8 inverters
System generation estimate:	360 000 kWh.annual^{-1} yield AC grid
Mount Type:	Galvanised Ground Mount Structure
LEGALITIES / AGREEMENTS	
Maintenance:	None
Licence:	Applied to NERSA
Pricing:	R6,2 million (loan)
Payback period:	5 years
OPERATION	
Does it work	Very good

Maintenance	Data recording and monitoring (inclusive)
Loss in efficiency	Varies with season
Other problems/constraints	-
Area necessary	Enough available to expand
Expected lifespan	20 years

COMMENTS

The solar energy plant is an Agri PV ground mounted grid-tied 3-phase system with 768 x 325 W solar panels giving it a design capacity of 240 kWp that can yield 1 200 kWh.day^{-1} or 420 000 kWh per annum. The processing of 12 months' historic data was used to size the plant. Nine transformers with 1 MVA total capacity was installed and the system is amalgamated with the existing ESKOM grid using eight step-up step-down CL 25 Optimum Plus Inverters. The installation includes a 5,5 km 3 300 V private medium voltage powerline which has resulted in the elimination of five ESKOM transition points ensuring more economic operation in the long term. Reversed power protection is part of the installation and a smart controller system balances the solar system with the load ensuring optimum output energy from the solar plant to pumps and equipment. A Power factor correction unit is installed on the grid supply side to mitigate kVA fluctuations and line instability.

The project was initiated in 2018 and is implemented in phases. The second phase provides for the delivery of a 200 kVA night-time load by means of a closed-loop hydro system. This will ensure a complete independence from the national grid. The project has characterised with a 462 tonnes CO_2 offset per annum. It is considered an economically viable project due to a short payback period with 20-year guarantee. Schneider Electric and Energyneering are the technologies behind this successful project.







Marlenique Estate Western Cape

GENERAL DESCRIPTION			
Renewable Energy System	Solar PV (ground & float)	**Location**	Franschhoek
Type of farming (crop)	Export apples, citrus, pears and peaches	**Extent**	> 100 ha
Irrigation system	Drip	**Service provider**	New Southern Energy
Water Use Authority	Berg River Irrigation Board	**Electricity service provider**	Drakenstein Municipality
Sun hr: 145-180 $hr.month^{-1}$	**Temperature:** 16°C	**Wind:** 7,5-15 $km.h^{-1}$	**Rain:** 912 $mm.a^{-1}$

DRIVERS FOR ADOPTING RENEWABLE ENERGY SOURCE	
Cost of electricity:	Not specified
Reliability of power supply:	Inconsistent supply
Economic Incentives:	Savings reliability of supply for enhanced production and processing.
Financial feasibility:	Good return on investment
SYSTEM CLASSIFICATION/CHARACTERISTICS	
Purpose:	Consume directly and sell excess electricity to grid
Configuration:	Grid-tied (bank surplus)
Tracking:	Static
Size of system:	594 kWp
Power:	DC
Proximity:	Installed microgrid combining 9 municipal points
SYSTEM SIZE	
DC system size:	594 kWp
AC system size:	490 kVA
Type and number of panels:	Canadian Solar 1800
Type and number of inverters:	SolarEdge
System generation estimate:	850 000 kWh per year
Mount Type:	544 kWp ground mount & 60 kWp floating
LEGALITIES / AGREEMENTS	
Maintenance:	Comprehensive maintenance agreement with NSE
Licence:	n/a
Pricing:	PVT
Payback period:	5 years
OPERATION	
Does it work	Very good

Maintenance	Data recording and monitoring (inclusive)
Loss in efficiency	14%
Other problems/constraints	Drakenstein municipality changing their export tariff
Area necessary	7 000 m^2
Expected lifespan	20 years

COMMENTS

The floating solar system at Marlenique Estate is the first commercial floating solar park in Africa which can produce 60 kW of energy and prevent evaporation. The invention is considered a better investment than a new orchard. A larger solar plant (peak production of 534 kW) was erected on unused dry land next to the floating solar plant. All the processes on the farm, from irrigation pumps to packing fruit, can be operated with the 594 kWp solar energy system. The RE company New Southern Energy (NSE) was responsible for building the plant.

According to the NSE, a microgrid system is the best solution for the farm in the long-term considering the high energy demand from its cold storage, venue and irrigation facilities and the increasing energy prices. Nine municipal points were combined allowing the farm to centralise their back-up power and dictate where the new high voltage feed had to be installed to cater for the new solution. The use of renewable energy has reduced the carbon footprint of the farm with more than 50%. A second phase to the project is planned where a battery system is to be installed which will allow the farm to be completely off-grid. Nedbank Agriculture financed the project with savings from the system. The asset can be paid over ten years according to a flexible structure based on the productivity of the farm which allows the farm to operate cash-flow positive.

Holpan North West

GENERAL DESCRIPTION			
Renewable Energy System	Solar PV	**Location**	Lichtenburg
Type of farming (crop)	Mealies	**Extent**	10 ha
Irrigation system	Drip	**Service provider**	n/a
Water Use Authority	None	**Electricity service provider**	None
Sun hr: 250 $h.month^{-1}$	**Temperature:** 19°C	**Wind:** 7-19 $km.h^{-1}$	**Rain:** 601 $mm.a^{-1}$
DRIVERS FOR ADOPTING RENEWABLE ENERGY SOURCE			
Cost of electricity	-		
Reliability of ESKOM power supply	-		
Economic Incentives	-		
Financial feasibility	Good		
SYSTEM CLASSIFICATION/CHARACTERISTICS			
Purpose:	Direct irrigation		
Configuration:	Standalone		
Tracking:	Static		
Size of system:	15 kW (380 V)		
Power:	AC to DC		
Proximity:	Close		
LEGALITIES / AGREEMENTS			
Maintenance:	None		
Licence:	n/a		
Pricing:	R 120 000		
Payback period:	1 year (R 200 000 for mealies in one season)		
OPERATION			
Does it work	Very good		
Maintenance	Part of farming activities (no extra cost)		
Loss in efficiency	Sun hours dependent		
Other problems/constraints	-		
Area necessary	Enough available to expand		
Expected lifespan	20 years		
COMMENTS			
– 56 x 330 W panels = 18 480 W (18,5 kW) independent – Inverter cost R 7 000 and quick to import directly from China			


CKMINE
WARNING
May cause injury or electric shock
Please wait at least 10 mins until DC Bus capacitors discharge
Please follow the safety instructions in the manual before installation or operation
Please use proper grounding techniques

Bokfontein North West

GENERAL DESCRIPTION			
Renewable Energy System	Hydro	**Location**	Brits
Type of farming (crop)	Citrus	**Extent**	2,4 ha
Irrigation system	Drip	**Service provider**	None
Water Use Authority	None	**Electricity service provider**	None
Sun hr: 200-400.month^{-1}	**Temperature:** 10-30°C	**Wind:** 6-15 km.h^{-1}	**Rain:** 620 mm.a^{-1}

DRIVERS FOR ADOPTING RENEWABLE ENERGY SOURCE	
Cost of electricity	n/a
Reliability of ESKOM power supply	Poor
Economic Incentives	Savings
Financial feasibility	Good
SYSTEM CLASSIFICATION/CHARACTERISTICS	
Purpose:	Direct irrigation, pump water to storage dam
Configuration:	Standalone, storage dam (pump surplus)
Size of system:	Equivalent to 3 kW
Power:	n/a
Proximity:	n/a
LEGALITIES / AGREEMENTS	
Maintenance:	Irrigation network and dam
Licence:	No
Pricing:	Minimal
Payback period:	-
OPERATION	
Does it work	Very good
Maintenance	Irrigation network and dam
Loss in efficiency	Flow varies with season
Other problems/constraints	-
Area necessary	-
Expected lifespan	-
COMMENTS	
Water is constantly pumped from a non-perennial stream in the Magaliesberg mountain to a 75 m^3 storage dam at an elevation 45 m higher by use of a ram-pump. This water is used to irrigate 1 200 lemon trees by means of gravitation at a 60 m lower elevation.	





