INVESTIGATING THE ROOT CAUSE OF SOLAR POWER UNSUSTAINABILITY IN KWAZULU-NATAL, SOUTH AFRICA.

By

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SUPERVISOR DECLARATION

I hereby declare that I have read this theses title "**INVESTIGATING THE ROOT CAUSE OF SOLAR POWER UNSUSTAINABILITY IN KWAZULU-NATAL, SOUTH AFRICA**" by Mr Bantubenzani Nelson Mdlolo (student number 21144192) and in my opinion this is sufficient in terms of scope and quality for the award of the master's degree of industrial engineering.

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STUDENT DECLARATION

I, Bantubenzani Nelson Mdlolo, student number 21144192, affirm that the satisfied information of this study signifies my effort and that this dissertation has not previously been submitted to any institution for academic consideration.

Student Signed: ________________ **Date: __________________**

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ABSTRACT

Like many other countries, South Africa as a developing country relies on electricity as the most important basic amenity needed for development. KwaZulu-Natal (KZN) is a province in South Africa affected by an erratic supply of electricity. In the past few years, some areas in KZN region have continued to experience load shedding, while other areas do not have access to electricity at all. Municipalities are responsible for electricity supply and regulation in the KZN communities.

Due to its geographical location KwaZulu-Natal enjoys a warm subtropical climate and receives year-round sunshine even in the winter months. It is thus an ideal region for the implementation of solar power on a large scale. Renewable energy in the form of solar power could easily generate an adequate supply of electricity to meet the electricity demand requirements and energy sustainability of the KZN province. South Africa has a renewable electricity generation of about 2% as per the research of United Nation Statistics Division of 2009 (Manju and Suger, 2017). However, the current access to electricity still faces the challenge of meeting demand and shortage of coal to generate electricity which the most important required to all South Africans; therefore, an effective alternative such as solar power is a necessity.

The main challenge to the solar electricity supply is its unsustainability in the region. Intermittent load shedding coupled with the unsustainability of solar power, has negatively affected the economic performance of the region. This challenge (solar power unsustainability) limits the region from meeting the energy demands facing the KZN region.

The main aim of this study was to investigate the root cause of solar power unsustainability in the KZN region. A quantitative method as well as a cost-benefit analysis was used to interrogate the solar power crisis in the KZN region. The Cost Benefit Analysis CBA gave an assurance of an early (financial) investment when implementing solar power in the eThekwini region. The adopted multiple regressions also revealed the high possibility of solar power performance of 0.75 r^2-value. All challenges facing solar power are investigated through the cause and effect diagram as well.

The Economical, Methodological and Environmental (EME) framework was proposed to address the unsustainability of solar power discovered in the region of KwaZulu-Natal. However, more work still needs to be done to investigate the potential growth of solar power in the region.

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LIST OF ABBREVIATIONS

BRICS – Brazil, Russia, India, China and South Africa

CBA - Cost benefit analysis

CO_2 - Carbon dioxide (CO_2)

CSP - Concentrated Solar Power

CT – customer tariff

df – dispatching factor

DG - Data group

DoE – Department of Energy

EU - European Union

FIT - Feed-in tariffs

FTC - Feed in tariff cost

FTR - Feed in tariff rate

GHG - Greenhouse Gases

IPP - Independent Power Producer

KZN – KwaZulu-Natal

LP – Load Point

MW - Megawatts

NERSA – National Energy Regulator of South Africa

PV - Photovoltaic

RE – Renewable Energy

REIPPPP - Renewable Energy Independent Power Producers Procurement Programme

RES - Renewable Energy Sources

RESA - Renewable Energy Sources Act

SE – self-use energy

SP - Solar Power

UN - United Nations

CHAPTER 1

RESEARCH INTRODUCTION

1.1 INTRODUCTION

Renewable energy is the alternative source of electricity generation in South Africa and other countries in the globe. Many researchers believe that fossil fuel energy has reached its optimum existence due to its negative impact on the environment. Governments promote renewable technology use to change from fossil-fuelled energy systems in order to decarbonise the energy sector (Castaneda *et a*l., 2017). As many types of renewable as there are, solar power energy has been seen as a more reliable energy source than other types of renewable energy such as wind, nuclear energy and wave energy in South Africa.

The current state of emergency in the South African energy sector has been caused by many factors and one of them is the increased economic development. South African energy consumption has risen due to growing economic development (Ye, *et al*. 2018). To mitigate the energy crisis, Eskom planned in 2005 to expand its generation capacity by 17,120 MW.

Jain and Jain (2017) cited that the Republic of South Africa is the southernmost country on the African continent that is found between latitude 22° to 35°, and longitude 17° to 33°. South Africa has nine provinces that experience sunlight in different magnitudes. Even though provinces experience sunlight differently, KwaZulu-Natal province is one of the three provinces receiving the most sunlight. The KZN region has multiple municipalities and one of them is eThekwini municipality. This study has been conducted based on the case study of eThekwini municipality. The author is of the opinion that the KZN region can play a prominent role in advancing the objectives of clean renewable energy in South Africa.

Fig.1 shows the map of South Africa with big cities located in each province. As this study focuses on the KwaZulu-Natal region, it is important to mention the cities located in these regions that are shown in the figure below. Ladysmith, Richards Bay and Durban are the major cities in KwaZulu-Natal as shown in the figure below. However, Durban is the most important city for this study since the eThekwini municipality is in Durban and it is a big city in the region of KwaZulu-Natal. However, the capital city of KZN remains Pietermaritzburg.

Figure 1. 1: South African map displaying capital cities (Jain and Jain, 2017).

This chapter covers the key definitions, background to the research, research problem statement, research aim and objectives, research questions, research methodology, research summary, research significance and the research rationale; it also outlines subsequent chapters outlines and ends with a conclusion.

1.2 KEY DEFINITIONS

Fossil fuel energy ─ according to Bulut and Muratoglu (2018), fossil fuel energy is energy generated through oil, natural gas and coal to conduct electricity.

Renewable energy sources (RES) ─ Dostal and Ladanyi (2018) defined RES as the technical means that gather the obtainable energy within range and begin to transform it and supply energy to the consumer for consumption.

Energy efficiency – according to Aliyu, Modu and Tan (2018) it is the act of replacing electrical equipment with equipment consuming less energy but with the same output magnitude.

Consumption rate ─ it the amount of energy used and is determined by numerous factors such as economic, social and physical essentials (Damari and Kissinger, 2018).

Sustainability system – a simple defined sustainable system is a system which survives or persists (Costanza and Patten, 2015).

Climate change – is the changing of the environment that impose probably the utmost long-term challenge bordering the human race (Shove, 2010).

Independent power producer (IPP) – NERSA (2018) defines IPP as typically limited-liability, investor-owned initiatives that produce electricity aimed at bulk sale to an electric utility or for retail sale to business or other consumers under certain conditions.

Renewable energy – is defined as energy generated from solar, wind, geothermal, tide and wave, wood, waste and biomass (Sebri and Salha, 2013).

Concentrated solar power (CSP) ─ is defined as a low-carbon technology that has the potential to contribute meaningfully to the energy evolution (del Río and Mir-Artigues, 2019).

1.3 BACKGROUND

South Africa is a developing country situated on the African continent. Electricity plays a very important role across the continent as far as economic development is concerned. A major portion of the energy in South Africa is currently generated through fossil fuel because it was found to be more reliable than other sources of energy. According to the study done by Afonso and Jalles (2017), fossil fuel remains the source of energy in the global energy mix most connected to the increase of carbon dioxide (CO_2) emissions. South Africa has historically relied primarily on coal for electricity generation, making the electricity sector one of the dominant greenhouse gas emitters (Musango *et al*. 2011). In the present generation, the human action that increases environmental damage needs to be eliminated. The access to modern energy services is crucial for sustainable socioeconomic development, given the optimistic relationship between energy access and human development (Sakah *et al*., 2017).

The current fossil fuel energy utilised by many countries including South Africa has had a negative impact on Earth and everything living in it (humans, animals and plants). One of the impacts is that it speeds up the changing of climate. Significantly, South Africa has been experiencing a high level of unsustainability of fossil fuel energy. The South African energy sector governed by Eskom has been forced to implement a system of scheduled load shedding because of power failure caused by, inter alia, a shortage of energy resources such as coal. As a developing country, there will be number of challenges that will face the country when it comes to renewable energy branching. On a positive note, South Africa is not isolated in that it is able to work together with many other countries who are in a similar predicament (for example, South Africa is part of the BRICS group of countries, the United Nations and the African Union). This is helpful in overcoming some of the challenges posed by RE.

Climate change has united countries in the form of the United Nations (UN) to deal with factors affecting climate. Renewable energy is classified as the next alternative energy source in the globe. Fossil fuels are more and more unattainable in terms of removal (from the earth) as new reserves become harder to find (Hadian and Madani, 2014). Development of cities or entire countries is reliant on the availability of energy to drive the latest technology (Hadian and Madani, 2014). Sunlight, wind speed, rainwater, tides, emissions, and geothermal temperature are examples of renewable energy sources (RES). Four vital areas of energy that are provided by renewable energy include electrical energy generation, wind and water heating/cooling, transport and country energy services. According to Halicioglu and Ketenci, (2018), South Africa's specific goal for greenhouse gases (GHG) is to set a goal of limiting annual global warming to 1.5° which will essentially result in a zero emission between 2030 and 2050.

The sustainability of renewable energy has become a challenge for industry since it is being considered as an effective response to climate change, which has a major impact on energy generation. The previous studies done clearly demonstrate that renewable energy has enabled job creation to a greater degree than coal/oil in developed countries such as United State and China. There is some background information available on the types of renewable resources that can be considered to generate energy at a low cost. However, the author has not come across the scientific report referencing such for South Africa.

Fig.1.2 illustrates the connection of power systems and the reaction of all resource of power in order to meet energy demand. In this diagram renewable energy is seen as an input and energy demand optimizer (RE assist in meeting energy demand and ensure energy sustainability) and controller in order to get the loads as an output.

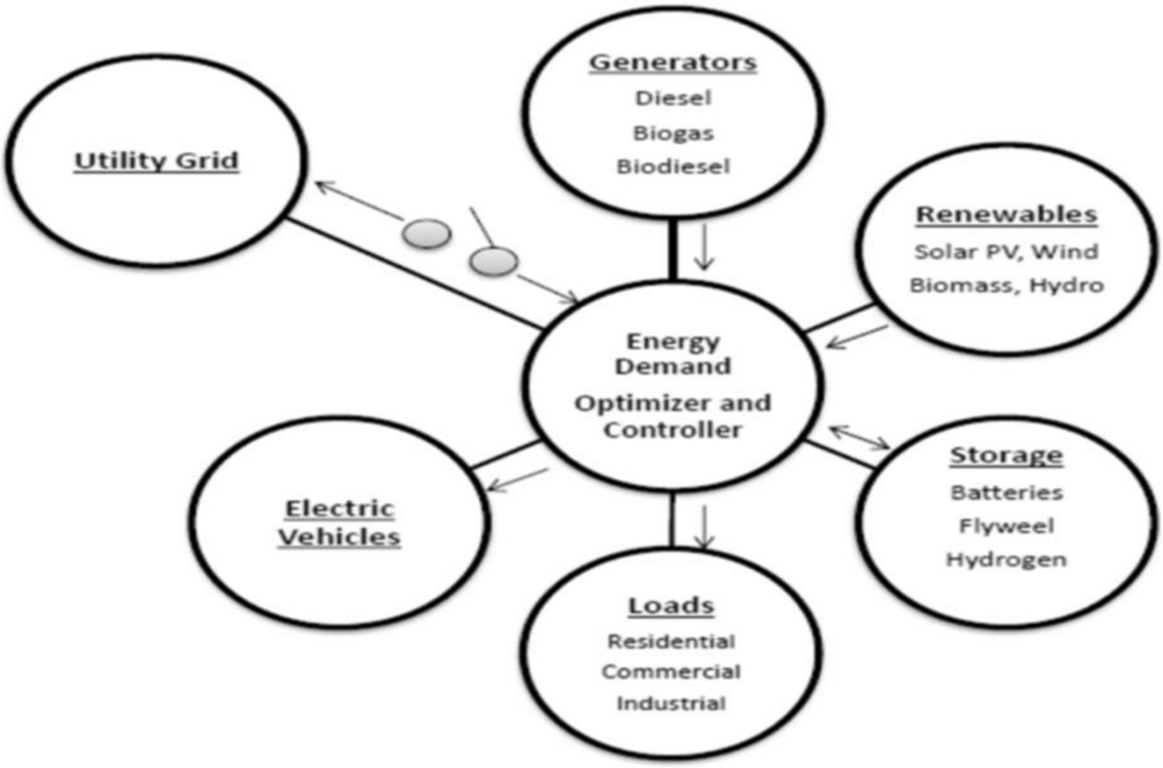

Figure 1. 2: Schematic of micro grid power system. (Ghenai *et al*. 2018)

In order to promote the use of renewable energy production and consumption, Halicioglu *et al*. (2018) believed that it would require a considerable tax incentive, special credit schemes, and political willpower to meet the substantial cost of a certain transition period. Electricity is utilised in mostly three categories, namely residential, industry as well as commerce and public service. All three electricity consumption areas are very important when it comes to the economy of the country.

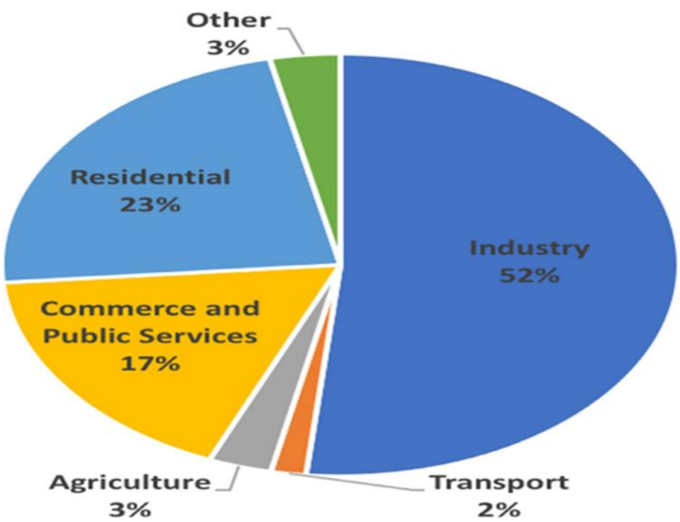

Figure 1. 3: **South African Sectorial Electricity Consumption in 2014 (Bohlmann and Inglesi-Lotz, 2018).**

Bohlmann and Inglesi-Lotz, (2018) believed that there was a need to conduct a detailed study on residential sector energy consumption patterns to determine suitable policies and measurements that will be able to tolerate future increases in electricity access in the residential sector whilst working on policies to reduce CO_2 emissions.

Many studies have been carried out to assess the need for electricity in SA. Tables 1 and 2 represent the energy demand at different times during weekdays. However, these tables do not show the whole of SA as they focused on Stellenbosch and KwaZulu-Natal, but its studies result of energy demand. Table 1.1 shows six groups' energy demand at different time intervals per weekday. The fourth category (22:00 to 05:00) shows a minimum energy allocation total of 3864 Wh while the third category (17: 00 pm to 22:00 pm) shows the highest energy consumption of 82552 Wh.

Table 1. 1: Weekday demand profile (per group and per house) (Monyei *et al*., 2018)

Group Number	**Time**			
	05:00–08:00 **df=0.8**	**08:00–17:00** **df=0.6**	**17:00–22:00** **df=0.8**	**22:00–05:00** **df=0.6**
1	3 213.6 Wh	480.6 Wh	712 Wh	373.8 Wh
2	1 1893.6 Wh	480.6 Wh	6312 Wh	373.8 Wh
3	1 2013.6 Wh	480.6 Wh	6712 Wh	373.8 Wh
4	2 2613.6 Wh	480.6 Wh	8712 Wh	373.8 Wh
5	2 4437.6 Wh	534.6 Wh	14792 Wh	415.8 Wh
6	1 6117.6 Wh	534.6 Wh	20384 Wh	415.8 Wh
Total (Wh)	24768 Wh	4968 Wh	82552 Wh	3864 Wh
df – dispatching factor				

Table 1.2 focuses on a daily consumption per household. Daily intervals are divided into four categories. The first one is from 5:00 am to 8:00 am; the second one is from 8:00 am to 17:00pm; the third one is from 17:00 pm to 22:00 pm and the last one is from 22:00 to 5:00 am. The consumption varies as per category and as per household. The energy consumption allocation shows that category 2 (8: 00 am to 17: 00 pm) has a constant allocation of 378 Wh. The other categories show different variations per household and this variation is determined by the number of activities conducted. However, house number 4 demonstrates a very high consumption of about 4669.07 WH per day. The minimum energy allocation is 1321.40 WH

per household. Table 1.2 clearly demonstrates the approximate energy demand per household during the different daily intervals.

Table 1. 2: **Weekday energy allocation per house (Monyei *et al*., 2018).**

		05:00–08:00	**08:00–17:00**	**17:00–22:00**	**22:00–05:00**	**Sub–total**	**Total**
House 1	LP1–LP4	213.60 Wh	378 Wh	356 Wh	373.80 Wh	1321.40 Wh	2021.40 Wh
	LP5–LP7	350 Wh	0 Wh	350 Wh	0 Wh	700 Wh	
House 2	LP1–LP4	213.60 Wh	378 Wh	356 Wh	373.80 Wh	1321.40 Wh	1321.40 Wh
	LP5–LP7	0 Wh	0 Wh	0Wh	0Wh	0Wh	
House 3	LP1–LP4	213.60 Wh	378 Wh	356 Wh	373.80 Wh	1321.40 Wh	3196.40 Wh
	LP5–LP7	750 Wh	0 Wh	1125 Wh	0 Wh	1875 Wh	
House 4	LP1–LP4	237.60 Wh	378 Wh	396 Wh	415.80 Wh	1427.40 Wh	4669.07 Wh
	LP5–LP7	1266.67 Wh	0 Wh	1975 Wh	0 Wh	3241.67 Wh	
House 5	LP1–LP4	213.60 Wh	378 Wh	356 Wh	373.80 Wh	1321.40 Wh	1988.07 Wh
	LP5–LP7	166.67 Wh	0 Wh	500 Wh	0 Wh	666.67 Wh	
House 6	LP1–LP4	213.60 Wh	378 Wh	356 Wh	373.80 Wh	1321.40 Wh	1321.40 Wh
	LP5–LP7	0 Wh	0 Wh	0 Wh	0 Wh	0Wh	
House 7	LP1–LP4	237.60 Wh	378 Wh	396 Wh	415.80 Wh	1427.40 Wh	3969.07 Wh
	LP5–LP7	916.67 Wh	0 Wh	1625 Wh	0 Wh	2541.67 Wh	
House 8	LP1–LP4	237.60 Wh	378 Wh	396 Wh	415.80 Wh	1427.40 Wh	3969.07 Wh
	LP5–LP7	916.67 Wh	0 Wh	1625 Wh	0 Wh	2541.67 Wh	
House 9	LP1–LP4	213.60 Wh	378 Wh	356 Wh	373.80 Wh	1321.40 Wh	1321.40 Wh
	LP5–LP7	0 Wh	0 Wh	0 Wh	0 Wh	0Wh	
House10	LP1–LP4	213.60 Wh	378 Wh	356 Wh	373.80 Wh	1321.40 Wh	1988.07 Wh
	LP5–LP7	166.67 Wh	0 Wh	500 Wh	0 Wh	666.67 Wh	
LP – Load point							

There is a demand for electricity provision in South Africa despite the challenges the energy sector is facing: electricity makes people's lives easier and supports innovation. There is evidence of tis in previous research which noted the slowed growth of the economy as a result of an unreliable supply electricity. Mustayen *et al*. (2014) also believe that the implementation of renewable energy in developing countries can play a critical role in reducing the demand for energy.