Naauwtesfontein, Northern Cape

GENERAL DESCRIPTION			
Renewable Energy System	Solar PV	**Location**	
Type of farming (crop)	Maize, wheat, lucerne	**Extent**	
Irrigation System	Pivot	**Electricity service provider**	ESKOM
Water Use Authority	Vanderkloof		
Climate:	**Temperature:**	**Wind:**	**Rain:**

DRIVERS FOR ADOPTING RENEWABLE ENERGY SOURCE	
Cost of electricity	Ruraflex electricity tariffs
Reliability of ESKOM power supply	Unreliable
Economic incentives	Cheaper than ESKOM
Financial feasibility	Good
SYSTEM CLASSIFICATION/CHARACTERISITICS	
Purpose:	Irrigation
Configuration:	Grid-tied
Tracking:	Single-axis tracking with MLD (maximum light detection)
Size of system:	198.25 kWp
Power:	AC-DC
Proximity:	near
LEGALITIES AND AGREEMENTS	
Maintenance:	Agreement with CENEC
Licence:	
Pricing:	Lease agreement with CENEC
Payback period:	20 years
OPERATION	
Does it work	Good
Maintenance	CENEC
Loss in efficiency	n/a
Other problems/constraints	None
Area necessary	Not a constraint
Expected lifespan	20 years

COMMENTS
The pivots are very far from the water source. The PV system is grid tied to ensure that electricity is always available to ensure proper operation. ESKOM electricity is used to pump water into irrigation dams. The PV system is alongside the irrigation dam and pumps water directly into the pivots. A lease agreement is in place with CENEC to lease the PV system from CENEC at a cost that is less than the R.kWh^{-1} the Ruraflex tariff. After the lease agreement is terminated the equipment belongs to the farmer.

Cookhouse, Eastern Cape

GENERAL DESCRIPTION			
Renewable Energy System	Hydro	**Location**	
Type of farming (crop)	Mixed crops/dairy	**Extent**	
Irrigation System	Pivot	**Electricity service provider**	ESKOM
Water Use Authority	Great Fish River		
Climate:	**Temperature:**	**Wind:**	**Rain:**
DRIVERS FOR ADOPTING RENEWABLE ENERGY SOURCE			
Cost of electricity		Municipality tariffs	
Reliability of ESKOM power supply		No ESKOM, Local Municipality	
Economic incentives		Continuous generating capacity	
Financial feasibility		Good	
SYSTEM CLASSIFICATION/CHARACTERISITICS			
Purpose:		Direct irrigation; surplus used to pump to elevated storage (battery)	
Configuration:		2 x Off-grid hydro plants. Own distribution network to rest of farm.	
Size of system:		280 kW and 520 kW	
Power:		n/a	
Proximity:		Far from irrigation, use own grid.	
LEGALITIES AND AGREEMENTS			
Maintenance:		Ossberger (Once in two years)	
Licence:		Great Fish River WUA agreement	
Pricing:		± R6 million and ±R8million	
Payback period:		5 year and 2 years	
OPERATION			
Does it work		Very good	
Maintenance		Low	
Loss in efficiency		n/a	
Other problems/constraints		Developing own grid	
Area necessary		n/a	
Expected lifespan		35 years	
COMMENTS			
The farm has two Ossberger cross flow turbines which was imported directly from Germany. He has an agreement with Ossberger to inspect the hydro plant every two years. The first turbine was installed in 2008 and has a capacity of 280 kW that is generated from a head of 12 m. The second turbine was installed during 2018 and has a capacity of 520 kW that is generated using a head of 28 m and a flow of 3 $m^3.s^{-1}$. The two hydro plants are off-grid and he developed his own distribution network on the farm. In both cases agreement with the Great Fish River WUA was crucial in the development the two hydro electrical plants			

because the water source is the canal. The fact that electricity is generated continuously results in surplus electricity. All the electricity that is nut used, is pumped to an elevated storage dam with a capacity of 600 000 m^3. The static head of the dam is used to irrigate his crops with centre pivots.

APPENDIX C – WORKSHOP REPORT

INTRODUCTION

There are still many questions regarding the feasibility of renewable energy in the irrigation sector, despite numerous farm level solar and hydro schemes. The need for a scoping study regarding the technical and financial feasibility of alternative renewable energy sources and technologies in irrigated agriculture was therefore found necessary. Outcomes and expected impacts from the study include research about improved energy security and transition to low-carbon economy and a reduction in dependency on expensive coal generated electricity. Subsequently this research can provide insight with regards to climatic aspects influencing feasibility of RE in the irrigated agriculture sector in different parts of the country and specifically at relatively small scale. Ultimately the scoping study aims to identify current outstanding issues contributing to the feasibility of using alternative energy sources and provide information on techno-economic factors affecting implementation.

Draft spatial guidelines (feasibility maps) for the technical and financial feasibility of alternative energy in irrigation were developed as part of deliverable seven of the study. This report serves as the eighth deliverable of the scoping study, reporting on the outcomes and feedback received at the workshops held to discuss the draft guidelines.

Both of the conferences where the project team had planned to present the Spatial Guidelines, during October 2021, were postponed to February 2022. It was therefore decided to have one-on-one sessions with identified people in the project team members' networks. The guidelines will still be presented at the SABI Conference during February 2022.

APPROACH

Presentation

A presentation was prepared to present the draft spatial guidelines at the SABI Conference. Since the conference was postponed, it was decided to rather present the draft guidelines in the form of one-on-one sessions with identified role-players.

Role-players identified

It was important to identify role-players who would represent the target group for whom the final report and guidelines of the study was intended, i.e. irrigation designers, consultants and water users. In conjunction to this, priority was given to the regions where the renewable energy resources seem to be more available and already applied in the irrigation sector. Attendance registers for some of these meetings are included in **Annexure A**.

The following role-players were identified:

- The Co-op – (Eastern Cape)
- Vaalharts WUA – (Northern Cape)
- GWK – (Northern Cape)

- Irrigators – (North West and Northern Cape)
- Various suppliers operating countrywide
- ESKOM Consultant
- Private Consultants

COMMENTS AND FEEDBACK

The following section summarises the comments and feedback of the different role-players following the introduction of the WRC study and the presentation of the guidelines. The scope of the study and the guidelines were well received by all the role-players. This unleashed numerous discussions about the feasibility of applying renewable energy, and specifically solar energy, in the irrigation sector. The role-players shared some of the challenges they face in their specific irrigation regions with regards to the implementation of renewable energy. They also identified knowledge gaps and shared some ideas in terms of a way forward. Further investigation and a detailed feasibility study for alternative renewable energy in the irrigated agricultural sector were encouraged. The role-players requested to be informed when this study is completed and that the information be shared with them. It was agreed that the database with technologies and suppliers be shared with them upon completion of the study. General discussions were held with suppliers, consultants and ESKOM to share their knowledge and opinion with regards to the feasibility of the application of alternative renewable energy in the irrigation.

The Co-op

The Co-op is a leading agricultural business that provides products and services to various farming disciplines. They operate in the Eastern Cape, Western Cape and Limpopo provinces. A division for Alternative Energy Services has recently been established at the Co-op. They offer Energy Audits to identify areas where the user can save on electricity. Services include the supply of PV solar panels, inverters, the latest Lithium-Ion Batteries as well as maintenance and repair. The Co-op also provides tailor-made Power Purchase Agreements and Lease Agreement options. They also have a range of generators, including diesel, petrol and low-pressure gas, ranging from 5 Kilowatts to 1000s of Kilowatts.

The representatives from the Co-op showed interest in the research study and agreed that there is a lot of potential for renewable energy to be applied in the irrigated agriculture. They are familiar with All Power and also indicated that they have been involved with the implementation of a few solar driven irrigation systems themselves. They also know about the hydro-system of Mr. Michael Vermaak near Cookhouse. Mention was made of the web-based sales and design tool, Helioscope, for solar professionals. They thought that the study initiative was good and agreed that there is a lot of potential for applying renewable energy in the irrigation, especially in the Eastern Cape.

Vaalharts WUA

The Vaalharts Irrigation Scheme (the largest in South Africa) is situated around Jan Kempdorp in the Northern Cape province. Water is diverted from the Vaal River at the Vaalharts weir and distributed (gravity-fed) to irrigators by means of a 1 000 km canal network. More than 39 000 ha land is under irrigation in this scheme.

The project team met with the CEO of Vaalharts WUA to introduce the study and present the guidelines. The study initiative was welcomed, and the presentation well received. A discussion followed. The CEO noted from the feasibility map for hydro-energy that the Vaalharts scheme had not been indicated. He shared that there have been presentations by Standard Bank and PEECA with regards to harnessing hydro energy from the flow of water in the canal network. However, since it is a gravity system where water is diverted at the Vaalharts weir, the flowrate is too low and there is not sufficient head available. Any disturbance of the flow in the canal can also be the cause of some farmers not receiving their full allocation. This explains why the system is not shown on the map. One of the options identified, is to build balancing dams at the outlets of the main canal to the branch canals. In doing so, a higher head and flowrate can be created.

In terms of solar energy – although the feasibility maps show a lot of potential for harnessing solar energy in this region, space is limited since the properties located in the scheme are a mere 25 hectares on average. There are small centre pivots, but where solar energy systems have been implemented, it has mostly been for other uses than irrigation. If irrigators in this area want to make use of solar energy, preference should perhaps be given to the installation of floating solar systems. The CEO of Vaalharts WUA asked to be informed once the study is completed and a follow-up study is initiated.

GWK – Douglas
GWK is an innovative agricultural business that provides a number of services to the agricultural sector. Representatives from the irrigation and agricultural services divisions of GWK as well as representatives from the Orange-Vaal WUA, attended the workshop in Douglas. The head of the irrigation division at GWK chaired the meeting and gave a short introduction with regards to what they at GWK already know about alternative energy sources and its application in the irrigation sector. The presentation opened many discussions around the research topic in general.

The role-players agreed that solar energy is a feasible option in their region based on availability and cost of implementation. However, they indicated that a huge challenge in terms of the application of solar energy for irrigation within the Orange-Vaal irrigation area is the lack of storage or balancing dams. This means that water cannot be pumped and stored to be used later since fields are irrigated directly from the canal. Although the solar potential in this region is vast, it is challenging to harvest it optimally. The installation of batteries to store the excess solar energy as opposed to storage of day-time pumped water is still an expensive option. With only five hours peak sunshine during September but an irrigation requirement of 24 hours or more, the solar energy will not be sufficient for the energy required if it cannot be stored. Other practical issues include poor installation and maintenance of solar panels.

The representatives agreed that the feasibility of renewable energy is site specific and influenced by a number of factors. The need exists to develop a model that is integrated with the design of an irrigation system, type of crop, soil type, irrigation scheduling and climatic conditions. The role-players at the GWK workshop asked the project team to be informed if further studies regarding this topic are undertaken since they believe they can also add some value.

Irrigators

North West

Irrigators in the North West province were approached to introduce the study to. They agreed that the option of making use of alternative energy is becoming more and more attractive. With increasing electricity costs and the added challenge of load-shedding, alternative energy sources might be more sustainable. One of the irrigators gave an example and said that the grid-tied option seems most feasible. If only two of the eight ESKOM supply points are supplemented with solar energy, savings of up to R350 000 per year are possible. There are already generators in place at these points and no batteries need to be installed. At the one site, irrigation water gravitates from a fountain in the mountain into reservoirs from where approximately 10 000 citrus trees can be irrigated with three pumps with a combined capacity of 15 kW. With the savings considered as well as the fruit production, the payback period can be less than five years. The implementation of grid-tied systems at the other existing ESKOM supply points on the farm is too risky since these locations are more exposed to vandalism and theft.

Northern Cape

The project team met with an irrigator farming along the Riet River who couldn’t attend the meeting at GWK in Douglas. He showed a lot of interest in the study and the feasibility maps. He indicated that two grid-tied systems of 1 MW and 4 MW are being planned along the Riet River between Kimberley and Douglas. The plan is to construct a dam at one of these sites on the farm which is located at the foot of a hill allowing for irrigation pumping with the benefit a downhill slope. Although these developments entail large investment costs, it is still considered feasible in the long-term compared to the losses due to load-shedding. He is still doing some research in terms of which suppliers to consult and what technology to use. He asked the project team to share the study information.

Suppliers

SAW Africa

Renewable Energy is feasible everywhere in RSA. Depending on the growth and demand of crops, the project can potentially be paid off over a shorter term. Each installation is unique and not necessarily based on basic principles. If the potential of solar energy for irrigation is compared to that of wind energy, it is important to note that that wind is a very localised phenomena and not all irrigation regions in RSA have sufficient wind to generate electricity. For example, a region might be classified as a wind still region, yet still have mountain winds.

Energyneering

Our approach is to select a specific location and do a detail PV solar analysis with either 5- or 30-minute intervals to see how much electricity can be generated. An irrigation schedule is requested from the user to determine how much water is required for the entire year. The solar availability can then be superimposed onto the irrigation schedule. Sometimes the user requires more water during the wintertime; then the solar panels can be tilted for wintertime production. Or accordingly for summertime. The size of the dam needs to be calculated if elevated storage is an option for gravitational irrigation.

The cost of the solar energy systems in irrigated agriculture is largely influenced by the number of hours per day when irrigation is required, the size of the dam and the centre pivot. All of this is considered to determine the most cost-effective way to proceed. The suppliers tend to know from experience what region yields what energy; and a certain amount of $kWh.kWp^{-1}$ for a certain type of installation is required. Solar radiation in RSA isn't that much different from region to region except perhaps in the Western and Eastern Cape where there are more overcast days. Solar radiation isn't really a cost driver. There are other factors that are substantially more significant if a sensitivity analysis is undertaken.