In as much as there are various sources of renewable energy available, the effectiveness of each source is limited by specific constraints. Sunlight energy seems to be the one favoured in the KZN region in South Africa. Having mentioned that solar power technologies can convert the solar radiation direct or indirect to electricity deprived of intermediate medium (Ogunmodimu and Okoroigwe, 2018). Solar plants can use one of the two sets of available technology, solar thermal or solar photovoltaic (PV) but solar photovoltaic (PV) has better possibilities than wind (Baker and Sacool, 2017).

Fig.1.4 illustrates the two sets of solar power plant technology, solar thermal and solar PV technology. Fig.1.4 shows the connection flow from solar to electricity production. Solar PV demonstrates an easier flow of energy compared to solar thermal. Electric power will be produced when all these connections are well connected and properly maintained.

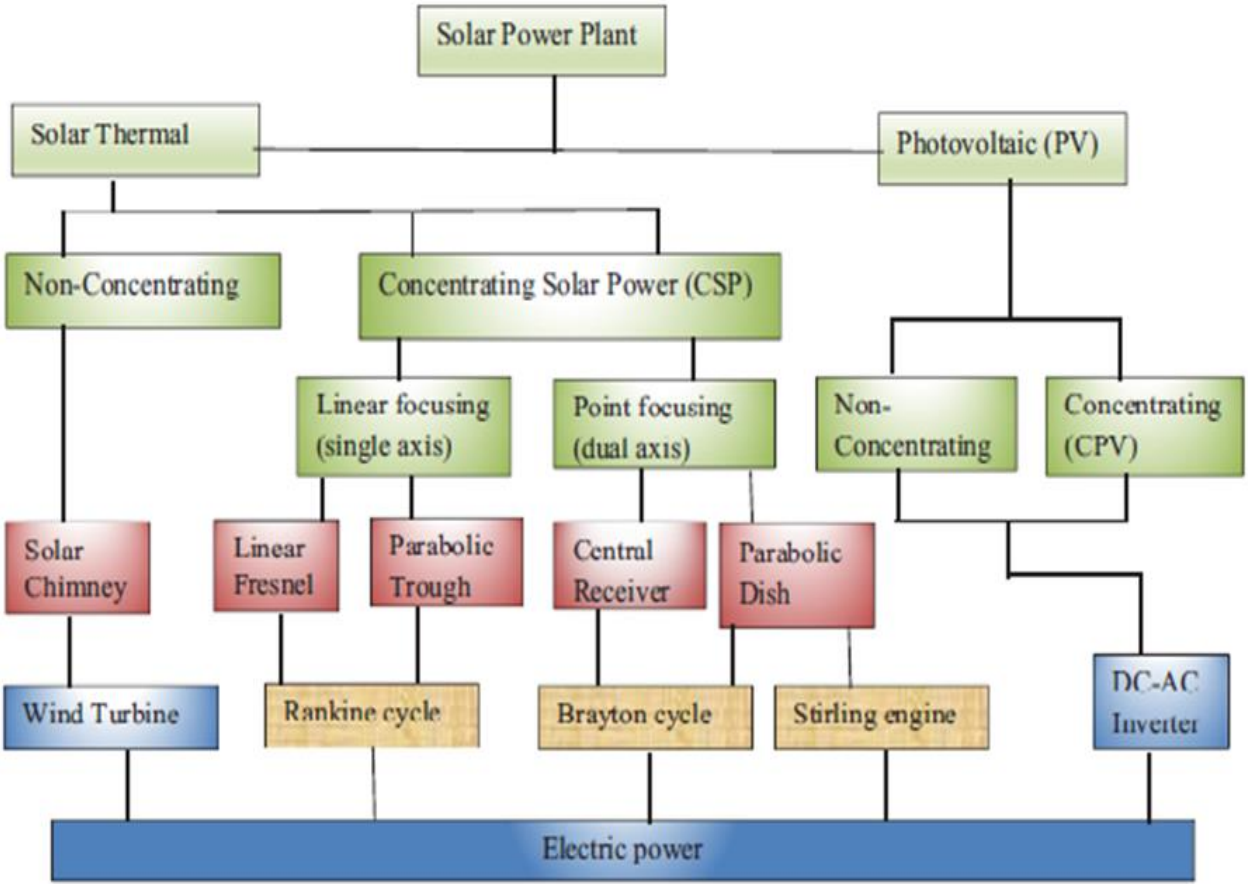

Figure 1. 4: Solar plant technology set (Ogunmodimu and Okoroigwe, 2018)

It is important to examine the system that shows less connection as demonstrated in Figure 1.4. Figure 1.5 only selected the photovoltaic (PV) technology for the purpose of analysing the solar power technology flow of current from the start to the finish as PV system clear demonstrate flow of current compare to CSP according to the author. Solar panels will absorb solar energy and distribute it to the control unit, where it is controlled and directed to the correct motor before being transmitted to the storage area. The energy will be supplied to the irritation system head and irrigation field for usage.

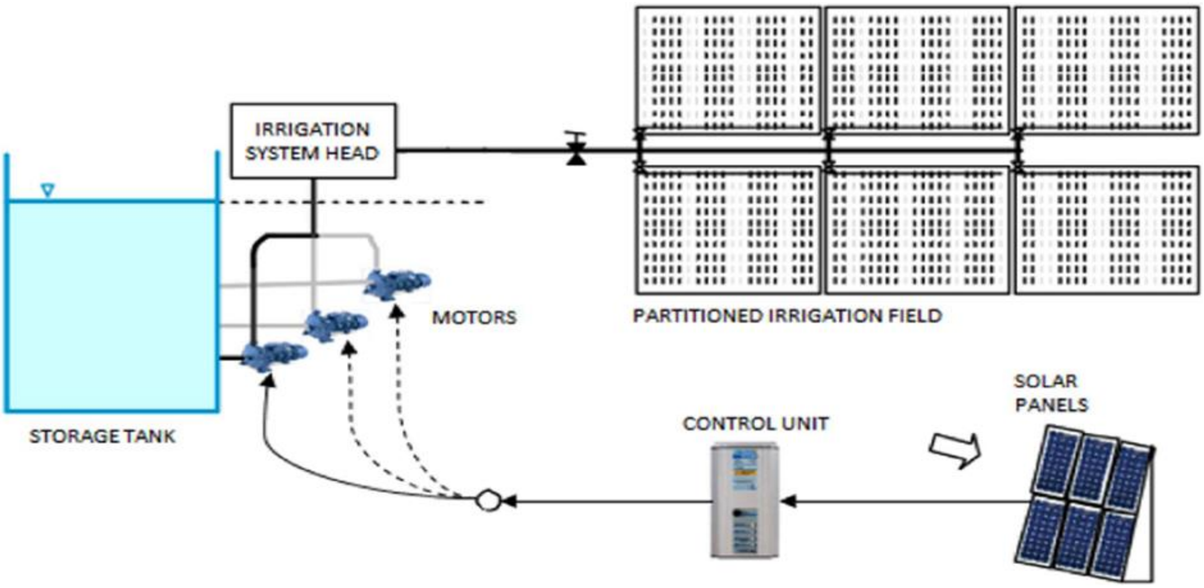

Figure 1. 5: PV irrigation system management layout (Jain and Jain, 2017)

The KwaZulu-Natal region is divided into rural areas, townships and urban areas and these areas all require energy. However, the rural areas seem to have less access to energy according to Jain and Jain (2017) as depicted in the statistics – 55% for rural and 88% for urban. In households in rural areas there is a trend away from low-quality fuel (e.g. biomass and firewood) to accomplish energy requirements (Bohlmann and Ingles-Lots, 2018). Manju and Suger, (2017) cited that South Africa has renewable electricity generation of about 2% as cited by the United Nations Statistics Division of 2009. However, this 2% is not applicable to the KZN region. The eThekwini municipality is planning to install 40% of its solar power systems by 2030 (Ntshalintshali, 2016).

There are many players when it comes to a country's energy implementation. In order for the energy sector to remain in good shape policies are needs to regulate the energy industry. South Africa has the National Energy Regulator of South Africa (NERSA) that regulates the energy industry when it comes to installation as well as pricing. The Department of Energy as well as Eskom, which is the producer of energy in South Africa, oversee the overall energy project in the country. These two bodies work together to ensure the sustainability of energy in the country.

Despite the slow growth of a solar power system in South Africa, other countries are forging ahead with solar implementation. Germany is one of the countries that are making good progress when it comes to implementing solar power projects. Germany has managed to increase electricity production from 7% in 2000 to nearly 25% in 2013 (Frondel *et al*., 2014). That being said, Germany has still not been able to comply with the target set by the

European Union (EU), or its own voluntary goal of a green electricity as part of 35% predicted for 2020.

Fossil energy sources, such as coal and oil, are blamed for environmental degradation that constitutes almost 60% of CO_2 emissions of greenhouse gas (GHG) (Halicioglu and Ketenci, 2018). This has led to the formation of the EU and Germany is one of the 15 countries that participate in the EU. According to Frondel *et al*., (2014), Germany was the leader in successful solar power installation, and they had focused the world's attention on the invention of solar electricity based on photovoltaic (PV) technology electricity production as best practice. The following table demonstrated the leading capacity of Germany in terms of PV with approximately 32 411MW.

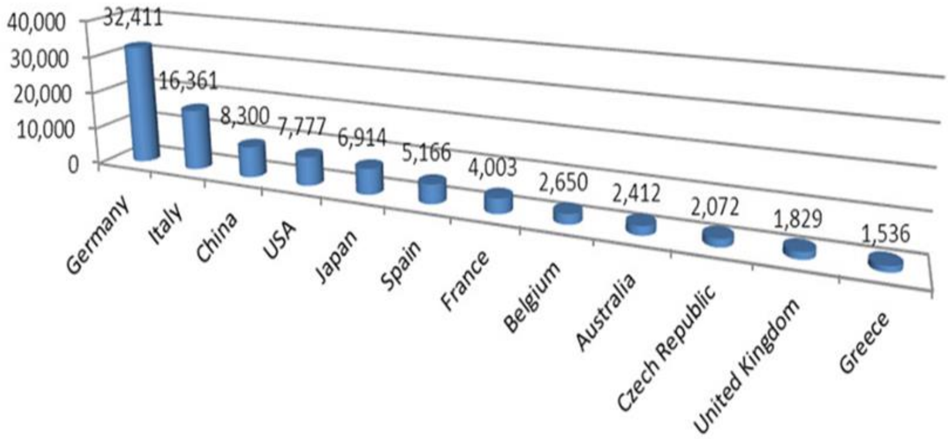

Figure 1. 6: **Total photovoltaic capacities in megawatt (MW) in 2012 (Frondel *et al*., 2014)**

Germany is reported to be largest emitter of CO_2 gases in the European Union (Weida *et al*., 2016). One of the reasons that has made German succeed in the installation on renewable energy is that government has prioritised the RE projects. According to Weida *et al*., (2016) in the Energy Concept, the German Federal Government has recognized determined goals for greenhouse gas (GHG) emissions reduction. The average monthly solar irradiation in Germany ranges between 160 kWh/m²/a (winter) and 1975 kWh/m²/a (summer), with only minor differences by region (Weida *et al*., 2016).

Although Germany is not a hot country like South Africa, and the KZN region in particular, it has installed solar projects successfully. When comes to RE (solar power systems) Germany has kept track of renewable energy technology that has developed significantly in recent years (Weida *et al*., 2016). Financing and marketing have also played a part in the successful installation of solar [power/energy] in Germany.

Germany has supported solar PV for many reasons and one of them is that it reduced the need for future investment in transmission and network capacity, as well as power generation capacity (Frondel *et al*,. 2014). The requirements for the KZN region are no different to Germany's solar projects but more support from the stakeholders including politicians is required [for solar projects to be successfully implemented]. Two criteria, namely economic and environmental criteria should be used to validate the profitability of this system (Brunet *et al*. 2018).

Renewable energy has many challenges that affect its sustainability. Even though Germany promotes the use of a solar PV system, there are still many challenges that have been found to affect the system. Brunet *et al*. (2018) compiled the following challenges facing the on-grid PV system. The KZN region will have to heed these challenges to ensure sustainability.

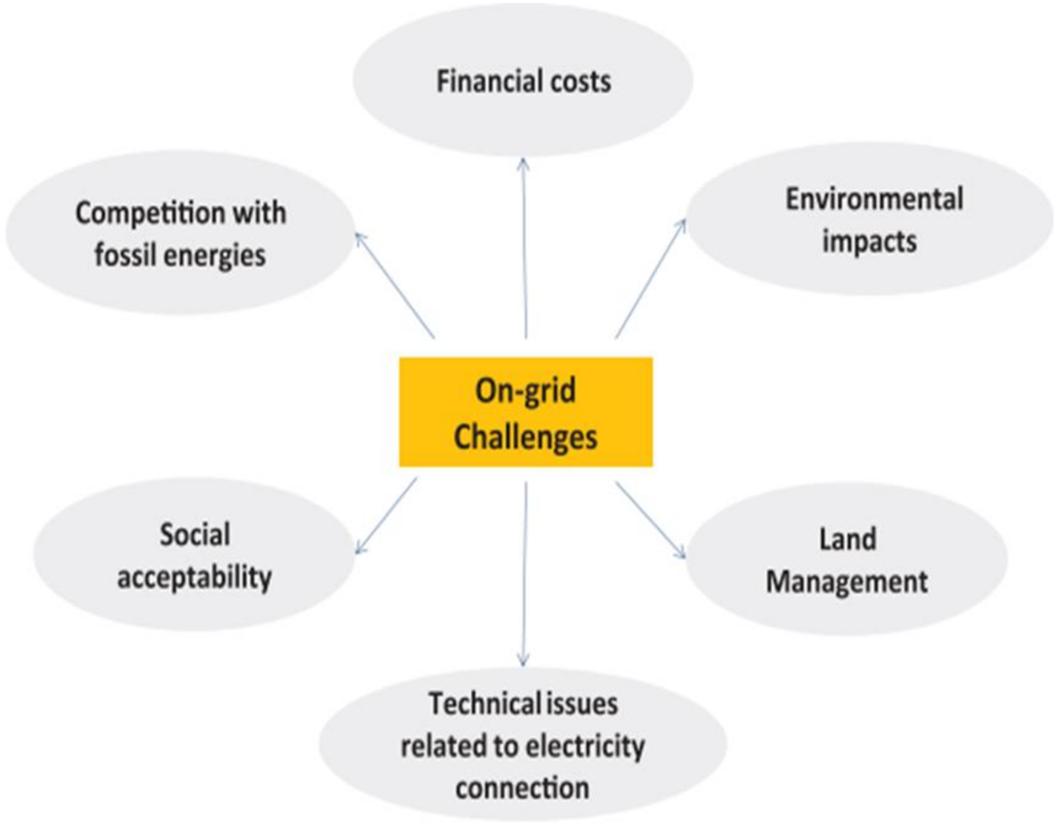

Figure 1. 7: Challenges of on-grid PV (Brunet *et al*. 2018).

1.4 PROBLEM STATEMENT

The South African (SA) energy sector has been experiencing challenges when it comes to implementing and sustaining renewable energy. Renewable energy technology poses a challenge to the SA energy sector although it dramatically improved the energy situation in developed countries such as China and the USA. Generally, energy consumption in South African residential areas has increased continuously due to the rise in population (Bohlmann and Ingles-Lots, 2018).

South Africa is one of the hottest countries in the world and as such, solar power is a possibility (Pan and Dinter, 2017). Fortunately, SA has an excellent solar resource (van Ravenswaay *et al*. 2015). However, renewable energy, solar power in particular, has not been implemented to any significant degree in the country as a whole, and thus also in the KZN region. KZN experiences more sunlight than some of the other provinces, but the major challenge is that solar power has not been significantly implemented and it is not as sustainable as it is in the Western Cape Province. Furthermore, the Northern Cape province has a concentrated solar power (CSP) plant located in the desert which has several advantages (Mahlangu and Thopil, 2018), while the KZN region has less than ten solar energy plants. Figure 1.8 shows the renewable energy plants in South Africa, where the KZN region shows minimal implementation of renewable energy. Figure 1.8 confirms that there is a less implementation of solar and other renewable energy in the KZN region.

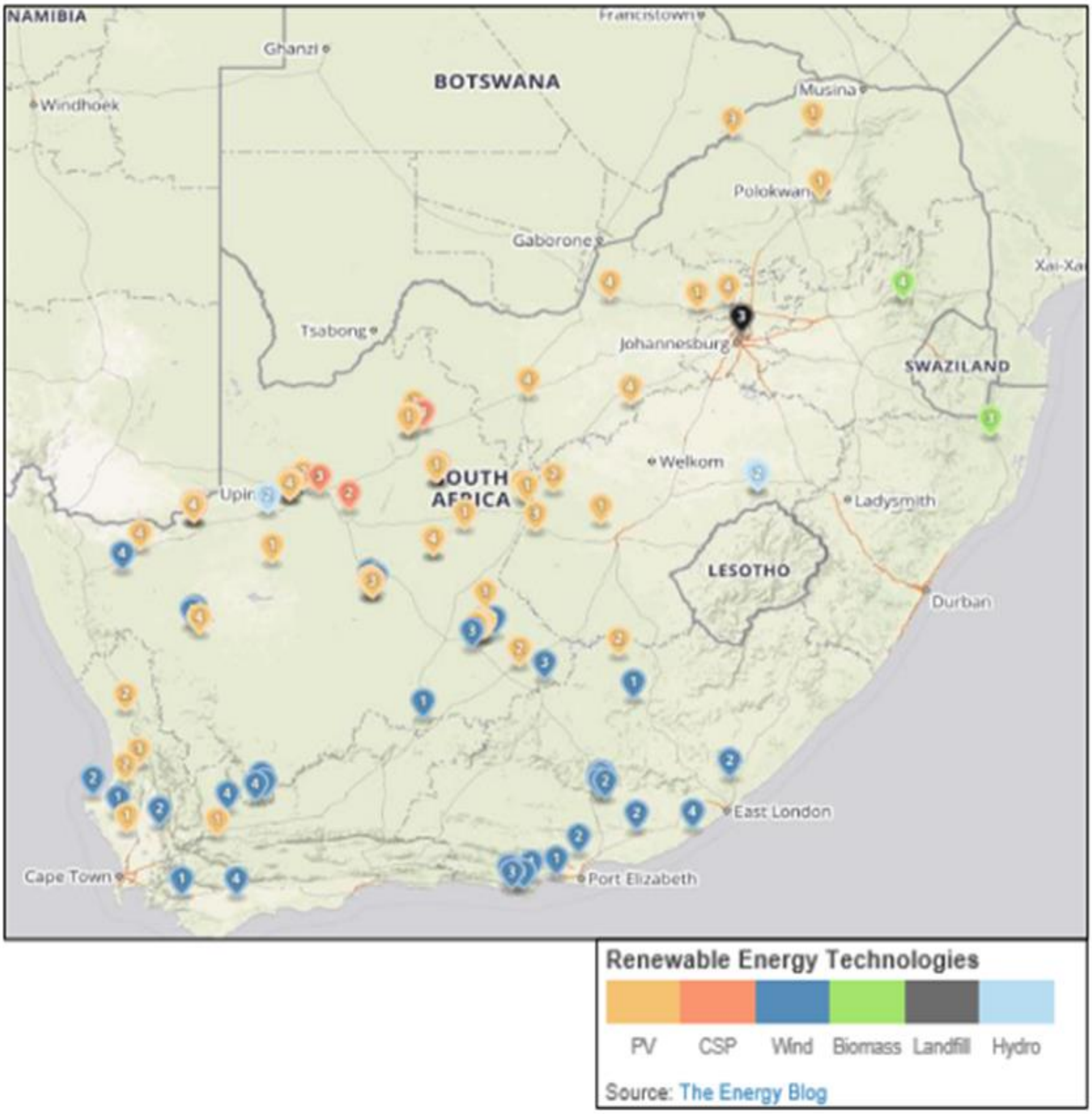

Figure 1. 8: **Geographical location of RE (DoE IPP Projects) in South Africa (NERSA, 2018).**

Reduced costs are one of the significant benefits of solar (Pierce *et al*. 2018). Availability, reduced costs and constructive economics as well as public acceptance are factors supporting solar exploitation (Nuortimo *et al*., 2018).