A bigger impact on costing, is the size of the battery and the size of the pump. Not so much the size of the solar system and region. And, if one considers including tracking, it can give up to two hours more pumping hours per day. Costs are increased substantially with this option, but it can result in a much smaller solar system allowing the application to become cost effective. Soiling, dirt on panels and how the panels are maintained are of greater importance than solar radiation. The production curve of a solar system is more important than the amount of energy that the system yields. When water is pumped with solar energy, it is good practice to design the system larger than is required. A system design can be up to 2,5 times more than the pump/motor size. The cost of the production of water ($R.m^{-3}$) is an alternative method to determine if the installation of a solar system on a specific surface area will be viable.

If a grid-tied system is planned, it can cost up to three million rand to connect to ESKOM if there isn't a connection already; if that expense is added to the investment cost of a solar system, it is cheaper to go completely off-grid. Additionally, the industry needs to look at combining wind and solar. Wind will be present at the most unexpected times of the day. In the Ceres and Tankwa Karoo and northern plateau regions, wind starts blowing from 4 am to 8 am and again from 4 pm to 10 pm at night. Wind farms are not considered economically viable because the total hours of wind available in a day are not enough. When there is enough sun at a specific area, a hybrid system with these two resources may be a more feasible option.

Van Heerden Solar Power

Ludwig van Heerden does solar energy installations nationwide. He is of the opinion that a farmer can irrigate a 12 ha lucerne field with a strong borehole. The system can pump 4 000 $\ell.hour^{-1}$ for 10 hours per day with a 5,5 kW pump and 6 kW solar panels (tracking). Ludwig requires the size of the existing borehole to determine the capacity of the inverter required for a solar powered system. To do a proper quotation, design and installation of either grid-tied or independent RE systems, a few months' of ESKOM accounts are required.

All Power

All Power is of the opinion that if no ESKOM power is available, or there is a strong prospect of power failing or disappearing for good, alternative energy is always a viable option. In the event of ESKOM being available for farming and agriculture, and it would be desired to reduce the power bills, this pay back will vary from three and a half years to seven years (depending on scale and type of usage and annual rate increments).

“We have several standalone systems, all of which are evidence of viability, however only viable if these can obtain up to 10 hours and more effective irrigation during summer. To achieve this, it is necessary to have the technology, something we have developed over the past 30 years.”

Sonfin (Grid-tied systems)
The Regulation Act of Electricity (Act 4 of 2006) requires RE installations to be registered with NERSA as well as to have approval of the supplier (ESKOM). All installations must meet government regulations. Previously only MV connections were used by big scale farmers with a cost of approximately R1 million. Since May 2019, ESKOM has started considering LV connections to generate power and return it to the power network. These connections will cost R50 000 to R100 000 depending on whether existing meters can be reprogrammed and if new meters should be installed. There is a limit of 350 kWp, ESKOM-permitting, depending on how big the transformer is at the connection point.

The first step for a farmer who wants to install a grid-tied solar system, is to apply to ESKOM for the connection of the system to the ESKOM network and pay the tariff calculation cost of R3 860. ESKOM then registers the project and issues the tariff cost letter after 90 days. This letter is valid for 12 months. A budget quotation letter, describing the scope of work required for coupling, must be received and the tariff cost involved must be paid during these 12 months. During this time, all the requirements of the project must be met for the project to be fully implemented. These requirements include the approval of the budget quotation, payment of the coupling rate, arrangement for guarantees as needed, the signing of agreement documents, and lastly, the proof of paid-up registration with NERSA.

Work done by ESKOM involves upgrading meters to four quadrants or six-register meters. They store active energy and reactive energy that is consumed and generated. Network diagrams are upgraded to indicate the solar power system. Signs should also be affixed at the meter boxes to show that solar power is connected to the relevant connection point. This work takes 6 to 12 months.

Work done by the customer himself include the installation of an additional safety mechanism (dead grid safety lock) on the side of the solar system; installation of an accessible and lockable switch box on the consumer’s side of the meter to give ESKOM staff access to work on the LV meter point; and clearly visible markers on the meter box to indicate that the LV generator is there. If network feedback is allowed, feedback control does not need to be installed. Compensation can only be obtained if the net measurement option is available. This feedback system means that you can return and store the power which you cannot use immediately on the ESKOM network. At the end of the month, the stored power is then set off against your consumption on a net measurement principle.

ESKOM does not pay for stored power. Storage power that was not eligible for net measurement can be transferred monthly for the next month’s usage. ESKOM costs remain the same whether you are using this feedback system or not. The meter is there for ESKOM to determine if you are returning power.

There is also a new cost in addition to the monthly line tariff. For both the balancing contract (offsetting) and the power banking contract, a tariff of R930.month^{-1} is required. Annual energy costs can be saved in this way and ESKOM's electricity bill will be limited to fixed cost elements. Most consumers have a seasonal consumption pattern and will benefit from the feedback and storage facility in the network. Rules of feedback and storage of power are that the consumer must remain a net consumer of power as well as to use stored energy by 31 March every year.

The most used system is the LV connections, where the ESKOM meter is installed on the 400 V side of the transformer. ESKOM owns the transformer and the point of connection is similar to the meter on the LV side. In MV connections, the farmer owns the transformer and the ESKOM meter is installed on the 11 V or 22 V side of the transformer for the access of ESKOM staff. The biggest difference between these two installations are the strict safety precautions required for each installation. LV connections solely require a dead grid safety lock.

NERSA has approved the process of installing privately owned solar systems. A once-off registration fee of R200 is payable, with only solar systems smaller than 1 MW currently being considered. If the application is complete, it takes approximately 30 days to receive the notice of payment from NERSA, and a further two months before the registration certificate is issued. Although, Sonfin is of the opinion that with certain applications it has taken ESKOM up to three years to issue a budget letter.

Credits are granted in accordance with ESKOM's Genflex tariff. Red equals peak times for power consumption in the mornings and evenings; Yellow equals peak times for power consumption through the day, and green equals peak times for power consumption at night and during weekends. If credit is earned for storage of power in red time, it must be used again during that time within the same storage cycle. Towards the end of such a cycle, credits are forfeited if not used and must be accrued again from zero from 1 April. ESKOM's fixed cost account must still be paid.

Depending on the size of the project, investment costs can be recovered within five to seven years with credits on an ESKOM account. Solar panels have a guaranteed supply capacity of 25 years and a service life of 40 years, with no batteries being required in these systems. Banks are starting to accept solar systems as security on loans. Section 12B of the Income Tax Act (Act 58 of 1962) allows for a depreciation period of one year for solar power systems less than 1 MW, i.e. 100% admission in one year.

Sonfin doesn’t have many installations in the irrigation sector. A few in agriculture for cold rooms. Compared to other systems, solar systems are less involved, not requiring allot of maintenance. There are too many moving parts in wind systems and they are high maintenance. In terms of hydro energy there are not many consistent water sources in South Africa for it to be viable for irrigation.

I & F Engineering

I & F Engineering delivers engineering services to farmers and industry. They are the sole agents in Southern Africa for Ossberger turbines imported from Germany. One of their services include hydro-electric power generation plants. Ian De Jager, Director, had the following to share:

To decide between off grid or connected to the grid mainly depends on the capacity of the plant as well as the energy provider in the area. Energy cost, availability and service of the provider can sometimes be the main problem. If you generate off grid you must be able to supply the maximum demand when needed and the water and head availability will determine if this is possible. It is a financial decision in terms of where to store the energy, in the grid or not.

ESKOM Consultant

Factors that influence farmers to invest in renewable energy sources

The factors that stand out include the unreliability of ESKOM. Supply doesn't allow uninterrupted production on the farms. The ever-increasing tariffs by ESKOM have also influenced famers to take up investment in the renewable energy sources. The NPV for such investment has meant that they are attractive for farmers. The need to protect the environment and invest in green energy has seen farmers also investing in renewable energy.

Energy sources for Pumping/Irrigation

Most farmers prefer using solar for their pumping as it is easier to work with than other renewable energy sources such as wind and hydro. Solar power is used with an option of power storage for application at night and on cloudy days. With solar power one can go completely off-grid although that is not advisable as the weather conditions may not be favourable to harness solar radiation for a number of days.

Private Consultants

MBB Consulting

Hydro power is definitely an option as renewable energy if there is a drop in elevation and security of water supply. Unfortunately, SA is a water scarce country with first world regulations difficult to overcome in the past. Energy is the product of flow rate and head. There are various infrastructure requirements when it comes to hydro sites. Many sites have already been identified. They are not aware of substantial use of renewable energy in the agricultural sector.

Biogas Consulting SA

There are a number of biogas plants established in the agricultural sector generating electricity – There is uncertainty however if the electricity is utilised specifically for irrigation purposes. It is however a practical option to do so. Most would be grid-tied.

CONCLUSION AND RECOMMENDATIONS

There are many possibilities for renewable energy for irrigation. It was found that these resources are feasible, but there is scope to improve management with reference to size of alternative energy plants. Not all the detail regarding the feasibility of alternative renewable energy sources in the irrigated agricultural sector is known since these applications are site specific. The idea of how to harness the energy from these resources (solar, wind and water) has been outlined. It is not always possible to use all the energy that is generated and therefore it can be recommend looking into energy storage options such as batteries and elevated storage.

Solar energy is probably the one alternative energy option that can be utilised most in South Africa. There is scope for a follow up study where solar is definitely an option as alternative renewable energy for irrigation. The detail factors to be considered need to be identified in such a study and the different system configuration options such as elevated storage, grid-tied, not grid-tied, etc. need to be considered. All the intricacies and detailed analysis in terms of what the feasible alternatives are, should be evaluated. There is potential for developing a framework for evaluating different type of systems in more detail and develop a calculation procedure or model that will assist users to undertake a detail analysis in terms of feasibility.

Sustainable access to energy in future will require adjustments in both supply and demand design approaches. In the case of irrigation, utilising an alternative energy source will not only require new knowledge and skills in the industry on designing, installing and managing "on-farm" electricity generating infrastructure but also adapted approaches to planning and designing the irrigation system in terms of operating hours available per day and strategic placement of water storages.

The recent bout of load shedding which coincides with the planting season has served as an uncomfortable reminder of how vulnerable the irrigated agricultural sector is in terms of a reliable source of energy and will definitely create renewed interest in the use of alternative sources. This emphasizes the importance and timing of this WRC study and acts as motivation for developing practical tools for the industry.

ANNEXURE A

WATER RESEARCH COMMISSION

SCOPING STUDY REGARDING TECHNICAL AND FINANCIAL FEASIBILITY OF ALTERNATIVE RENEWABLE ENERGY SOURCES AND TECHNOLOGIES IN IRRIGATED AGRICULTURE

WORKSHOP – GWK DOUGLAS, NORTHERN CAPE

27 OCTOBER 2021 @ 11H00

	Attendee	Designation	Company/Organisation/Region	Email address	Telephone	Sign
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APPENDIX D – KNOWLEDGE DISSEMINATION

Workshops

One of the planned activities in terms of the knowledge dissemination and research uptake was a workshop to be held in 2021 to discuss the draft spatial feasibility guidelines. It was important to identify role-players who would represent the target group for whom the final report and guidelines of the study was intended, i.e. irrigation designers, consultants and water users. In conjunction to this, priority was given to the regions where the renewable energy resources seem to be more available and already applied in the irrigation sector. It was finally decided to rather present the draft guidelines in the form of one-on-one sessions with identified role-players.

The following role-players were identified:

- The Co-op – (Eastern Cape)
- Vaalharts WUA – (Northern Cape)
- GWK – (Northern Cape)
- Irrigators – (Northwest and Northern Cape)
- Various suppliers operating countrywide
- ESKOM Consultant
- Private Consultants

The scope of the study and the guidelines were well received by all the role-players. This unleashed numerous discussions about the feasibility of applying renewable energy, and specifically solar energy, in the irrigation sector. The role-players shared some of the challenges they face in their specific irrigation regions with regards to the implementation of renewable energy. They also identified knowledge gaps and shared some ideas in terms of a way forward. Further investigation and a detailed feasibility study for alternative renewable energy in the irrigated agricultural sector were encouraged. The role-players requested to be informed when this study is completed and that the information be shared with them. It was agreed that the database with technologies and suppliers be shared with them upon completion of the study. General discussions were held with suppliers, consultants and ESKOM to share their knowledge and opinion with regards to the feasibility of the application of alternative renewable energy in the irrigation.

Article

As part of the knowledge dissemination at least one popular article on the spatial feasibility guidelines should be published in a relevant publication. Arrangements were made with SABI and an article was prepared and submitted to be published in the SABI magazine later in 2022.

Conference

Another activity planned for knowledge dissemination included at least one presentation on the spatial feasibility guidelines at the national conference of a subject society such as SA Irrigation Institute (SABI) or the SA Institute of Agricultural Engineers (SAIAE). The outcomes of the research study were presented at the SABI Conference during March 2022 titled: "Taking irrigation to the next level". The conference abstract is shown below.

Spatial guidelines for the technical and financial feasibility of alternative renewable energy in irrigation

(WRC scoping study)

Sarlet Barnard [1], Isobel van der Stoep[1], Bennie Grové [1] and Richard Moyo [2]

1. Isowat Consulting Pty Ltd
2. University of Fort Hare

ABSTRACT: The recent bout of load shedding which coincides with the planting season has served as an uncomfortable reminder of how vulnerable the irrigated agricultural sector is in terms of a reliable source of energy and will definitely create renewed interest in the use of alternative sources. There are still many questions regarding the feasibility of renewable energy in the irrigation sector, despite the success of currently implemented schemes. The need for a scoping research study regarding the technical and economic feasibility of alternative renewable energy sources and technologies in irrigated agriculture was therefore found necessary. The approach entailed a literature review to identify the factors affecting the feasibility of alternative renewable energy sources for irrigation; an overview of the potential and availability of renewable energy sources across South Africa and the ongoing or completed research in this regard; the current implementation of renewable energy use in South Africa relating to irrigated agriculture was assessed; a database with various clients and suppliers and the type of RE system they installed was prepared; a general framework to evaluate the planning and design of renewable energy systems was developed; solar feasibility maps were developed for daily energy requirements of 100 kWh, 500 kWh and 1 000 kWh. It was found that the techno-economic viability of alternative RE systems is influenced by numerous factors such as: the available space and design of the system, installation costs, operational and maintenance costs, financing options, electricity usage profile of the site, the generation profile of the plant, how often the system will be offline and the applicable electricity tariffs. The potential of renewable energy sources across South Africa has been investigated and measurement sites have and are being erected. Tools for assisting with feasibility analyses have been developed. Technological progression increases the viability of using RE as energy source for irrigation. The South African irrigated agriculture sector will benefit most from innovations with respect to solar photovoltaic systems. There is scope for a research study where solar is definitely an option as alternative renewable energy for irrigation. The detail factors to be considered need to be identified in such a study and the different system configuration options such as elevated storage, grid-tied, not grid-tied, etc. need to be considered. All the intricacies and detailed analysis in terms of what the feasible alternatives are, should be evaluated. There is potential for developing a framework for evaluating different type of systems in more detail and develop a calculation procedure or model that will assist users to undertake a detail analysis in terms of feasibility.