Moreover, the climate of Durban (eThekwini municipality city) is described as humid subtropical with a hot summer and mild winter (Zawilska and Brooks, 2011). With this in mind, it can be expected that a solar power system would perform well.

1.5 AIMS AND OBJECTIVES OF THE RESEARCH

1.5.1. Research aims

The main aim of this study was to investigate the root cause of solar power unsustainability in the KZN region. Moreover, this study intended to make recommendations on improving the current solar power status in the region.

1.5.2. Research objectives

The objectives of the study were as follows:

● to determine the root causes of solar power unsustainability,

● to investigate why solar power installation in KZN is not increasing,

● to investigate the impact of solar power failure in the region,

● to investigate costs related to renewable energy (solar power energy).

● to develop a model that will assist in eliminating the causes of solar power failure in the KZN region.

1.6 RESEARCH QUESTIONS

● What are the root causes of solar power unsustainability in the KZN region?

● What are the processes involved in implementing solar power in the region and are these processes effective when solar promotion in region?

● What are the costs benefits related to the implementation of solar power energy in the KZN region?

● How long would it take the KZN region to successfully implement and sustain a solar power system?

1.7 RESEARCH METHODOLOGY

This study reviewed available literature and data sources connected to renewable energy, solar power in particular, from the previous studies. Information and data used were taken from the municipality supplying electricity to KZN. Secondary data was extracted from recent papers and articles dated from 2010 to the present. These sources were selected based on the value of the information and its ability to provide an impartial contribution from the scientific community and energy industry as a whole.

The study adopted the quantitative method in the form of analysing the correlation between the use of solar power and its energy production. A cost benefit analysis was conducted to rationalize the implementation.

1.8 STUDY RATIONALE

The research was motivated by the fact that there is a high demand for electricity in the KZN region. Electricity has a very significant role in today's life. Therefore, an innovative and effective alternative way of meeting this growing energy demand has to be researched and developed.

It was therefore important that the solar power information and current status was analysed in such a way so as to eliminate solar failure in short term and increase future electricity production.

1.9 SIGNIFICANCE OF THE RESEARCH

Energy consumption in South Africa has risen due to the increase in economic development (Ye *et al*. 2018). The energy demand crisis is increasing in the region and there is a less implementation of the solar power as an alternative of energy supply. The KZN region is the one of the areas that has experienced the rising costs of electricity supply in South Africa. This brought many insecurities, for instance the hazards of energy security has also increased, therefore there is a need to come up with alternatives such as solar power to overcome the energy scarcity and high cost., and solar energy in particular becomes an option because of However, solar power sustainability need to be taken to consideration in order to see it advantages such as being environmentally friendly, less expensiveness and providing a reliable energy source.

1.10 LIMITATIONS

This thesis did not cover the topics listed below as they are outside the scope of the study.

- The design of solar power system, but not an analysis of the current solar system.
- The safety and precaution analysis of a solar power system.
- The development of new solar policies but overlooking the current policies.
- A business analysis and market survey of the press brake in South Africa.

1.12 CHAPTER SUMMARY

The dissertation study includes five chapters, defined as follows:

Chapter 1 - Introduction: provides a background to renewable energy, a problem statement of the study, the method used, the aims and objectives, and an overview of the significance of the study and research questions. This chapter also reflects on the rationale and research layout.

Chapter 2 – Recent literature supported by research findings is reviewed and summarised and is used to analyse the challenges confronting the implementation of solar power in the KwaZulu Natal region.

Chapter 3 – Methodology: this chapter discusses the research strategy and the methodology used to approach the problem and explains how the data was gathered. This chapter explains the process followed to identify and analyse problems and indicates the way in which the study was planned.

Chapter 4 - Focuses on the analysis of results using the Cause and effect technique, cost benefit technique as well as the statistical tool such as ANOVA to conduct multiple regressions and also discusses the suggestions emanating from the results.

Chapter 5 - As the last chapter of this dissertation, it concludes the study by providing answers to the research questions and objectives and makes some valuable recommendations. The chapter concludes by identifying areas of possible future research opportunities.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This literature review in this chapter reviews appropriate past rese renewable energy (mostly solar power) research and concentrates on articles written between 2010 and 2018 to acknowledge the latest studies regarding renewable energy.

Sustainability is a critical aspect when it comes to implementing renewable energy in South Africa or any other country. Various aspects with regard to renewable energy have received attention by researchers in the past few years (2010 to 2018); some of the aspects that have received interest are:

- Significance of renewable energy
- Sustainability of renewable energy
- Financial aspects
- Education around renewable energy
- Environmental and technological development
- Government policy regarding renewable energy
- Energy consumption overview.

These critical aspects of renewable energy have been discussed in detail and analysed by various researchers.

2.2. SIGNIFICANCE OF RENEWABLE ENERGY

Development of renewable energy (RE) continues to be promoted by the growing concern about climate change that necessitates the reduction of greenhouse gas (GHG) emissions according to Zhang *et al.* (2019) and Mahlangu and Thopil (2018). Zerrahn *et al*., (2018) believed that utilizing renewable energy sources is the main strategy for decarbonizing the global economy. Ozonoh *et al.*, (2018) added that the emissions from the coal projects (fossil fuel energy) pose an enormous threat to the environment. The primary role for government is to set specific targets for the total power generation and each energy source and government policy makers should consider the uncertainty in the energy demand (Kim *et al*., 2018).

There is wide gap that needs to be bridged in energy access between rural and urban areas yet there is limited fossil fuel energy to close the gap (Monyei *et al*., 2018). Li *et al.* (2018c) believed that fossil resources are on the verge of exhaustion, and this throws up a demand for renewable energy sources to close the gap. Demands for electricity have grown rapidly and this demand will continue for the next 25 years according to Labordena *et al.* (2017) citing EIA, 2013 and IRENA, 2015a. As energy demand increases, Kumar, Prakash and Dube (2017) pointed out that non-renewable energy resources are being depleted at an alarming rate and renewable energy is the best alternative source of energy.

Jain and Jain (2017) pointed out five consequences of diminished or no access to electricity, which are:

- Absence of industrial development
- Scarcity of employment opportunities
- Lack of educational equality
- Persistent poverty
- Diminished standard of living.

Developing countries such as South Africa are facing a severe power crisis and have failed to meet their own electricity demands thus precipitating a real need to seek alternative sources of energy (Jain and Jain, 2017). Joubert, Hess and Van Niekerk (2016) concurred when they said that renewable and sustainable alternatives were becoming every important as individuals realised the harmful effects of fossil fuel emissions on health and the environment.

2.3 SUSTAINABILITY OVERVIEW

There are some key factors that affect the sustainability of the world (Malkki *et al*. 2015). Malkki *et al*. (2015) analysed the learning result to recognize the learning outcomes and basics of the courses (such as engineering sciences), together with renewable energy along with sustainability. The approach to sustainability and the skills required to develop renewable energy have to improve in order to increase renewable energy and improve efficiency.

Dostál and Ladányi (2018) believed that the time profile of electrical and thermal energy varies which increases energy supply unreliability, this brings a major challenge as energy consumers consistently needs it reliability and availability. The increasing unreliability of energy increases the need to meet the demand for energy, particularly in rural areas. Germany established the significant Renewable Energy Sources Act (RESA) that proposed favourable circumstances to effect savings in renewable energy electricity production, assuring steady feed-in tariffs (FIT) for close to two decades and even longer to ensure sustainability (Frondel *et al*., 2014). According to Dostál and Ladányi (2018), energy storage presents technological challenges. Energy storage technology seems to encounter challenges because energy cannot be stored for any length of time.

Inasmuch as technology to generate electricity and technology affecting utilization hours of electricity generation differ, sustainability remains the challenge (Weida *et al*., 2016). Among all the forms of RE (wind, solar, sea etc.), solar energy seems to be the most reliable energy source, but the solar system relies mainly on sunlight energy, battery, panels and technology wiring which make it more reliable (Spachos and Mackey, 2018). Furthermore, an added benefit of solar power is that solar devices do not require power maintenance in the form of replacement or boosting, which is common to most wireless devices, according to Spachos and Mackey (2018).

In order for the sustainability of renewable energy to be a success, certain factors need to be considered. The scale of any renewable energy project also needs to be taken into consideration for various reasons, one of which is to ensure the sustainability of renewable energy, solar energy in particular. Fig. 2.1 discusses these factors from the past research conducted by researchers. Environment, economical, technical, political and social factors are factors that could have an effect as presented in fig. 2.1.

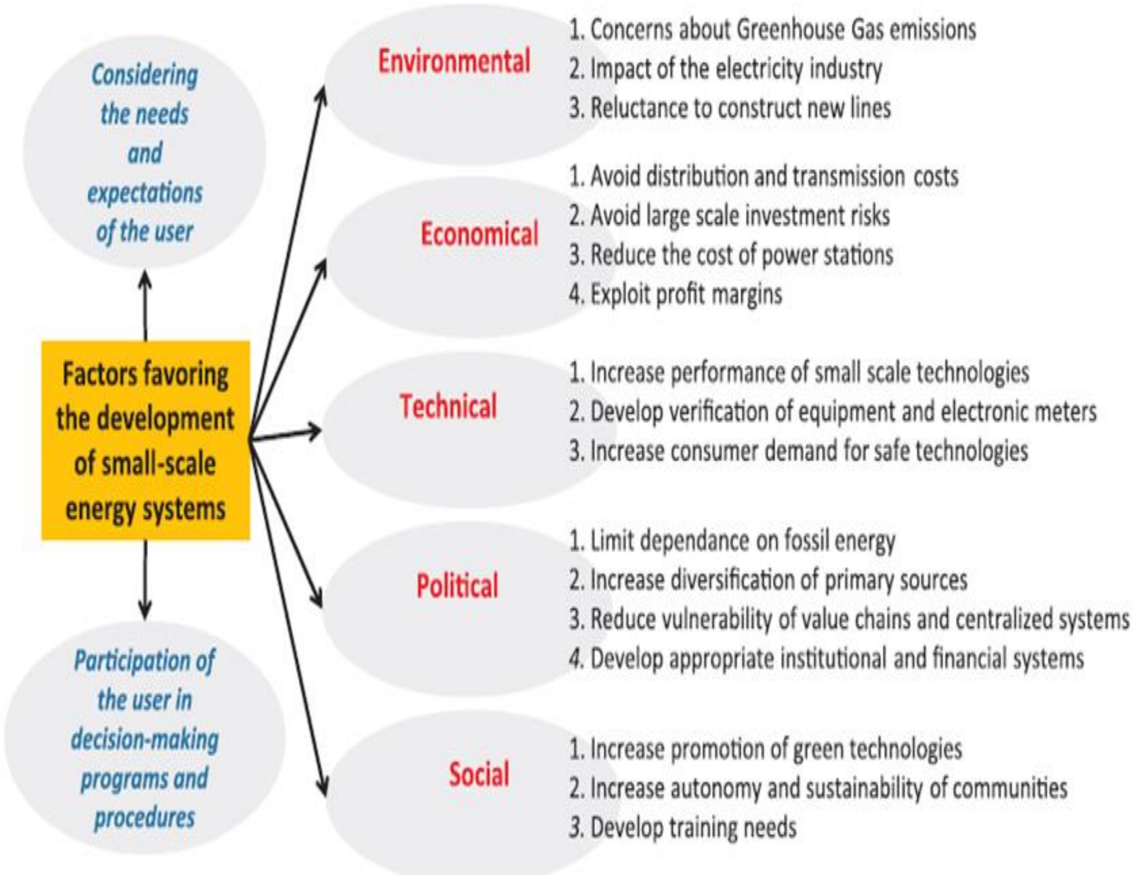

Figure 2. 1: **Factors affecting the development of small-scale energy systems Brunet *et al*., 2018)**

Fig. 2.1 represents factors that favour the small-scale development; the factors mentioned above are the contributors to the sustainability point of view. If all the factors were taken to consideration before implementing the renewable energy project, sustainability wouldn't be a challenge (e.g. if the environment was analysed prior to implementation to see if it was suitable for renewable energy implementation there would not be any challenges facing renewable energy). The same would apply to economic factors since renewable energy requires the necessary financial support which comes from investors. Investors would need a surety that investing in a RE project won't generate a loss.

2.4 FINANCIAL FACTORS AFFECTING RENEWABLE ENERGY

Renewable energy investors are exposed to high risk when the renewable energy project fails, which creates financial risk for renewable energy compared to fossil fuel, while renewable energy require huge initial investment (Schwerhoff and Sy, 2017). The sustainable development goals have shown that renewable energy has a huge potential to accomplish financial, social and ecological objectives (Schwerhoff and Sy, 2017). The total quantity of renewable energy connected is reliant on additional influences contributing to the entire connection cost of the structure (Dinh *et al*., 2018). Renewable energy funding is still lagging behind. Jadhav *et al.,* (2017) confirmed that there is a lack of appropriate financial environments when it comes to renewable energy, especially for solar technologies. Hence, financial outlay on renewables seems to play a significant role in policy making but the challenge lies in policy and educational circles (Zerrahn, *e*t *al*. 2018).

The development of renewable energy is based on capital intensive investment from investors in order for any renewable energy arrangement to be successful (Best and Burke 2018). The rate of electricity independence by 2030 and the important use of intermittent energies influencing the dependability of the electrical system were concerns that were addressed by conducting the forthcoming analysis of the Reunion Island electricity mix by 2030 (Didelot *et al*., 2017).

As renewable energy is capital intensive, governments wanting to show interest in promoting renewable energy, must capitalize the required groundwork according to Njoh *et al.*, (2019). The forecast of specific technological charges for 2030 are created from the learning curve ideal and solar PV in particular has a learning rate of about 15% and 3% respectively for onshore wind mostly (Weida, *et al*., 2016). However, for the economic examination, RET Screen needs numerous assumptions for costs of PV systems for both preliminary and yearly targets (Weida, *et al*., 2016).

Sakah *et al.,* (2017) strongly believed that renewable resources should be utilised to develop economic state such as providing electricity through renewable resources, which is why most countries established policies and supporting instruments in order to invest in renewable electricity. Generally, successful strategies are those with the capability to control the irregular nature of renewable creation (Afonso *et al*. 2017; Baker and Sovacool, 2017).

However, Polzin *et al.,* (2014) believed that investors are discouraged by the lengthy repayment periods and not enough resources attached with extraordinary controlling needs as well as consistent hesitations. These factors have negative economic implications for the renewable energy projects around the globe, including the KZN region. Gxasheka, *et al*., (2018) believed that the reduction of technology costs through competitive procurement programmes would result in lower energy prices in South Africa.

Table 2. 1: **Average global costs of renewable energy between 2010 and 2017 (Gxasheka *et al*., 2018; NERSA, 2018)**.

RE Technology	**2010 USD/kWh**	**2017 USD/kWh**
Solar PV	0.36	0.10
CSP	0.33	0.22
Total	0.69	0.32

Table 2.1 represents the economic change in technology prices around the globe. It is clear that solar PV technology was more expensive in 2010 compared to CSP global, even though there were not any major differences between the two technologies in 2010. Solar PV technology improved economically across the globe after 2010, which recently has made it a preferred technology. Its cost has reduced by 56% in 2010 and cost 0.10 USD/kWh. Yet CSP showed price reduction of 33.3% to be 0.22kWh from 0.33kWh in 2017. These dramatic changes have reduced the costs of solar technologies from a total of 0.69kWh in 2010 to 0.32kWh in 2017.

2.5 EDUCATION AROUND RENEWABLE ENERGY

In supplying information about all sorts of renewable energy, education could play a significant role. South Africa has initiated the Renewable Energy Independent Power Producers Procurement Programme (REI4P megawatts) for continuous assessment and public discussion in respect of delivery versus main purposes (Walwyn and Brent, 2015). There is still a lot to be done in educating people when it comes to renewable energy implementing policies. Renewable energy implementing policies are not being followed as expected (Energy, 2015).

Science and technology are developing at a rapid pace and the education system (vocational-technical education mostly) seems to lag behind, which affects developing countries the most (Kacan, 2015). That is why it has been found to be extremely important to conduct research and studies toward analysing and evaluating the existing energy and renewable energy education programs (Jaber *et al*. 2017). Assali, *et al*. (2019) believe that it is vital to measure the awareness of the youth when it comes to RE in conservatories such as state or private universities. The main reason for this is the fact that renewable energy implementation failure globally has to do with a lack of community awareness, policy failures and market classification (Assali, *et al*. 2019).

Finally, Jennings, (2010) insisted that education and training be delivered on every level from customers to managers in order to guarantee that renewable energy systems encounter the maximum values of dependability and efficiency.

2.6 GOVERNMENT POLICY REGARDING THE RENEWABLE ENERGY

Matters relating to renewable energy developments are precisely the political program from administration harbour (Ikejemba *et al*., 2017). Government policies are developed by the politicians in parliament. Activities such as renewable energy policy developments end up getting mixed up with politics. According to Ikejemba *et al*., (2017) critical developments such as renewable energy ends up being awarded to contemptible organisations because of political connections. Policies are more important in the new development of renewable energy and its sustainability.