Keywords: Renewable Energy (RE), irrigation, technologies, feasibility

APPENDIX E – CAPACITY BUILDING

Individuals

Ms. AV Mlahlwa

During the first year of the study, a student from the University of Fort Hare assisted the project team with Deliverable 1 – Literature Review. Mr. Richard Moyo from UFH, one of the project team members, prepared a report for the student to indicate her progress and experience in terms of capacity building.

Ms. T Matiba

The Water Research Commission with support from the Department of Science and Innovation (DSI) and National Treasury has rolled-out the Water Graduate Employability Programme (Water GEP) as part of the Presidential Employment Stimulus (PES) Plan that aims to create a mechanism to address capacity and work exposure of unemployed youth, specifically graduates. The main objective of the programme is to develop the next generation of innovators and thought leaders in emerging knowledge areas; expand work exposure and experience through access to employers and meaningful work; and improve graduate employability through an integrated approach. During 2021 Working Solutions International (WSI) was appointed to host the Water Research Commission's Graduate Placement programme.

Isowat Consulting indicated that they would accommodate a graduate in their organisation / institution. The graduate involved was Ms. Thabelo Matiba (ID:9701040365086) who has completed her BSc environmental sciences at the University of Venda, School of Environmental Sciences, and department of ecology and resource management. Thabelo assisted with compiling the draft project report and presentation that was presented at the workshops. She has written a short summary on the experience and knowledge she has gained from the research project.

Mr. TV Netshituni

Mr. Netshituni assisted with the data analysis and compilation of the feasibility maps by applying his knowledge in GIS. He indicated that he has improved his current skills and learnt many new concepts and skills from the project which he is sure to apply in future. He has particularly learnt to work with complex data in the context of data management and quality assessment. The project exposed him to the possibilities of exploring solar data and enlightened him on the PV systems as a potential energy source. Mr. Netshituni's assistance has contributed immensely towards the completion of one of the main outcomes of the study.

Institutions

A permanent staff member and one student (as per section 3.1.1) at the University of Fort Hare were directly involved in the project. This created an opportunity for the university to benefit directly from the project by gaining knowledge and awareness of new technologies in the field of alternative energy sources. The School of Agriculture and Agribusiness in the Faculty of Science and Agriculture at the University of Fort Hare is the only institution of its kind in the Eastern Cape Province. Together with one Agricultural College (Fort Cox), a section of the Nelson Mandela Metropole University and five Research Institutes, this School is responsible for the majority of agriculture related training and research in this province.