Developing policies is another way a government can provide support to renewable energy development. Ling-zhi *et al.*, (2018) believed that the CSP industry needs urgent intervention in terms of government support with policies, particularly the policy rate. Comparable to other renewable energy power technologies, a good example has been set by the Chinese government when they embraced price subsidy policies to support the CSP progress (Ling-zhi *et al.*, 2018). Pfenninger and Keirstead, (2015) believed that a strategic energy policy can recommend technology over another policy for reasons to do with lasting energy security or other governmental benefits.

Governments across the globe used different stimulatory procedures and tools such as Feed-in Tariffs (FIT) to achieve installation targets, point of sale repayments, such as Renewable Energy Certificates (REC) as well as tax benefits (Chapman *et al*., 2018). Among others, demand-pull procedures (e.g. feed-in-tariffs) have demonstrated they are extremely resourceful in fostering renewables growth and many countries have implemented them to duplicate the pioneers' successes (Kuik *et al*., 2019). Kuik *et al*., (2019) said that the feed-in tariffs policies end up as set distinguished tariffs through sites and vary in terms of the agreement period. They added that accessing grid and approval procedures might be as important as the feed-in-tariff (Kuik *et a*l., 2019).

Renewable Electricity support is the first policy targeting the solar sector that uses the PV Roofs Programme which is classified as a regulatory instrument and endorsed by the installation of solar PV (Polzin *et al.,* 2014). There are many other decent policies that provide policy support mechanisms such as strategic planning which prove to be more operative (Polzin *et al.*, 2014). South Africa is classified as an upper-middle income country where policies are divided into two categories which are a Regulatory policy and Fiscal incentives and public financing. REN21, (2017) at the 22nd Conference of the Parties (COP22) in November 2016 grouped all policies that need to be considered by upper-middle income countries in order to promote RE and deal with climate change, namely:

2.6.1 Regulator policy:

1. Feed-in tariff/premium payment
2. Electric utility quota obligation/ Renewable portfolio standard (RPS)
3. Net metering Transport obligation/mandate
4. Heat obligation/ mandate
5. Tradable REC
6. Tendering.

2.6.2 Fiscal incentives and public financing:

1. Investment or production tax credits
2. Reductions in sales, energy, VAT or other taxes
3. Energy production payment
4. Public investment, loans, grants, capital subsidies or rebates.

On top of all these policies, South Africa has had its own energy policies that regulate energy in the country. NERSA has put in place policies that assist in promoting renewable energy in South Africa. Table 2.2 stipulates three policies and explains them briefly (NERSA, 2018). These policies also measure the success of implementing the RE goal in SA such as job creation.

Table 2. 2: Policies promoting renewable energy (NERSA, 2018).

Policy	**Description**
2003 White Paper on Renewable Energy	Set a target of 10 000GWh by 2013 to be sourced from various renewable energy technologies.
Integrated Resource Plan (IRP) 2010-2030	It is currently being updated.
	Outlines the preferred energy mix aimed at ensuring that the electricity demand is met over the 20-year planning period

South Africa launched the Green Economy Accord1 at the Conference of Parties (COP17)	Launched in November 2011 in Durban at the COP1
	Aimed at creating 300 000 new jobs by 2020 in economic activities as diverse as energy generation and manufacturing.
	The other objective was to ensure that there are farming activities to provide feedstock for biofuels, soil and environmental management and ecotourism.

2.7 TECHNOLOGICAL AND ENVIRONMENTAL OVERVIEW

Polzin *et al.*, (2014) viewed renewable energy technologies as major subjects connected with commercialization as well as the dissemination of innovations. Feed-in tariff includes connecting renewable energy sources such as solar PV, wind farm, micro hydro plant etc. on a service grid and exporting electrical energy to the service grid to be remunerated at a quantified rate per kWh for a certain period (Aliyu *et al*., 2018). Figure 2.2 demonstrates the general flow and system link of a renewable system, solar power system precisely. This system is in the form of technology that allows sunlight energy to be converted to energy and stored at the same time for later use. This solar panel is connected to the grid.

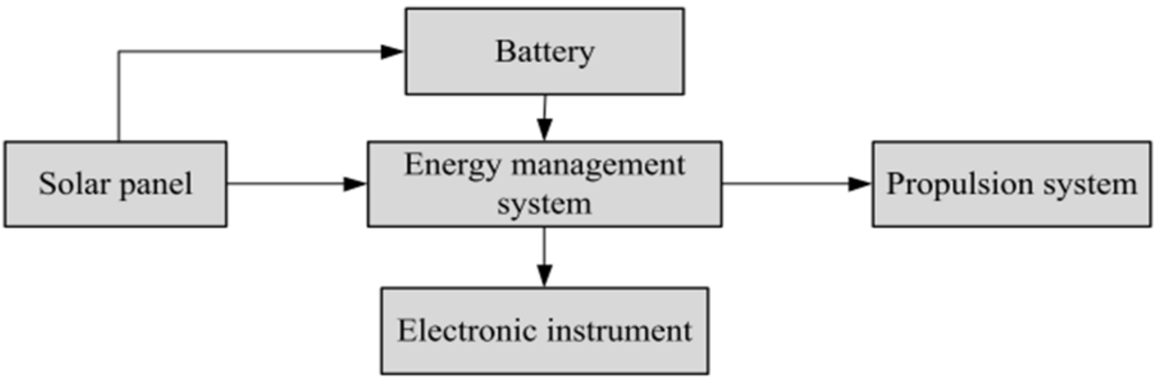

Figure 2. 2: Renewable power system of stratospheric airships (Zhu, *et al*. 2019).

Technology plays a very significant role in renewable energy and has an impact on the environment that leads to a change of climate. Pan and Dinter, (2017) believed that South

Africa is classified as one of the greatest sunspots on Earth and they believed it was suitable for photovoltaic (PV) and Concentrated Solar Power (CSP) systems considering that performance and energy production from renewable energy sources, such as PV and CSP, are extremely dependent on local conditions (Marzo *et al.,* 2018). According to Marzo *et al.,* (2018), Chile is one of the countries that demonstrated a speedy growth in solar energy technologies application in both PV as well as CSP. Jain and Jain (2017) agreed with them that solar energy is plentiful and freely available and both solar PV and thermal applications are most suitable.

Solar PV and CSP can play a prominent role in providing clean energy in South Africa. Energy mix in South Africa consists of all types of energy technology playing a role in achieving expected capacity according to the national development plan established by the South African government. Solar PV and CSP are among these technologies. Fig.2.3 illustrates the energy mix of South Africa for 2018 and 2030.

The results in Fig. 2.3 show us the achievement of introducing renewable energy in South Africa. However, fossil fuel is also represented by coal. South Africa promoted a policies framework to increase the share of RE in the national energy mix (Jain and Jain, 2017). The energy mix is currently producing a capacity of 47818MW in 2018 and it is targeted to grow this to 78344MW by 2030. Solar energy is currently contributing 300MW and 1474MW through SCP and PV respectively. There is slow growth in PV compared to CSP that has already achieved 50% of what is expected by 2030 in the country (Gxasheka, *et al*., 2018). Yet solar PV systems have only achieved 1474MW, which 18.5% of what is expected in 2030 (Gxasheka, *et al*., 2018; NERSA, 2018). The growing implementation of all renewable energy will assist in reducing coal energy by 5279MW in 2030, which is a 13.5% reduction (NERSA, 2018).

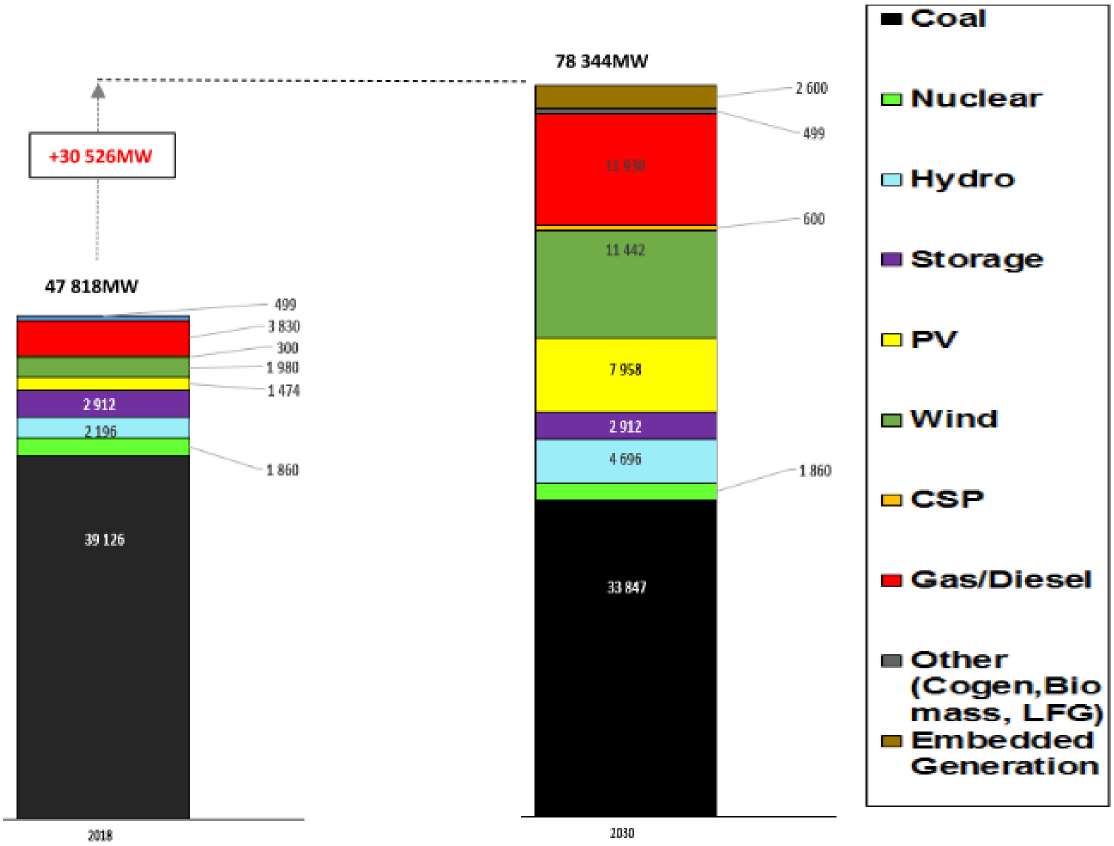

Figure 2. 3: RE Technological contribution to Energy mix of South Africa (Gxasheka, *et al*., 2018)

2.7.1 SOLAR PV SYSTEM

Past research indicates that solar PV is more utilized compare to solar panel. The solar PV system is extensively used in technology around the globe (Dondariya *et al.*, 2018). Solar Photovoltaic (PV) technology has been improved for continuous development (Peng *et al.*, 2018). Le Roux (2016) and Dondariya *et al*., (2018) reported that South Africa showed an increase in residential and overseas investment in solar power systems, and among them is photovoltaic panels. Furthermore, Zurit *et al.*, (2018) reported that solar Photovoltaic (PV) was found to be the leading RE generation technology since it signified overall 47% of new renewable energy capacity installed in 2016.

Fig. 2.4 shows the connection of a solar PV system and how it is being supplied in residential areas. Taking to account the amount of sun that penetrates the soil, previous research demonstrated that solar radiation goes into the Earth's atmosphere at an average solar intensity (Isc) of 1 W366.1 /m² (Ashfaq and Ianakiev, 2018). The connected grid system is the key global market for photovoltaic which uses the grid connection system as its storage alongside (Aliyu *et al*., 2018).

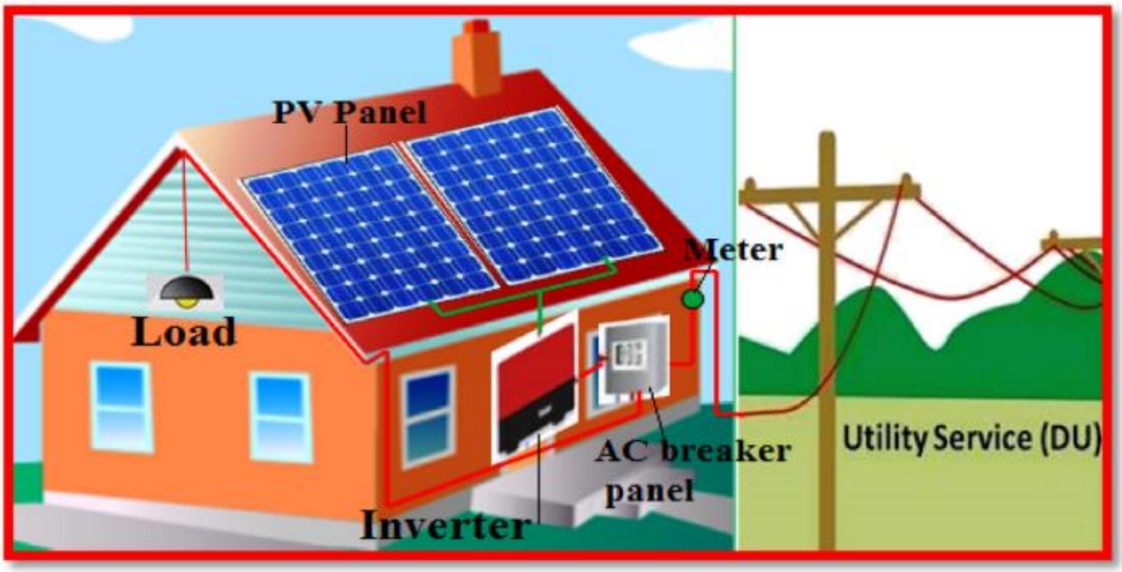

Figure 2. 4: Schematic of the connected grid PV system (Dondariya *et al.*, 2018).

According to Ayazoğluyüksel and Filik (2018), the PV system is more preferred because of numerous advantages, such as:

- It uses batteries to store additional generated energy,
- It protects the environment,
- It is user friendly with basically structure and easy application.
- PV systems economically affect industrial electrical generation energy since it requires less labour and technology,
- The significance of the PV system is that it ensures much lower carbon production.

However, Dondariya *et al.*, (2018) and Sultan *et al.*, (2018) indicated that there are two solar Photovoltaic systems formations namely, grid-connected PV systems (On-grid) as well as stand-alone Photovoltaic systems (Off-grid). Sultan *et al.*, (2018) further found that a grid-connected rooftop PV system in places such as Ujjain is technically possible, and there are considerable benefits in the application of this system such as energy effectiveness and eradication of CO_2 production. On-grid solar systems are commonly used in industry. In these systems, there is no battery bank for storage, and solar vitality is found to be the only key source as well as grid utilised in the system (Sultan *et al*., 2018).

There are certain challenges to this technology as well that prevent it from being readily successful all over the globe. Karjalaine and Ahvenniemi, (2019) reported four barriers to implementing solar PV systems, namely:

1. ***Sociotechnical barriers***

- Lack of information
- PV systems show low quality standards in some countries
- Deficiency of information on the supply side (e.g. among designers and planners)
- Professed difficulty of collaboration between people and PV systems
- Professed difficulty of solar PV technology
- Undesirably professed qualities of solar PV systems such as low battery storage and little energy competence
- Insufficient installation space.

2. ***Management barriers***

- Insufficient financial support for low-income residents (e.g. rural area residents)
- Weak after-sales services
- Unproductive advertising and teaching campaigns

3. ***Economic barriers***

- Expenses of PV systems
- Extensive repayment period
- Expensive maintenance

4. ***Policy barriers***

- Unproductive policy procedures: solar PV systems reported not to be economically cost-effective without policy support.
- Elimination of government support
- Policy care aimed at other energy sources

Hydera *et al*., (2018) believed that sun tracking PV systems can be designed but they increase the total price of energy generation since they are costly and necessitate maintenance. The selling price of the photovoltaic module was costly but recently it has steadily declined over the past decade (Aliyu *et al*., 2018).

2.7.2 CSP SYSTEM OVERVIEW

Shirazi *et al.* (2018) revealed that solar thermal technologies continue to demonstrate rapid growth for applications like energy production, industrial progressions, domestic hot water, and space heating and cooling. Electricity projects conducted from concentrating solar power (CSP) or solar thermal are not beyond the reach of emerging countries such as Nigeria as well as the whole of sub-Saharan Africa (Ogunmodimu and Okoroigwe, 2018). Mahlangu and

Thopil (2018) and Wagner *et al.*, (2018) analysed Solar CSP technology and found that it consists of four technologies, namely:

- Parabolic trough - concentrates the sun's rays by means of parabolic channels to the fluid that in turn heats the steam to drive the turbine to produce electricity;
- Linear Fresnel reflector - transports heat to the heat exchanger to run the steam generator that produces electricity by focusing the extensive and thin segment of mirrors on the sun's rays to a fixed absorber.
- Solar towers - use heliostats to focus the sun's rays onto an essential receiver to heat the fluid for steam production to produce energy;
- Parabolic dish – concentrates the sun's rays with its dish-shaped mirror onto a central receiver where the thermal energy is responsible for electricity production.

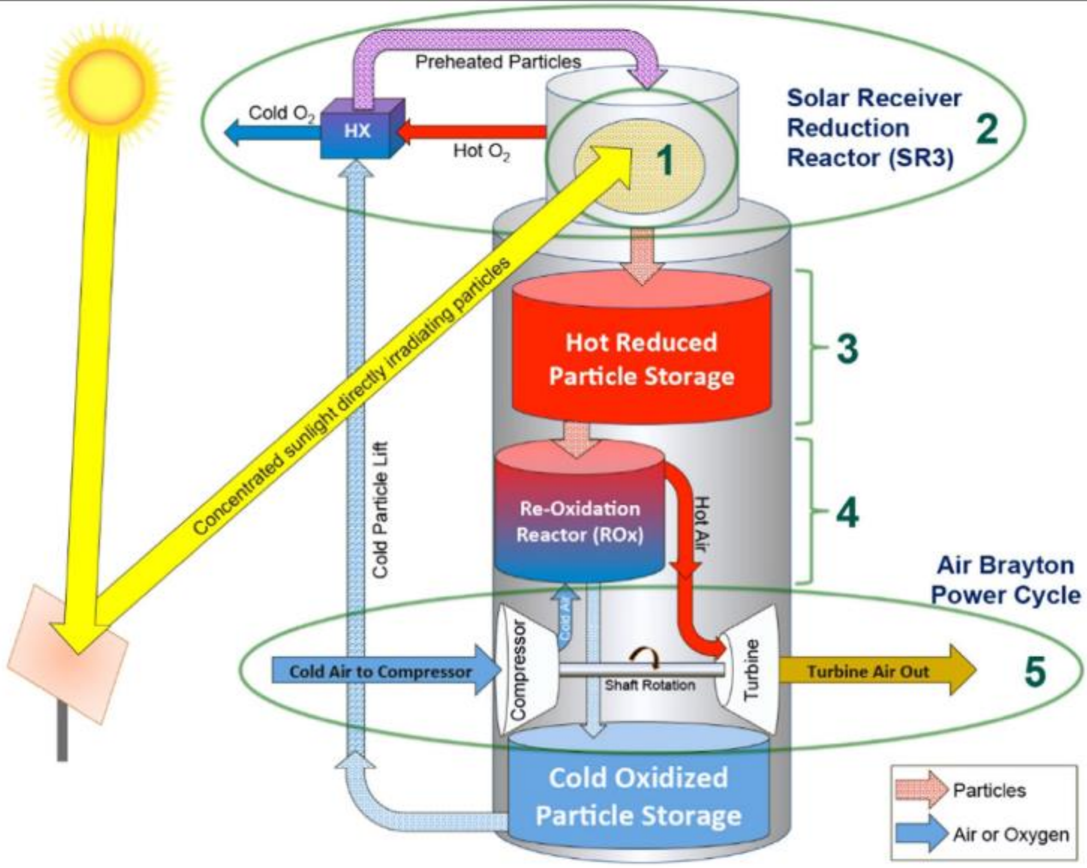

Figure 2. 5: TCES system diagram utilising CSP technologies (Dizaji and Hosseini, 2018).

Fig. 2.5 shows us that the connection of CSP in the Thermochemical energy storage (TCES) systems has attracted considerable interest in concentrated solar power (CSP) applications in the past few years (Dizaji and Hosseini, 2018). According to Zourellis *et al.*, (2018), CSP technology is the optimal operational solar heating technique for high temperature ranges.

Nonetheless, the South African CSP manufacturing sector depends on countries such as the USA, Germany and Spain to import key CSP components which manufacture the elements (Mahlangu and Thopil, 2018). Wagner *et al.,* (2018) reported that some uses of CSP thermal energy might be:

(i) Dispatched to create electricity as soon as accessible;

(ii) Reserved for peak stages (e.g. later in the same day or during the next day at the risk of filling storage and dumping energy); or

(iii) Set aside to maintain equipment temperatures, falling energy cycle start-up period.

Ling-zhi *et al.,* (2019) reported that CSP growth could face a turning point based on industry life cycle philosophy. But Li *et al.,* (2018a) disagreed, pointing out that the predictable challenges standalone CSP plants experience currently, like massive investment, lower efficiency compared to fossil fired plants, as well as substantial thermal energy storage (TES) system scale requirements. Ling-zhi *et al.,* (2018) emphasised that the costs of CSP systems are seen in two ways: fixed as well as adjustable components. Whereas fixed rates such as preliminary investment, construction costs as well as land expenditure are substantial, the adjustable costs, which are annual costs, mainly involve Operation and Maintenance expenses, insurance costs and tax expenses.

Solar energy is considered to be the most dependable and environmentally friendly of all the renewable energy types according to Mustayen, et al. (2014).

2.7.3 ENVIRONMENTAL OVERVIEW

When implementing solar system, selection of site becomes a very important factor to be analysed. Fig.2.6 shows factors that solar PV developers consider before implementation of a solar PV project. Environmental factors are the geographical factors most commonly analysed together with climate factors according to Vasel and Iakovidis, (2018). Aspects such as land use and solar radiation form part of the analysis of the two factors mentioned respectively.

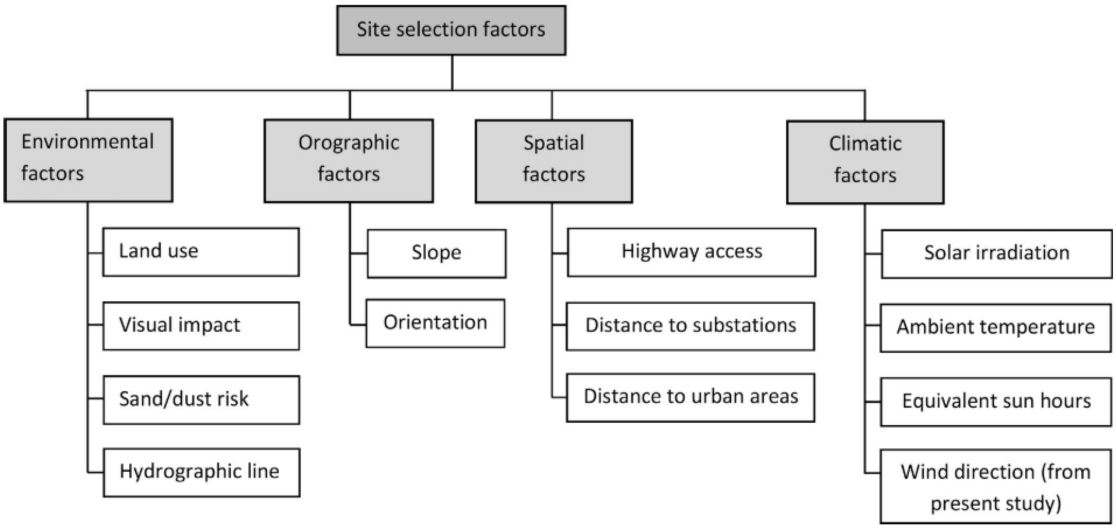

Figure 2. 6: **Selection of suitable site factors taken into consideration for developing a solar PV plant (Vasel and Iakovidis, 2018).**

Criteria such as environmental aspects could improve and forecast the acceptance of solar PV systems; therefore Kausik *et al*., (2017) believed that there should be environmental awareness. Some researchers believe that solar PV technology faces challenges notwithstanding its superior qualities such as land; solar PV technology raises concerns with regard to the land requirement of urban spaces, capture efficiency and negative public perception caused by the lack of pleasing aesthetics (Hydera *et al*., 2018). Wu *et al.,* (2017) agreed and added that construction in urban areas could block the line of sight (LOS) of the Solar-powered unmanned aerial vehicle (SUAV) sensor which is part of solar technology. The challenge to SUAV application, especially in an urban environment is the high-rise buildings that could pose a challenge by blocking out the sunlight and creating shade in the area (Wu *et al.,* 2017).

2.8 ENERGY CONSUMPTION OVERVIEW

The energy consumption rate of a household tells us about the affordability of energy among families. It is important to measure energy consumption to understand the effects of energy barriers correctly. As Damari and Kissinger, (2018) said, the realm of energy consumption must be understood completely, for the monthly consumption to be translated to an annual figure with a generated index by using the average consumption of the whole investigated population of each month.

Fig.2.7 shows us that the consumption rate is very high for young people from age 5 to age 30. The reason for this could be that they have many gadgets that utilise energy such as play stations, laptops and cell phones. Whereas the middle aged (40 to 50 and 50 to 60) don’t have a high level of energy consumption. This group mostly uses electricity for TV, cooking and lighting.

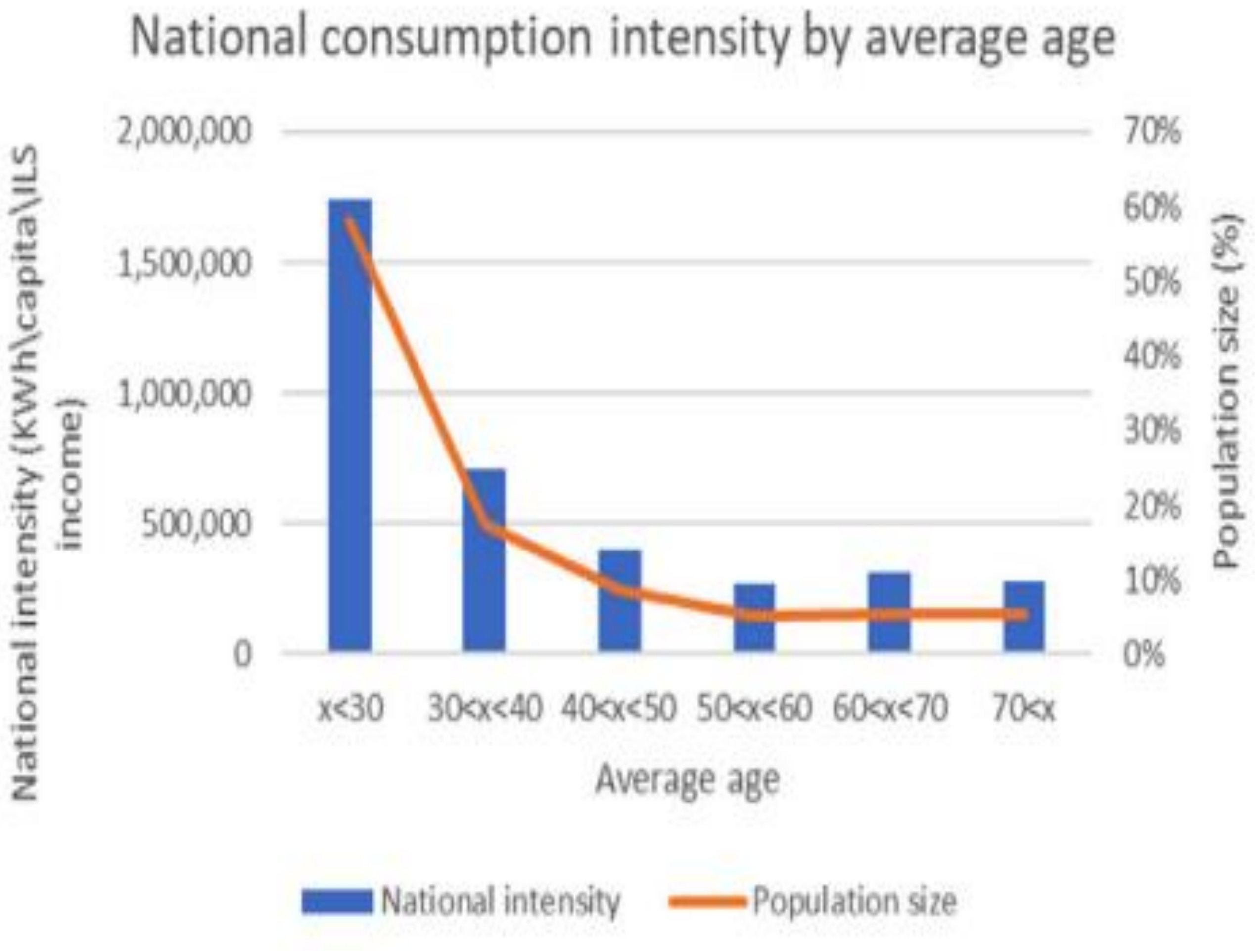

Figure 2. 7: Consumption by household by average age (Damari and Kissinger, 2018).

However, Costa-Campi *et al.*, (2018) believed that actual gross domestic product (GDP) would not be affected by the policies that foster efficiency in energy consumption. On the other hand, Halicioglu and Ketenci, (2018) considered that the increasing usage of renewable energy production as well as consumption needs should be supported by means of significant tax incentives, exceptional credit schemes, as well as party-political determination to encounter the substantial changing cost of the period.

Production has had an effect on the consumption of energy. In the past few years demand for non-renewable energy has declined due to the many challenges it faces. Fig.2.8 shows the relationship between renewable energy and non-renewable energy. This figure clearly demonstrates that there has been gradual growth in renewable energy production for the past 35 years.

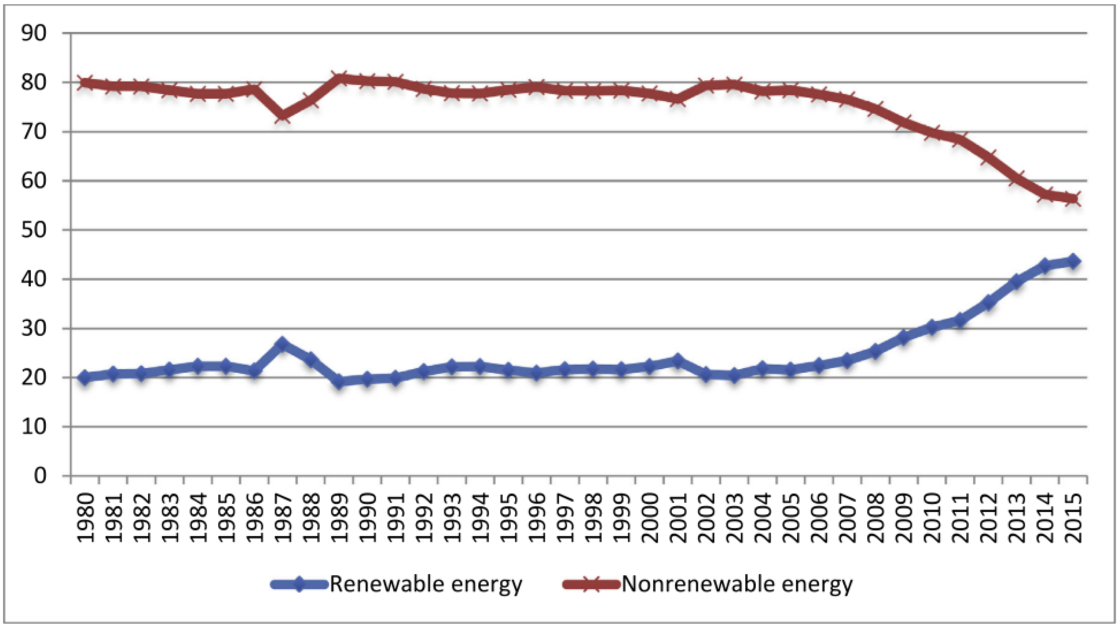

Figure 2. 8: Share of renewable and non-renewable energies in total energy production for 15 European Union countries (Halicioglu and Ketenci, 2018).

However, the South African energy status indicates that renewable energy was produced at a much lower rate. Figure 2.9 clearly shows that in 2018 renewable energy production at minimum of 29 478 MWh was sold out.

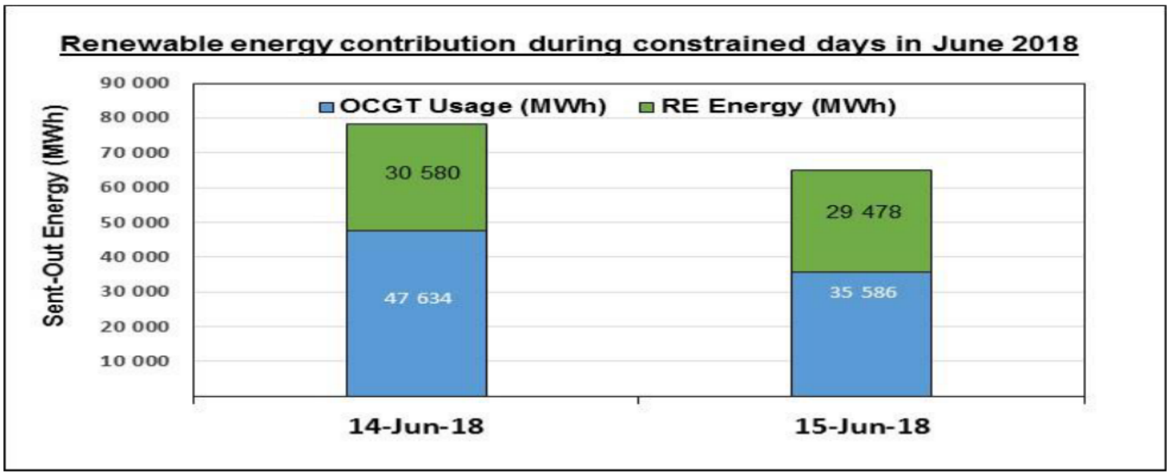

Figure 2. 9: Contribution of REI4P power plants in constrained periods in June 2018 (Gxasheka *et al*., 2018).

Even though renewable energy is still at minimum there is positive growth in SA as whole. Fig.2.10 shows a comparison between 2016 and 2017 monthly energy production from

January to December conducted by NERSA regarding the renewable energy. Each month shows growth in energy production even though April and May show minimum growth. A factor that contributed to minimum growth in May was that the project was still in the initial building phase. The summer season shows promising growth particularly in December.

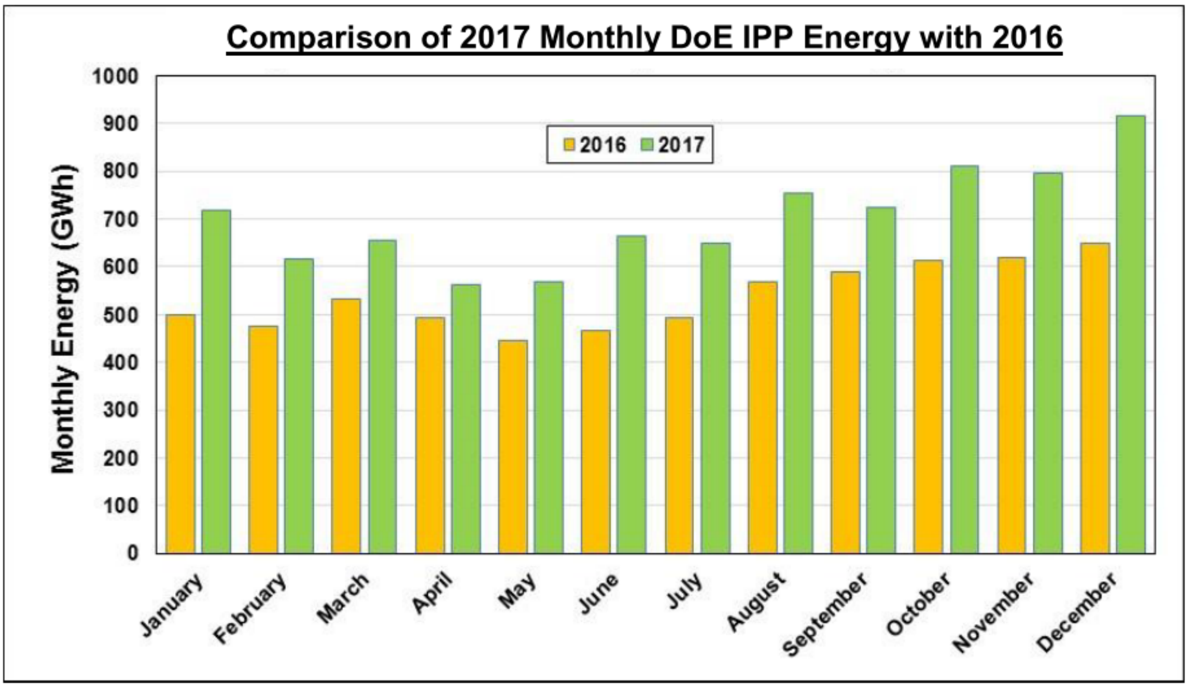

Figure 2. 10: Comparison of monthly energy production in 2017 with 2016 (NERSA, 2018).

One of the most critical moves performed in 2017 by the Department of Energy was to implement the Department of Energy Renewable Energy Independent Power Producer (DoE IPP) power plants which increased the grid capacity by 872MW (NERSA, 2018).

2.9 SUMMARY

The literature studied revealed that Renewable energy is the next promising source of energy. Developed countries such as Germany, the USA and China have pursued renewable energy sources such as solar energy. Solar energy is considered the best source of renewable energy (O'Shaughnessy *et al.,* 2018; Yang *et al.,* 2018). Solar energy has two sets of technology that have been found to be more effective on Earth, and they are solar PV and CSP. However, PV technology is more effective than CSP technology according to previous research conducted.