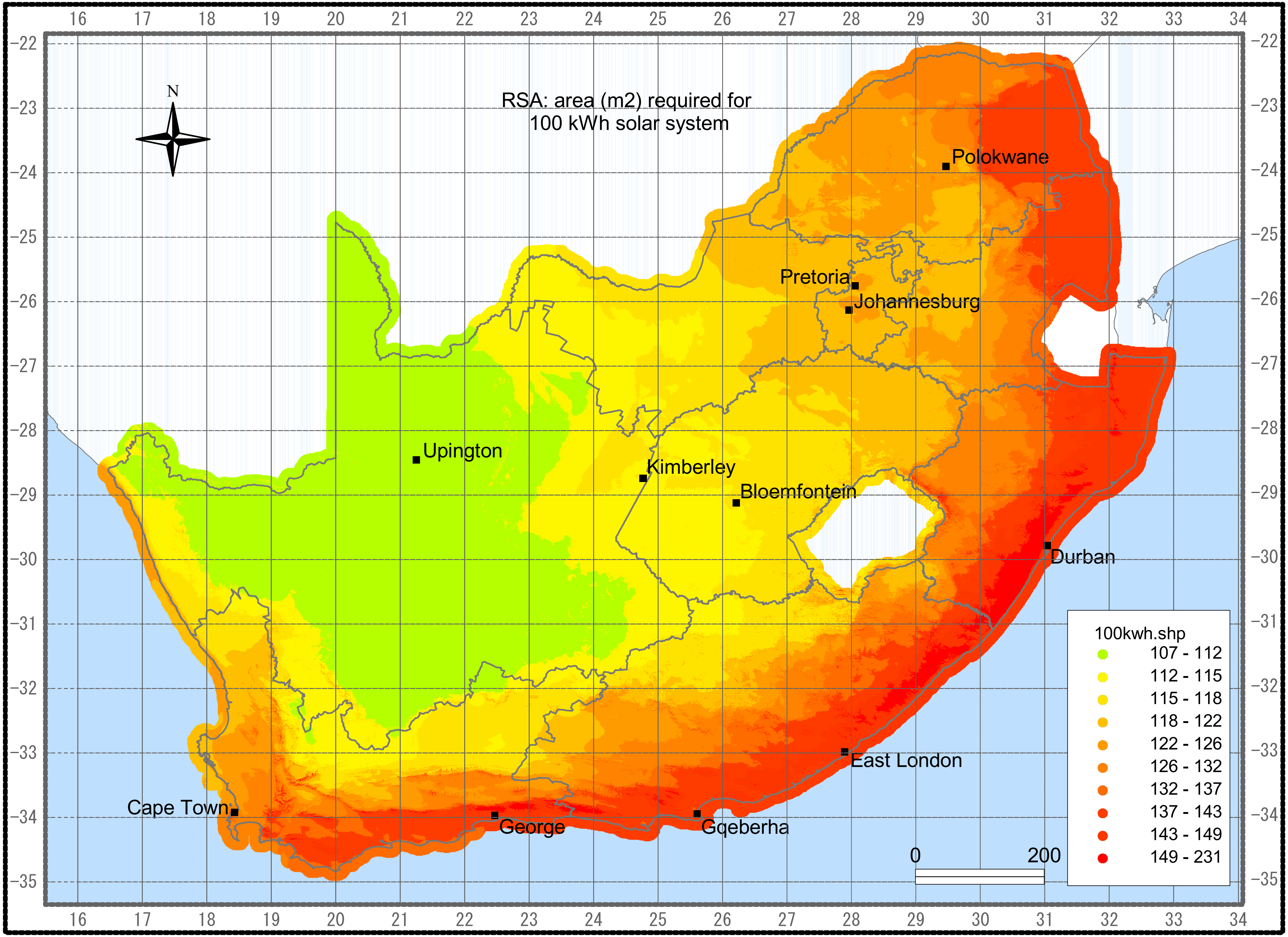
Community

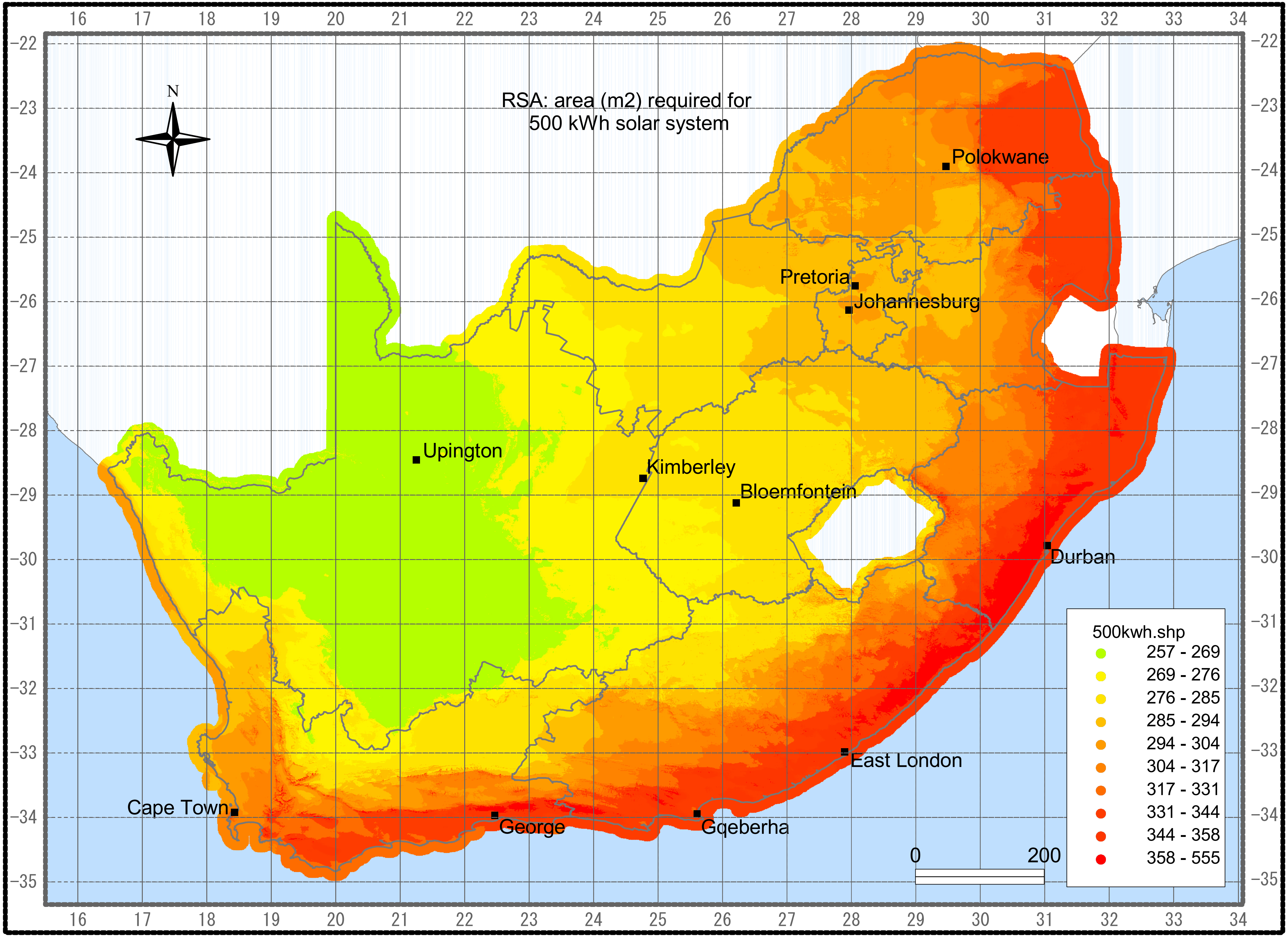
One of the deliverables of this research study entailed identifying the current implementation of alternative renewable energy systems related to irrigation that are already installed or in planning in South Africa. Some of the sites identified were visited; this directly relates and contributes to capacity building at a community level. The Irrigators who were visited, showed interest in the research project and were also willing to share information and knowledge gained of their installations.

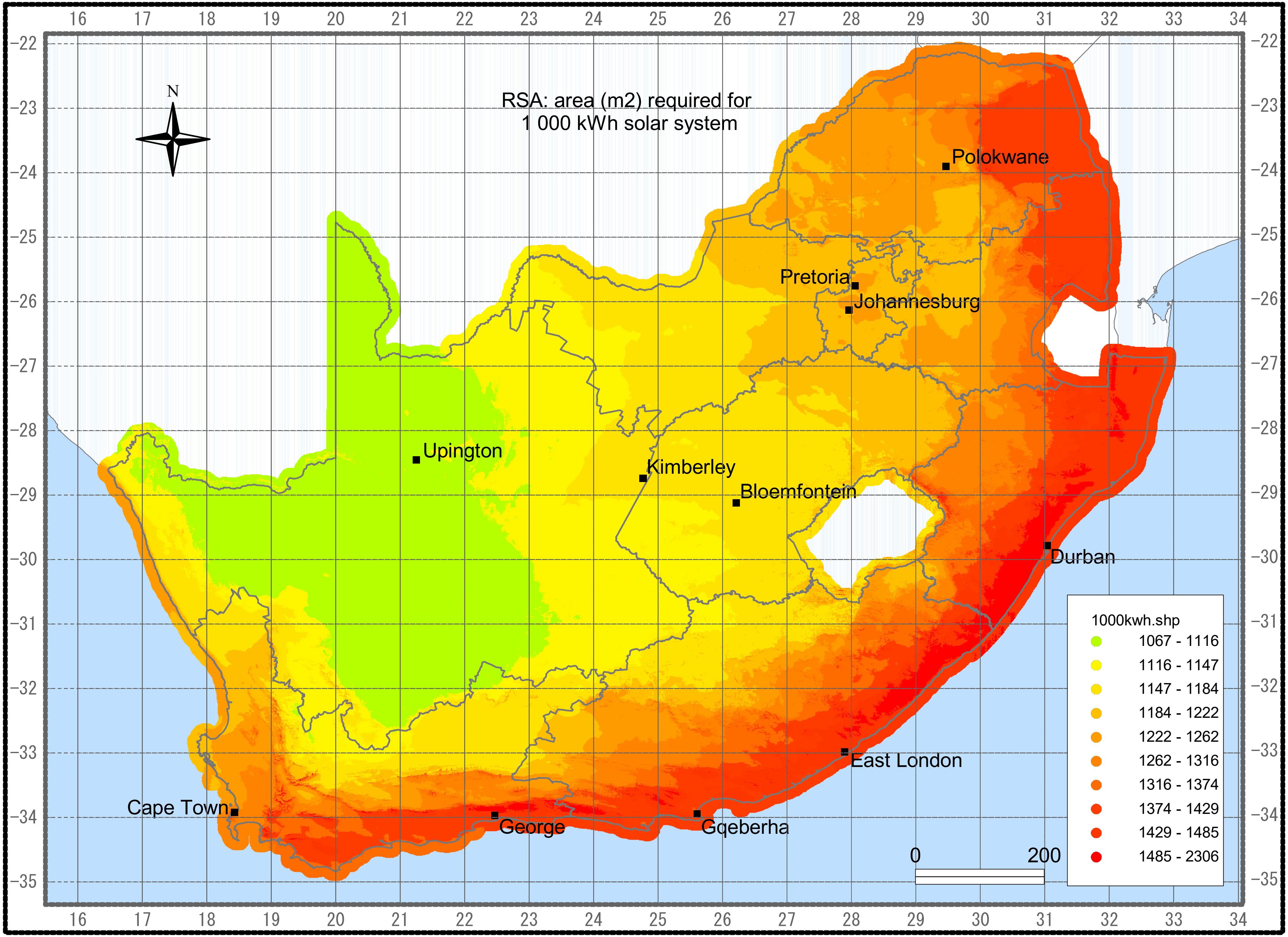
These sites include:

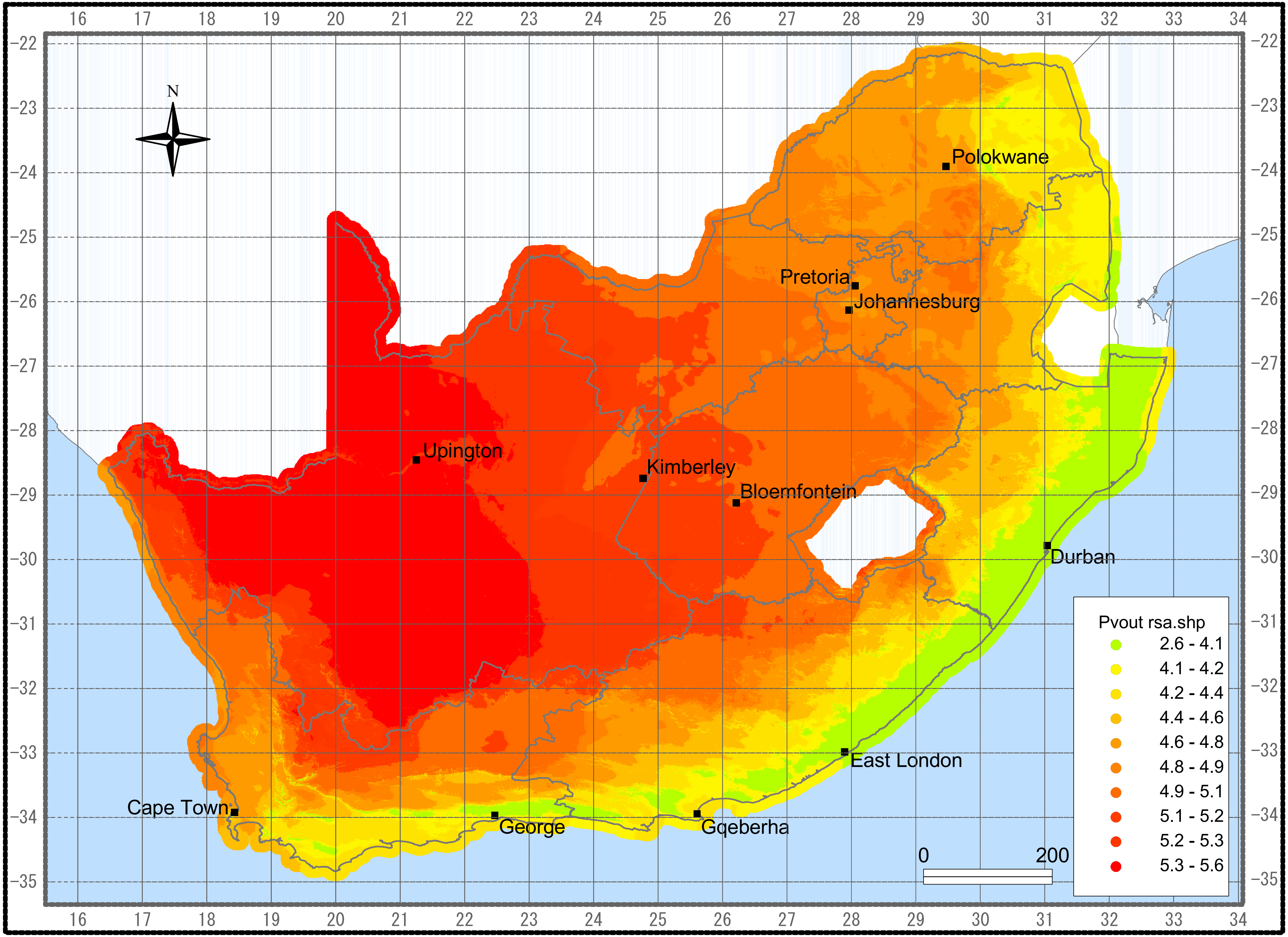
- A solar farm in Tolwe in the Limpopo Province where potatoes, onions, lucerne and pecan nuts are irrigated on an area of 200 ha. The configuration of the 240 kWp grid-tied system comprise a storage dam with a diesel generator as standby. It has a payback period of five years and an estimated lifespan of 20 years.
- A citrus and pepper farm in Brits in the North West Province which is irrigated by means of a ram pump (off-grid system) with a payback period of approximately one year.
- An off-grid 250 kW and 520 kW hydro system near Cradock in the Eastern Cape Province driving centre pivots with payback periods of five and two years and a lifespan of 35 years.

APPENDIX F – SOLAR FEASIBILITY MAPS


RSA: area (m2) required for
100 kWh solar system
N
Polokwane
Pretoria
Johannesburg
Upington
Kimberley
Bloemfontein
Durban
East London
Cape Town
George
Gqeberha
100kwh.shp
107 - 112
112 - 115
115 - 118
118 - 122
122 - 126
126 - 132
132 - 137
137 - 143
143 - 149
149 - 231
0
200
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31
-32
-33
-34
-35


RSA: area (m2) required for
500 kWh solar system
N
Polokwane
Pretoria
Johannesburg
Upington
Kimberley
Bloemfontein
Durban
East London
Cape Town
George
Gqeberha
500kwh.shp
257 - 269
269 - 276
276 - 285
285 - 294
294 - 304
304 - 317
317 - 331
331 - 344
344 - 358
358 - 555
0
200
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31
-32
-33
-34
-35


RSA: area (m2) required for
1 000 kWh solar system
N
Polokwane
Pretoria
Johannesburg
Upington
Kimberley
Bloemfontein
Durban
East London
Cape Town
George
Gqeberha
0
200
1000kwh.shp
1067 - 1116
1116 - 1147
1147 - 1184
1184 - 1222
1222 - 1262
1262 - 1316
1316 - 1374
1374 - 1429
1429 - 1485
1485 - 2306
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
-22 -23 -24 -25 -26 -27 -28 -29 -30 -31 -32 -33 -34 -35



N
Polokwane
Pretoria
Johannesburg
Upington
Kimberley
Bloemfontein
Durban
East London
Cape Town
George
Gqeberha
Pvout rsa.shp
2.6 - 4.1
4.1 - 4.2
4.2 - 4.4
4.4 - 4.6
4.6 - 4.8
4.8 - 4.9
4.9 - 5.1
5.1 - 5.2
5.2 - 5.3
5.3 - 5.6
0
200
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
-22 -23 -24 -25 -26 -27 -28 -29 -30 -31 -32 -33 -34 -35