Technology also imposes challenges in renewable energy development, resulting in the slow growth of solar energy implementation across the globe. This has led to the implementation of policies to regulate renewable energy and to protect the environment. The unsustainability of solar energy in South Africa continues to be a major challenge that needs to be dealt with. Taking to consideration the importance of education, renewable energy investment and the rate of energy consumption, the KZN region in particular will have to focus on solar energy.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

Solar power is more dominant than other renewable energy (such as wind) which make solar power more important in South Africa. However, the KZN region needs to first deal with the issue of solar energy unsustainability in order to take advantage of sunlight energy that could potentially become readily available if harnessed in a sustainable way.

This chapter focuses on the research model set up to deal with the solar energy crises facing the KZN region, namely the slow growth and unsustainability of solar energy in the KwaZulu-Natal region. This chapter discusses how and where data was collected in order to try to resolve the unsustainability of solar power in the region. It further discusses and justifies the methods used in the study.

Literature was reviewed and discussed in the precious chapter to give an overview of and the background to the study. However, other approaches need to be considered in order to meet the study requirements. These methods include the root cause technique, a cost benefit analysis and the statistical approach. Identification of sample subgroups and selection of participants are also addressed. The study will adopt a quantitative method to analyse the correlation between the solar installation and its energy consumption in the region. A cost benefit analysis will also be conducted to rationalize the implementation of solar energy in the region of KZN.

3.2 RESEARCH DESIGN

In order to answer the initial research questions, it is necessary to analyse the research design. This research consists of numerical phases or stages in order for it to be success. All these phases or stages are interconnected; however, each phase or stage can be developed independently. Fig.3.1 represents the research design model and it phases. It begins with problem discovering as an initial vital stage of the research. To proceed with the research, the next phase was necessary, which was data gathering. In this stage relevant data was collected on renewable energy focusing on solar energy.

The utilisation of collected data becomes the next stage. Here data is analysed using various techniques such as cost benefit analyses, statistical approach and cause and effects diagram.

Then in the next phase data was checked for validity. Results and recommendations are addressed in the next stage, when the presentation and interpretation of data is discussed. Lastly, the research conclusion is presented; this is a summary of everything discussed in this study.

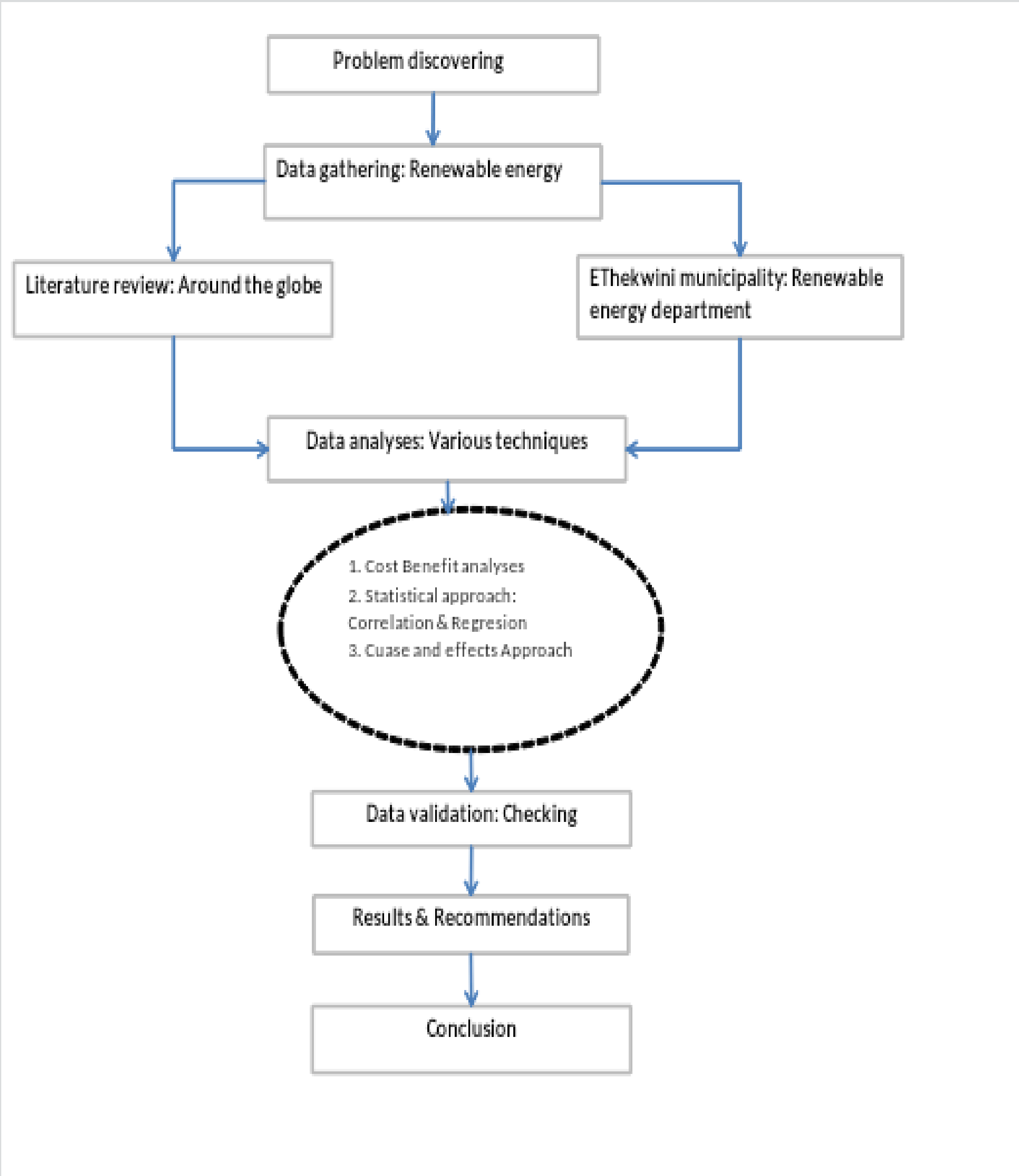

Figure 3. 1: Study research design diagram overview

3.3 DATA GATHERING

The research on solar energy uses the case study of the KwaZulu-Natal region. KwaZulu-Natal is one of the provinces in South Africa and it is made up of municipalities operating together at local government level. Several methods were used to gather data including telephoning, emailing and face-to-face meetings and were used to communicate with relevant personnel in the municipality. More details on the communication methods are listed in table 3.1.

TABLE 3. 1: Detail gathering communication methods

Communication types	Description of uses
Emailing	- Initially used to schedule meetings between the researcher and municipal representatives. - To receive data and send follow-up questions from the researcher to the municipal representatives.
Telephoning	- Used to remind the municipal representatives about meetings and to follow up of how far the person with expected data is.
Face-to-face meetings	- Used to introduce the researcher and to outline the type of data expected from each partner.

Data utilised in this research on solar energy was extracted from the database of eThekwini Municipality under the department of renewable energy. This makes the study a retrospective study in statistical terms since it uses historical data (Garza-Ulloa, 2018). The primary data was obtained from the departmental database through the help of the Municipal manager, and the secondary data was obtained from the literature review.

The literature review was one of the methods used to gather more information on renewable energy as a whole. Many renewable energy publications across the globe from countries such as China, Germany, USA and Brazil have reviewed the available literature. The literature review in this research is taken from the latest publications (2010 to 2019) as said earlier in chapter 2. The reason for using the latest publications is to ascertain the actual state of renewable energy and to know what future research still needs to be done. Microsoft Excel was then used to store and analyse data that was obtained in the database.

3.4 SAMPLE AND POPULATION

The population target for this study was the directly involved users of eThekwini municipality solar power projects developed in the past decade and available in the database. The eThekwini municipality owns a number of buildings and solar power energy has been installed in some of the buildings such as the Moses Mabhida stadium, the Metro police building and uShaka Marine World. The historic data for installed solar energy was used in the case of eThekwini.

This study focused on the information provided by almost 37 solar panels that have been installed by eThekwini municipality around Durban. The data received at uShaka Marine World was for one year from February 2018 to January 2019. The solar panels installed use the solar PV system and there is no track record of solar CSP installation information in the region. Assouline *et al*., (2017) cited the importance of the feasibility of solar PV installations not only for single property owners, but for local governments and municipalities as well.

3.5 JUSTIFICATION FOR PURSUING THE QUANTITATIVE APPROACH

To attain the objectives of this research, the study was conducted using the quantitative method. There are three analysis approaches in this research that were used to support the quantitative method, namely:

- **Root cause analysis**: the analysis of the major problems facing the KZN region and its contributors revealed problems such as the environment (dramatically changing environment), manpower (lack of skill), and method (inadequate method), etc.
- **Cost benefit model**: this method is useful to demonstrate the financial implications of installing solar power in the region. It will also demonstrate how long it should take before the region could expect some return on investment. Courtois, et al., (2018) believed that it was worthwhile to begin with a basic model that consists of few types and a simplified management decision purpose when presenting a cost benefit model and decision criteria.

- **Regression analysis**: this will give us an overview of whether installing solar in the region is worth it or not. According to Schorr and Lips, (2018) the regression method, especially in respect of a linear relationship, can be used to popularize a motive and to compare the literature during discussion and decision making. On the other hand, Deerfield, (2018) believed that regression analyses can be used to investigate the association between independent variables and dependent variables. According to Kuan, (2018) it should be expected that some experiential equations as well as regression equations do not replicate the correlation among variables.

The analysis of the solar energy costs also indicated that the approach selection would be the best method to be used. The cost benefit study gives an economic understanding of a new solar energy project to be implemented in the region. The linear regression analysis technique is best for inspecting the connection between two quantitative variables (Bewick *et al*., 2018). In summary, the literature clearly demonstrates that quantitative results become more user friendly where data is numerically presented or analysed. Note that regression implementation is discussed in detail in section 3.8 below.

3.6 ROOT CAUSE ANALYSIS OVERVIEW

The research objective was to investigate the root causes of solar unsustainability in the region of KwaZulu Natal. It was thus necessary to properly analyse the root causes. The cause and effects diagram are useful in analysing the challenges contributing to the unsustainability of solar in the region. Kastner *et al*., (2017) recommended that implementation of renewable energy sources should be systematic in order to obtain successful models of renewable energy in Germany. The analysis of root causes has been found to be the best method at this point in time. Understanding the factors contributing to or the causes of a system failure can help develop actions that sustain the correction.

As all factors contributing to the unsustainability of solar energy are analysed, they are also rated in terms of the contribution of each on a 1-5 scale where 1 represents the minimum contribution and 5 represents the maximum contribution to the unsustainability of solar energy in the region.

3.7 COST BENEFIT MODEL

The cost benefit analyses (CBA) model is important in revealing the root cause of this modification of solar power sustainability in the region. According to Cao *et al.,* (2018) it is necessary to perform a cost-benefit analysis because it closes the gap between estimated costs and actual costs. This tool assists in making financial decisions when developing a new project or reviewing an existing project. In general, charges increase, and resource demand increases which create a resource scarcity. This will create a shortage of renewable energy (solar energy technology) supply in KZN region as well if it is implemented.

The South African government should also base resolutions on net ecosystem services value in order to obtain sustainable development and environmental refurbishment, like the government of China, to ensure that they account for the associated costs (Cao *et al*., 2018). The cost benefit analysis conducted in this study is divided into three sections, namely total benefits, total costs and lastly, return on investment. Yang *et al*., (2018), believed that a cost benefit analysis can be used to investigate whether the effort exerted to achieve the specific target was cost operative or not.

The total benefits section (*TB*) deals with two kinds of benefits, namely tangible benefits and intangible benefits. The difference between the two is that tangible benefits are based on the performance of the business, for example, customer tariff cost and intangible benefits are influenced by the service provided by the systems (for example, rent and grid connection). The formulae used in this study to calculate this section is:

$$TB = \sum (T + I) \quad (3.1)$$

Where:

$\sum$ - Summation sign

TB is the associated total benefits, and

T represents the sum of all the tangible benefits of solar energy activities carried out in the KZN region.

I represent all the activities that belong under the intangible category. Adding up all the activities with both tangible and intangible benefits gives the required total benefits.

The other section of this study is total costs (*TC).* A total cost represents all the relevant costs needed to carry out the solar energy projects in the region of KwaZulu-Natal. Based on information obtained on the database, total costs are also divided into two, the first one is developmental costs (*D*), where these costs represent all the one-time costs in the solar energy projects. They don’t have any effect when the projects are up and running; an example of this is installation cost. Installation cost is only charged once, at the initial stage. The second costs that make up the total costs are Operational costs (*O*). Operational costs are costs that will affect the solar energy project throughout the entire existence of the project. There are many types of operational costs that will be involved in the calculations. A useful example is the licence operating cost, and the cost will be charged every year. Therefore, it is necessary to calculate the total costs of the section, using the following formulae:

$$TC = \sum (D + O) \tag{3.2}$$

Where *D* represents the sum of all activities that belong to developmental costs,

$$D = \sum n, \tag{3.3}$$

Where:

n is for all activities.

And *O* represents the sum of all the activities that are carried out in the operational category,

$$O = \sum m, \tag{3.4}$$

Where,

m is for all activities.

The third and last section on costs benefit analysis in this study is return on investment (*ROI*). Since this is a feasibility study, there is a need to calculate the profit or a loss during the existence of the project. EBIT is the difference between total benefits and total costs. The formula that represents this calculation is:

$$EBIT = Ii + TB - TC \tag{3.5}$$

I*i* - initial investment

TB - total benefits

TC - total costs

The inclusion of tax comes in at this stage, where benefits and losses have been calculated to get taxable operating income. The taxable operating income is the different between total benefit and total cost with the exclusion of initial investment. The formula is as follows:

$$\mathrm{T}oi = \mathrm{TB} - \mathrm{TC} \tag{3.6}$$

The operating tax is calculated only when the taxable operating income is greater than zero and not less than zero. The tax percentage is 28% on the taxable operating income, as arranged between South African Revenue Service (SARS) and the municipality. This percentage was taken from the SARS tax table.

$$if \quad Toi > 0, Tp = \text{Toi} \times 28\% \qquad (3.7)$$

Where:

T*oi* – Taxable operating income

T*p* - Tax payable

The return on investment (*ROI*) is the total output in the form that demonstrates the business loss or profit for each year. The formula that represents calculation of return on investment is presented below:

$$ROI = \text{EBIT} - \text{OIT} \qquad (3.8)$$

Where:

EBIT – earning before income tax

OIT – operating income tax.

The cost benefit analyses will end after obtaining the return on investment for each year until the targeted period (seventh year). The probability will then be investigated using the statistical analysis tool that will assist in predicting the success rate of the installation of solar power in the region.

3.8 DATA ANALYSES AND CLARIFICATION PRESENTATION - REGRESSION

According to Garza-Ulloa, (2018) statistical methods remain valuable for two purposes, describing and understanding variability. After carefully viewing the financial overview on this research, it is useful to implement the statistical techniques to check whether the variable used in this study has a relationship and to predict future performance of solar energy in the KZN region. The study adopted regression analysis as a statistical approach which basically involves quantitative analysis. This technique is vital to illustrate the relationship between the study variables such as the independent variable (energy consumption) and the dependent variable (solar installation), as previous studies recommend using the statistical approach.

Jeon, (2015) believed that the relationship between variables was easily investigated by using statistical approaches.

Bewick *et al*., (2010) believed that relationship investigation between the variables must be demonstrated graphically, preferably using a scatter diagram for clear understanding. Decisions are motivated by the results conducted on statistics.

3.8.1 Regression analyses synopsis

Gkioulekas and Papageorgiou, (2018) and Yuan *et al*., (2018) both defined regression as a predictive analysis tool that examines the relationship between independent and dependent variables, while Chen *et al*., (2017) recommended regression analysis as a reasonable statistic approach to make predictions. Therefore, in this study regression analysis appeared to be a useful technique to have been used to predict the future performance of solar energy in KwaZulu-Natal region. Having mentioned that, regression also assists in predicting the demand for solar energy in the near future. There are a number of regression forms such as simple regression, multiple regression, quantile regression as well as logic regression.

Multiple regression analysis is the most suitable regression approach since it is a statistical technique that mostly analyses the relationship between a single dependent variable and several independent variables (Fang, 2013). Multiple regression analyses are considered to be just as important as simple regression analyses, but it is more reliable since it tests more than one independent variable (fang, 2013). The dependant variable in this study is solar energy consumption (Y) and a few independent variables are solar self-consumption (x_1), export energy (x_2) and import energy (x_3). The independent variables are only considered to be significant if the value $p < 0.05$ (Garcia-Sierra and Alvarez-Moleiro, 2014). The results are presented graphically in the next chapter.

The equation of a straight line is given by $Y = a + b_1x_1 + b_2x_2 + b_3x_3 + \varepsilon$ where the coefficients *a* and *b* are the intercepts of the line on the y axis and the gradient, where *y* is the solar consumption rate and *x* represents the solar energy independent variables mentioned in the previous paragraph (Bewick *et al.*, 2010). To estimate the true effects of this independent variable on the dependent variable, we must include all the independent variables in the regression (Fang, 2013). The useful formula utilised in this study is (Fang, 2013):

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + \varepsilon \tag{3.9}$$

Where:

Y is the dependent variable (output)

x: independent variable (input)

a: intercept (Y value at *x* = 0)

b: gradient of the regression line

ε: accidental error.

Decisions are influenced by the results obtained from the analysis including the regression results. In order to improve the current status, it is necessary to overlook the cause of failure or possible causes of failure. The analysis of variance will be computed through Microsoft excel (Fuqiang *et al.,* 2018).

The coefficient of determination in this study was included to show how well the data fits the regression equation during the calculation of multiple regressions (Fang, 2013). The correlation between variables was also researched to investigate whether there was a relationship between the variables. The coefficient of r^2 was calculated to see how strong the relationship between solar production, solar installation and solar consumption, etc. was as Mukaka, (2012) stated that measurement of correlation needs a coefficient that represents the linear association between the variables investigated. The mathematical coefficient formula used in this research is:

$R^2 = [\sum(xy)- (\sum x)(\sum y)/n))/\sqrt{}(\sum x^2 -(\sum x^2/n)(\sum y^2-(\sum y^2/n))]^2$ = variation explained by regression/total variation (Bewick *et al*., 2010).

Rawski *et al*., (2016) purported that r^2 coefficient ranges between 0 and 1 and a value above 0.5 is called satisfactory and anything below 0.5 will be unsatisfactory. In the case of this study it means that solar energy in the region of KZN can be sustainable; therefore, prioritisation is necessary.

3.9 CHAPTER SUMMARY

This chapter's focus is on the proceedings of the whole research to achieve the desired study aims that were outlined in chapter one. Better understanding of how the data used in this research was obtained was clarified through the research design diagram. As much as research design gave research flow, data gathering was explained in detail. The sampling procedure that was aligned with the quantitative method to meet the research standard was briefly explained. Furthermore, a brief overview of selecting quantitative methodology was given to support the research outcomes. Notably, the number of approaches that were used to support the descriptive quantitative study were outlined and explained in detail. These approaches include a root cause analysis, a cost benefit analysis as well as a statistical approach. The statistical approach used in this study will be multiple regression. The equations for all these approaches were given and defined in this chapter.

As Chapter three deals with introducing the research methodology, the application of all the useful approaches explained will be used for data analyses following the quantitative methodology.

CHAPTER 4

DATA ANALYSES AND RESULTS

4.1 INTRODUCTION

In the previous chapter (Chapter 3), the study presented the process followed to conduct the study and the method that would be used to analyse the data obtained from the eThekwini municipality database. The solar power raw information from the eThekwini region covering a period of ten years from 2008 to 2018 was used to obtain the presented results. The analysis was divided into three phases as reported in chapter three: phase 1 deals with the analysis of the root cause [of unsustainability] and the contribution it has had on the major problem. It presents factors that seem to be the major challenge to solar power unsustainability in the region. Phase 2 presents a financial analysis of installing solar power in the region. It explains the financial benefit of installing solar energy in the region and predicts the period of return on investment. The third analysis was the regression analyses which assisted in making the decision about the installation of solar power in the region. Quantitative descriptors are presented in the findings as the nature of the study uses the quantitative method. Within the discussion below literature is used to support the statements of the findings.

4.2 ROOT CAUSE ANALYSIS APPLICATION ON SOLAR ENERGY UNSUSTAINABILITY

The results are presented in the form of a diagram (fishbone diagram) to simplify the findings and for better understanding of results. Dobrusskin, (2016) noted that cause and effect analysis is prevalent for many reasons; some of the reasons are:

- it consists of easy learnable and usable principles;
- its application can be addressed to a different kind of problems due to its flexibility;
- it gives in-depth details of a problem.

Table 4.1 introduces the contributors posing a challenge to solar power sustainability. It also emphasises their importance and explains why they warrant an in-depth analysis. These are the major resources that contribute to the unsustainability of solar in the region.

Table 4. 1: An overview of the contributors to the challenge to solar power (Dobrusskin, 2016).

Contributor	Description
Environment	Investigated impact of environment on solar power technology and it cause to understand problem even more batter. The objective of analysing the environment is to see how solar power installation can reduce environment climate change.
Man	How people that are responsible for solar power contribute to its unsustainability. These are the major stakeholders in solar power since planning relies on the manpower available.
Method	To further understand the importance of the installation method in the solar unsustainability. The objective of analysing the method is to ascertain the most effective method that could be used in the region.
Material	Solar power uses unique material to absorb sunlight, therefore it is very important to analyse its contribution to the unsustainability of solar power in the region.

The author decided to focus on the four contributors mentioned above as they are the major challenges to the sustainability of solar power in the KZN region. However, fishbone diagram includes six causes that are normally discussed. The two excluded causes in this study are machine and measurements. Machine was excluded because they not needed in the implementation of solar power and solar plates are not manufactured in the KZN region. Herrero-Ruiz, (2018) recommended that focus be put on the different reasoning procedures in order to create meaningful effects of the system. The measurements are not included because they form part of method in the case of eThekwini municipality; they are not analysed separately to avoid repetition of the challenge.

Table 4. 2: Associated measuring ratings for contributors on Solar power.

Rate	Description
1	Less impact to the challenge.
2	Less impact to the challenge but might become troublesome.
3	Good to be controlled but not that significant to be prioritized

4	This warrants attention since it has high impact on the challenge.
5	This signifies a very high contribution to the challenge.

An overview of the causes presented in Figure 4.1 below:

- **Environment** – Environmental change affects the implementation of solar energy, as it becomes difficult to find a suitable place to install the solar panels due to excess CO_2 emissions in the atmosphere. Continuing to use coal energy will delay solar energy implementation. It then becomes a challenge to decide which technology should be used and it becomes necessary to do more research on suitable technology. Environment is therefore rated at 4 because its contribution does not have a high impact on whether or not to progress with solar installation. Jaber *et al*., (2017) believed that environmental degradation was becoming a reality due to heightened contamination by GHG emissions produced by the energy sector. The high rating of this contributor is because of its impact on solar power energy, considering the fact that solar power systems are exposed to weather conditions that have an effect on the environment.

  Solar power depends on solar radiation as its primary source; that is why it is classified as an important provider of electricity generation. Jain and Jain, (2017) confirmed that there is a high degree of sunshine in South Africa and most regions experience normal daily sunlight radiation of 8-10 hours. Meanwhile individuals and societies noticed a need to begin addressing issues of energy sustainability in relation to climate change (Kruger, 2015). Even though solar power has positive effects on the environment and society, it also carries harmful consequences such as damage to biodiversity, and alteration of the landscape (Liebe and Dobers, 2019). All these factors that affect the environment need to be controlled to enable solar power sustainability.
- **Man** – the key player in a solar energy installation project. However, the unavailability of skilled manpower for solar energy installation caused by the scarcity and poor quality of training provided can cause a delay in the installation of solar projects. Older employees are thus often demotivated and hesitant to learn about solar energy systems. Inadequate training also requires employees to conduct research for themselves and they thus feel that a solar project increases their workload. This

contributor is rated 3 because this challenge can be overcome, and resources can be organised.

- **Method** – the factors that affect this category are linked to a lack of knowledge. The use of a variety of methods to install solar systems has been found to be the cause of solar unsustainability because it takes more time when doing operations. This is caused by the fact that solar development is still new in the country, so research is still needed to overcome this challenge. In addition, there is no documented method to be used and as a result, there is a lack of job responsibility: anyone can do any job, which causes confusion. It is then rated 3 because of its significance in successful solar energy implementation.
- **Material** – the use of inadequate material because of a scarcity of finances also affects solar project. The long lead-time on proper material ordered from overseas forces local cheaper alternatives to be used. Policy is the major material that is needed to guide the project, which is in line with the National Development Plan (NDP 2030). This category is rate 4 because it very important.

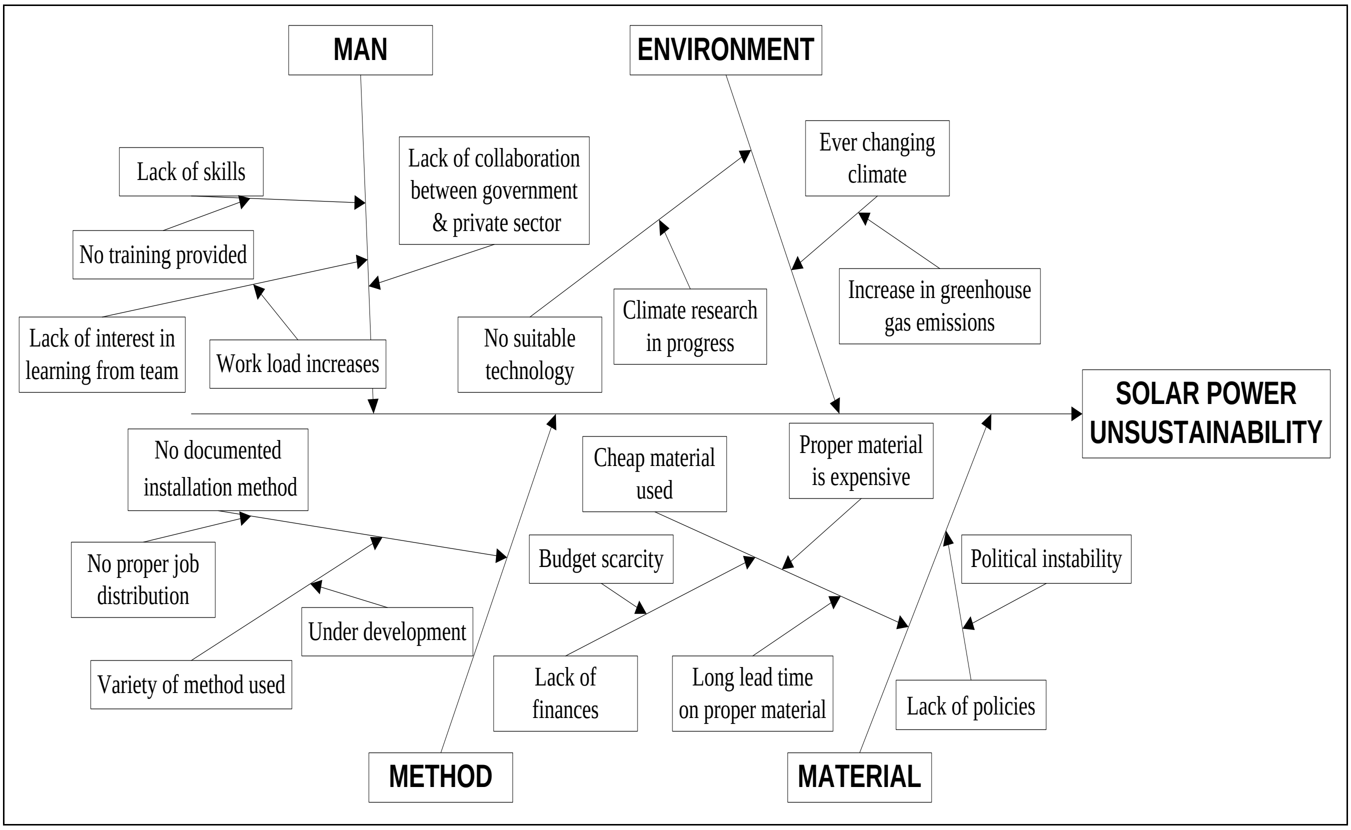

Figure 4. 1: Solar power cause and effects diagram of eThekwini municipality

5. Application of 5 whys on the discovered challenges of Solar power energy

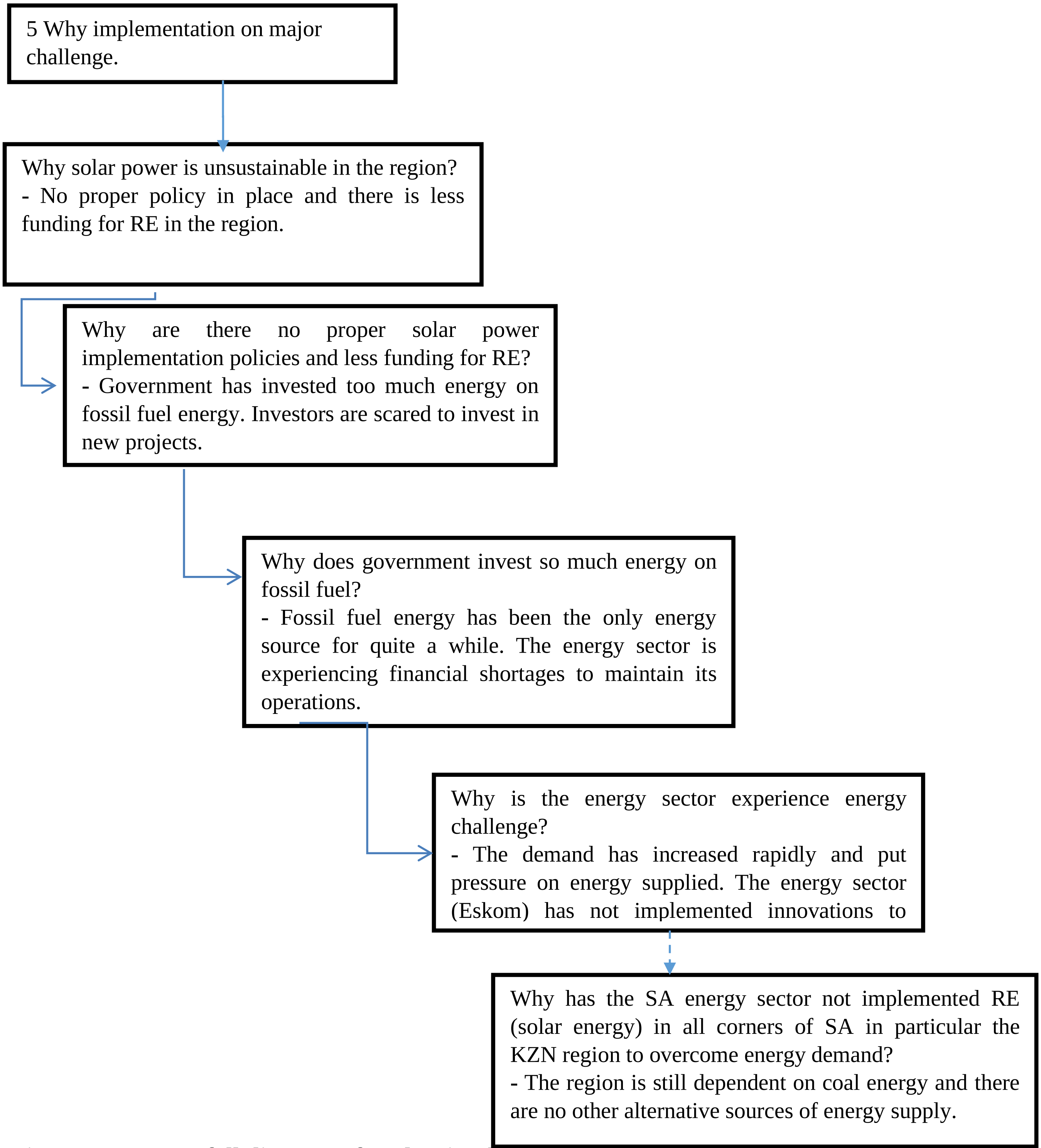

Figure 4. 2: Waterfall diagram of 5 whys implementation to solar unsustainability.

Fig. 4.2 represents the major overview of solar energy unsustainability in the region of KwaZulu-Natal. The major challenges presented in the fishbone diagram were further analysed in the 5 why's technique to obtain better understanding. The unavailability of policy together with the unavailability of funding for solar energy projects are the main contributors to the unsustainability of solar energy. The contributors make investors hesitate to be part of solar energy projects in the region. The financial analysis has to be conducted to check the feasibility of implementing solar energy in the region of KwaZulu-Natal. The eThekwini municipality will need a small category (100 KW) as it is a quarter of the KZN region.

4.3 FINANCIAL ANALYSIS AND PROJECTION OF COST BENEFIT ANALYSIS

The main objective of this economic model is to provide guidance on the potential costs of Renewable Energy installations (Solar power) in the eThekwini municipal area. Small (<100KW) installations have been planned. The model was developed to calculate the benefits of installing solar power in the region. It is divided into sections: output, income and rates, investment and installation, and expenses. Table 4.3 below represents the figures that are used to calculate the overall implementation of solar power in the KZN region.

The Output section in table 4.3 contains basic information containing the total capacity of 10 kWp which is expected at the end of the desired period which is 17 years. The income section represents the income and rates component that were utilised to obtain the tangible benefit for the solar power system; it also describes how much the plant will earn. Components such as inflation adjustment are used on all tariffs and operational costs. The investment and instalment section deal with the investment and installation components such as turnkey, grid connection, other initial costs, and among them is project development which is useful in calculating the projected development cost found in the developmental cost. Lazzarin and Noro, (2018) notified everyone that high initial costs were common to almost all renewable energy project installations.

The expenses section clarifies the expense components of implementing a solar power system. These components are Insurance premium as a percentage used to calculate the insured project material for a certain duration of time; the upkeep component is used to obtain the annual maintenance cost of the solar connection system to ensure the reliability and sustainability of the system; the Allowance for component change (first year) which is vital for component variance costs, and the Land/Roof Lease is set to zero in this case because the municipality will be owning the land or roof that will be used for the solar power project. Table 4.3 represents the possible percentage calculation for the duration of the study.

Table 4. 3: Financial model component for a solar power system in eThekwini municipality (Ntshalintshali, 2016)

FINANCIAL MODEL FOR SOLAR POWER IN ETHEKWINI MUNICIPALITY		
1. Output		**Unit**
Total capacity	10	kWp
Annual insolation	1 890	kWh/m^2
Performance ratio	83,0%	
Annual degradation	0,30%	
Yearly production (first year)	15 687	kWh
Percent self-use	95%	
2. Income and rates		
Customer tariff (avoided electricity)	1,35	R/kWh
Feed-in tariff	0,65	R/kWh
Carbon credit	0	R/kWh
Tax rate	28%	
Inflation adjustment	7%	per annum
3. Investment and installation		
Turnkey EPC	18 000	R/kWp
Grid connection	0	R
Project development	1 000	R
Other initial costs	0	R
Decommission	0	R/kWp
4. Expenses		
Upkeep (first year)	400	R/kWp/annum
Allowance for component change (first year)	1 000	R/annum
Land/Roof Lease	0	R/annum
Insurance premium	0,8%	of initial invest

The South African Government implemented the National Development Plan for 2030 in 2010. One of the plans is to change over from coal energy to renewable energy with a certain percentage. The KZN region has a role to play in the NDP 2030 through renewable energy projects to meet the energy demand facing the region and to reduce the CO_2 emission. Since solar energy has been discovered as the next potential energy source in the country, the study has to focus on the financial side of the solar project to gauge its feasibility in the next 10 years of NDP 2030.

In view of government's plan, the cost benefit study was carried out considering the period of expectations. The CBA in the table below was conducted for 17 years since there are almost 10 years remaining to achieve the NDP plan. The extra seven years were added to ensure the performance moved forward after attaining the government plan by 2030.

The energy produced by the solar power will be shared by the users and the feed-in tariff is considered in order to obtain the total energy used. The annual degradation of 0.30% is also considered for the yearly energy produced. This assists in understanding the actual amount of energy that can be produced.

The tangible benefit of the project is obtained by adding the feed-in tariff cost and the customer tariff cost. The two parameters are calculated based on the annual target of solar power implementation in the region. The calculations are as follows:

$$FTC = FTR \times FTC, \tag{4.1}$$

Where,

FTC – Feed-in tariff cost,

FTR – feed-in tariff rate,

FTC – feed-in tariff charge.

The feed-in tariff rate is 748 kWh in the first year. The feed-in tariff charge is R1/kWh. However, this charge is not expected to increase for the next 17 years because solar power is still in the developmental stage. Feed-in tariff costs are added to the customer tariff to obtain the actual cost. The customer tariff is as follows:

$$CT = ST / SE, \tag{4.2}$$

Where,

CT – customer tariff,

SE – self-use energy

ST – self-use tariff

This formula was obtained from a percentage of 95% set by the region for that year. The combination of these figures in the first year gave us R 30590/kWh, which is the total tangible benefit. The carbon credit in this cost is R0/kWh but there are no charges related to it at this point.

Intangible benefit is another part of the benefit that completes the possible total benefit of the solar implementation project in the region. In this project there is a rent and grid connection where rent will assist the project to generate income by renting the solar system to the municipality customer (Shaka marine world) with an initial fee of R3000 for the first four years because rent still costs the municipality for maintenance and installation and this figure is recommended to be 1.7% of the investment cost. The four-year fixed term drive by the expected solar power challenges is still minimum at the initial stage. For the next four years (5^{th} to 9^{th} year) and eight remaining years it will increase to R4500 and R5500 respectively because solar system output increases by 100 kWh yearly. This will also be affected by maintenance costs that the system will need due to the increased capacity of the solar system.

Grid connection will be an annual charge when the customer has installed his/her own solar power system. This is done to control the grid connection and for proper maintenance of the grid system. These charges are not that high compared to the rent cost since they only come at a value of R1100 per year for the first 9 years and increase to R1200 year for the rest of the duration of the project and these charges will be directed to the greenhouse gas emission funds of the municipality. The connection to the grid needs to be regulated at all times that is why there is an annual connection fee of 0.6% of the initial solar power project investment. Local Government Emissions such as the eThekwini Municipality account for almost 6% of the total eThekwini emission which was found to be 27 067 912 tCO_2 e (Municipality, 2015; 2016). Even though solar power, especially the PV system, is considered to be low-carbon energy technology (Malkki and alanne, 2017). Furthermore, Augutis *et al.*, (2015) discovered that energy security guarantees national security and that is why such importance is placed on energy security at an adequate level to the function of a model economy, and that’s how R1100 and R1200 grid connection costs came about.

Table 4. 4: Cost Benefit Analysis (CBA) for solar energy in eThekwini region

Cost Benefit Analysis (CBA)

		Year																
Total benefit (TB)	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
a) Tangeble benefit																		
Energy produced	kWh	15687	15640	15593	15546	15499	15452	15405	15358	15311	15263	15216	15169	15122	15075	15028	14981	14934
Self use	kWh	14903	14858	14813	14769	14724	14679	14634	14590	14545	14500	14456	14411	14366	14321	14277	14232	14187
Feed in teriff	kWh	784	782	780	777	775	773	770	768	766	763	761	758	756	754	751	749	747
Feed in teriff	R/kWh	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Customer teriff	R/kWh	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Carbon credit	R/kWh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total TB cost	R/kWh	**30590**	**30498**	**30406**	**30314**	**30223**	**30131**	**30039**	**29947**	**29855**	**29764**	**29672**	**29580**	**29488**	**29397**	**29305**	**29213**	**29121**
b) Intangible Benefit																		
Rent cost	R/kWh	3000	3000	3000	3000	4500	4500	4500	4500	4500	4500	5000	5000	5000	5500	5500	5500	5800
Grid connection licence	R	1100	1100	1100	1100	1100	1100	1100	1100	1200	1200	1200	1200	1200	1200	1200	1200	1200
Total benefit	R	**34690**	**34598**	**34506**	**34414**	**35823**	**35731**	**35639**	**35547**	**35555**	**35464**	**35872**	**35780**	**35688**	**36097**	**36005**	**35913**	**36121**
Total Cost(expenses)																		
a) Developmental cost																		
Project development	R	-50000																
Labour cost	R	-44000																
Transportation cost	R	-45000																
Solar panel cost	R/m²	-25000																
b) Operational Cost																		
Facilities management	R/kWh	-1000	-1070	-1145	-1225	-1311	-1403	-1501	-1606	-1718	-1838	-1967	-2105	-2252	-2410	-2579	-2759	-2952
Depreciation	R	-36200	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
Allowance of component change	R	-1000	-1070	-1145	-1225	-1311	-1403	-1501	-1606	-1718	-1838	-1967	-2105	-2252	-2410	-2579	-2759	-2952
Maintenance cost	R/kWh	-4000	-4280	-4580	-4900	-5243	-5610	-6003	-6423	-6873	-7354	-7869	-8419	-9009	-9639	-10314	-11036	-11809
Insurance premium	R	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448	-1448
Total cost	R	**-207648**	**-7868**	**-8317**	**-8798**	**-9313**	**-9863**	**-10452**	**-11083**	**-11757**	**-12479**	**-13251**	**-14077**	**-14961**	**-15907**	**-16919**	**-18002**	**-19161**
EBIT	R	**8042**	**26730**	**26189**	**25616**	**26510**	**25867**	**25187**	**24465**	**23798**	**22985**	**22621**	**21703**	**20727**	**20190**	**19086**	**17911**	**16960**
Taxable operating income	R	-172958	26730	26189	25616	26510	25867	25187	24465	23798	22985	22621	21703	20727	20190	19086	17911	16960
Operating income tax	R	0	7484	7333	7173	7423	7243	7052	6850	6664	6436	6334	6077	5804	5653	5344	5015	4749
Operating income After Tax	R	-172958	34214	33522	32789	33933	33110	32239	31315	30462	29421	28955	27780	26531	25843	24430	22926	21709
Return On Investment (ROI)	R	**-172958**	**-138744**	**-105223**	**-72434**	**-38501**	**-5391**	**26848**	**58163**	**88624**	**118045**	**147000**	**174780**	**201311**	**227154**	**251583**	**274509**	**296219**

Financial calculations formation table 4.3:

1. **Energy production (EP**) = yearly production x [1- annually degradation x (1-number of years)]

   = Yp x [1 -Ad (1 -Y)

2. **Self-use energy (SU) =** energy production x self-use percentage (95%)

   = EP x SU (%)

3. **Feed-in tariff =** energy production (EP) – self use energy (SU)

   = EP – SU
4. **Feed-in tariff per unit =** benchmarked/ municipal unit cost

5. **Customer tariff per unit =** Benchmarked/municipal unity cost

6. **Carbon credit =** benchmarked

7. **Rent cost** = material cost + labour cost + profit (5%)

   = MC + LC + P
8. **Grid connection licence cost** = municipal charge based on connection cost
9. **Project developmental cost** = design cost + research cost

   = MC + RC
10. **Labour cost** = cost per hour x hourly rate x number of labour hours

    = hr x R/hr x L
11. **Material cost =** benchmarked for local suppliers

12. **Facilities management** = labour cost at a rate of R30/hr

13. **Depreciation** = investment cost x depreciating percent (%)

14. **Allowance of component change** = benchmarked cost/ municipal cost

15. **Maintenance cost** = total capacity x upkeep cost

16. **Insurance premium** = investment cost (R) x insurance premium (0.80%)

17. **Transportation cost =** distance (km) x cost per distance (R/km)

    = D x R/km

The project of solar power system in the region of KZN will face many challenges since it will be at an initial phase. The solar energy project for the duration of 17 years will require R181, 000 for the project to be successful. This financial model shows that solar implementation will not generate profit for approximately five years. The return on investment is presented in the table 4.4. In the first year it will run at a loss of about R172, 598 for the whole year. During the first year almost 4.4% will be returned by the project.

The increase will begin to show as from the second year since the project will be running at about a loss of R 138744 and will manage to accumulate a 23.3% return on the initial investment. This shows an amazing return in the short term of about 19.1% difference from the first year. In the third year, solar projects were running at a loss of about R105, 223 and managed to return almost half (41.9%) of the initial investment. This clearly demonstrates a positive sign of the project, since the project duration is 17 years and yet in the third year it returns almost half of the investment.

In the fourth year it will run at a loss of R72,434 with an investment return of 60% and in the fifth year 78.7% will be returned by this solar energy project since it will be running at a loss of R38,501 in that financial year. This will be the last loss of the project since in the sixth year the solar project will manage to reach the breakeven point. In the sixth year there is no loss or profit made by the solar energy project. In other words, every cent that was invested in the project will be fully returned in the sixth year. As every cent that was invested in the project has been returned and the project will then start generating profit as from the seventh year. The first proof that profit will be generated will be equivalent to R26, 848 which is almost 15% of the initial investment.

The return on investment has been delayed by the total cost of the project such as developmental costs and operating costs. These costs are considered as running costs for a solar project in the region. The most respectable thing about developmental costs is that they are onetime costs. The contribution of the developmental costs to the solar energy project in this case is the sum of project developmental cost (PD), labour cost (LC), transportation cost (TC) and solar panel cost (SC) to the value of R168,000. Developmental cost is almost 93% of the proposed investment. The calculation details to be used below are given in the following calculation formula:

Developmental cost = PD + LC + TC + SC

= (R1670 + R3330) + (R45 x 8 x 122 x 1) + (320 km x 140.6) + R29000

= R5000 +R44000 + R45000 +R29000

= **R168, 000**

The operating cost, on the other hand, is not a onetime cost, it is a recurring cost in every year. This has a contribution of R43, 648 which adds almost 24% to the investment cost in the first year of the project. Among other operating costs are facility management cost (FC), depreciation cost (DC), allowance of component changes cost (AC), maintenance cost (MC) and insurance cost (IC). However, the depreciation cost will be further calculated for the [next] period of 10 years since it only affects the value of the solar system not the investment and encourages proper maintenance. Most solar systems can only be removed when defective, but most solar systems showed high levels of defects and required more maintenance after ten years (Al-Saqlawi *et al.*, 2018). To add onto that, the NDP still has almost ten years to yield results, therefore the study can focus on a minimum of ten years for it to be in line with the government's plan, particularly for the KZN regional government. Calculation details used below are given in the calculation formula below:

Operating cost (OC) = FC + DC + AC + MC + IC

= R1000 + (R181000 x 20%) + R1000 + (10 km x R400) +

(R181000 x 0.80%)

= R1000 + R36200 + R1000 + R4000 + R1448

= **R43, 648**

These two costs (developmental cost and operating cost) have overturned the return on investment for almost 5 years but in the first year have demonstrated a loss of R172, 598 to zero costs in the sixth year as clearly demonstrated in fig. 4.3.

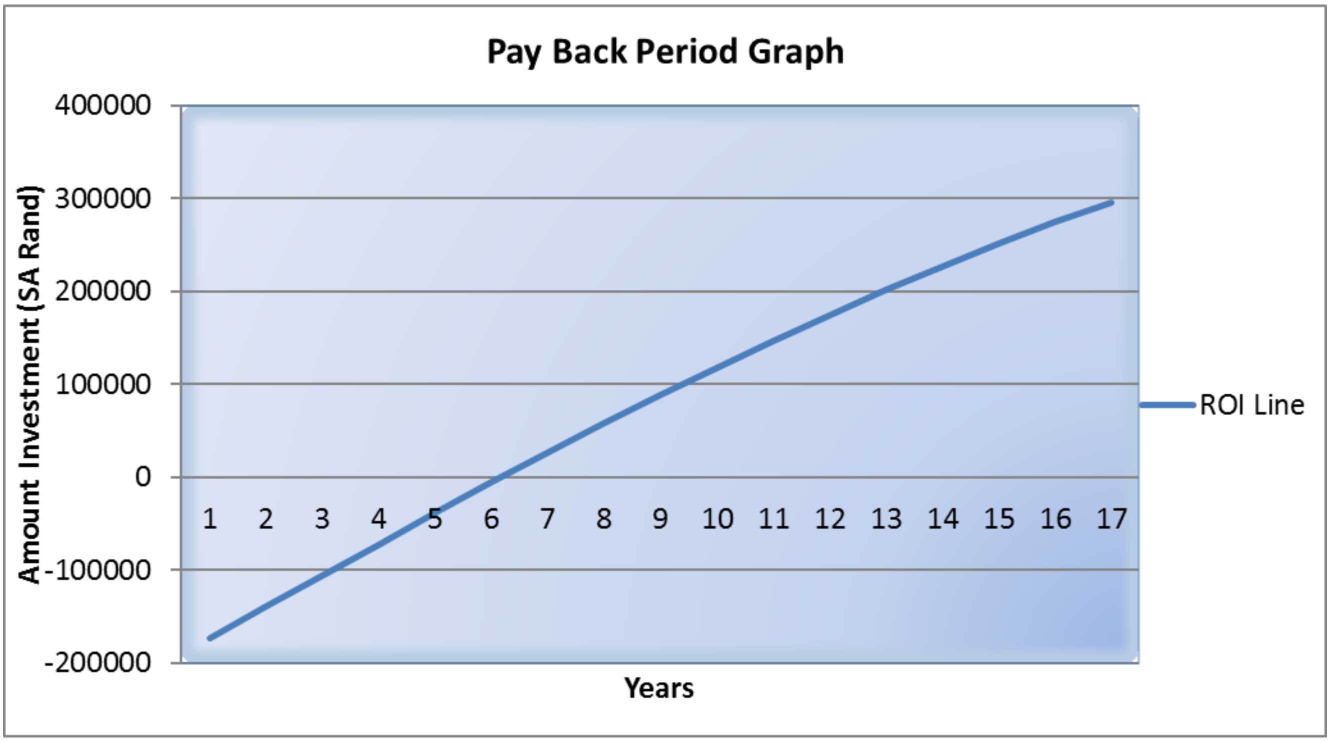

Figure 4. 3: Payback period on solar power implementation

A positive cost trend will be seen in the next ten years after the 15% increase in the seventh year. A consistent 15% increase will be seen in each year throughout the estimated period. In the 12th year the profit will almost double the investment cost with a profit of R174780. This is almost equivalent to 97% of the initial investment, and which ensures the future financial stability of the energy department in the region.

However, the solar system still needs to be monitored closely as it is made of a depreciating component. In the table below depreciation of ten years is calculated from the initial value invested. The annual depreciation percentage utilised is 20% each year. The reason why the first 10 years is focused on is because of NDP 2030, and the aim is to align the project with national government's plan.

In other part of the country such as Johannesburg you can look at a repayment period of about 7.9 years to install solar power system of the same quantity (Ferrer, 2017). Whereas here in eThekwini, it will take a payback period of approximately 6 years according to the research conducted in eThekwini municipality. According to Ozorhon *et al*., (2018), the service life of a solar power project is seen to be very long to generate profit after the breakeven point. Investors appreciate the fact that any solar power investment will give return on investment within the estimated timeframe and will not take a long time as is the case with fossil fuel (Ozorhon *et al*., 2018).

Table 4. 5: Depreciation of solar energy system each year in eThekwini region.

Year	**Calculation of solar energy system value (R)**	**Solar energy system value (R)**	**Calculation of Depreciation value (R)**	**Depreciating value (R)**
1	=R181000 - R0	181000	=18100 x 20%	36200
2	=R181000- R36200	144 800	=144800 x 20%	28960
3	=R144800 – R28960	115 840	=115840 x 20%	23168
4	=R115840 – R23168	92 672	=92672 x 20%	18534
5	=R92672 – R18534	74 138	=74138 x 20%	14828
6	=R74138 – R14828	59 310	=59310 x 20%	11862
7	=R59310 – R11862	47 448	=47448 x 20%	9490
8	=R47448 – R9490	37 958	=37958 x 20%	7592
9	=R37958 -R7592	30 367	=30367 x 20%	6073
10	=R30367 – R6063	24 293	=24293 x 20%	4859

Clarification of the above depreciation calculations:

Calculation of solar energy system = investment value – depreciation value

Calculation of depreciation value = solar energy system value x depreciation percentage

The graphical presentation in Fig. 4.4 gives a clear demonstration of the difference between system value and depreciation value. The less the system depreciates, the more reliable the system performance. The result below shows that the solar energy system depreciates much less by viewing the figures presented below. In the first year there is R36, 200 of depreciating value, this clearly tells us that the solar system can still perform at its optimum. In second year R144, 800 versus R28, 960 system depreciation is seen, which still gives hope for the solar system. In the fourth year the system reached almost half (50%) of the invested value (R92, 672). From the fifth year to the tenth year, the system shows a dramatic depreciation, but the value of the system is still above 10% of the initial value in the tenth year (R24, 293). By the look of things, the depreciating value is very close to zero.

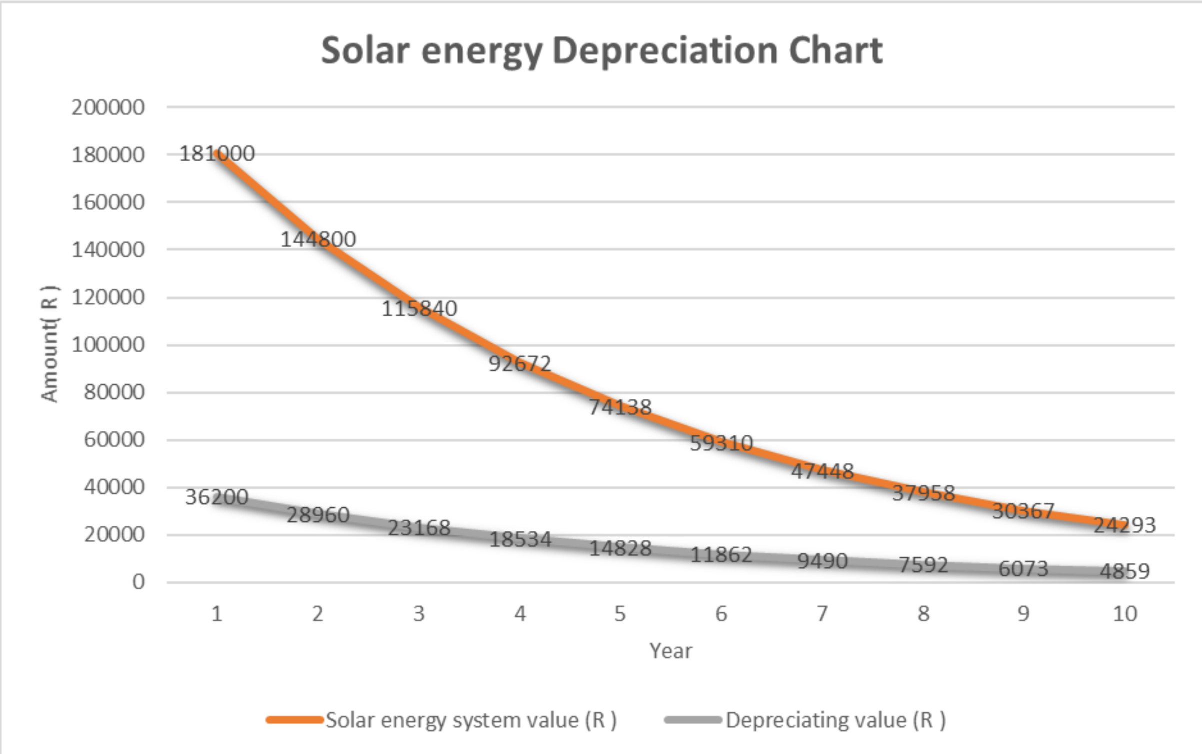

Figure 4. 4: Solar system depreciation overview for the 10-year period.

In the tenth year the depreciating value is R4859, but the system remains controllable above the 10%. Depreciation values could assist in maintenance scheduling to keep the solar system in good performing shape. Ghenai *et al.*, (2019) claim solar systems can have a lifespan of almost 25 years with a solar cell efficiency of 16%.

4.4 SOLAR POWER CONTRIBUTING TO FACTOR ANALYSES AND DATA CONTRIBUTION

These categories consist of different temperatures throughout the year. The temperature is the most important factor in solar system power. This factor (temperature) has recently been classified as being most affected by climate change; however, an increase in temperature has been seen in the past years. The average temperature was calculated and is presented in table

4.6. The average minimum and maximum temperatures were calculated throughout a number of days in a month. All twelve months are represented in the table below to show the temperature variation throughout the year.

Table 4. 6: KZN region temperature variation throughout the year from STAR lab ground-based data

Months	**Monthly Average Temperature**	
	Minimum (°C)	**Maximum (°C)**
January	21	28
February	21	29
March	19	28
April	17	26
May	14	25
June	11	23
July	10	22
August	13	24
September	15	25
October	17	25
November	18	26
December	20	27

For clear understanding of variation in temperature a graphical presentation is also presented below in figure 4.5. This figure demonstrates the average temperature variation throughout the year. As it is shown in the table above February is the hottest month of the year with a maximum of 29°C followed by January, March and December with maximum temperatures of 28°C, 28°C and 27°C respectively. Bear in mind that temperature is considered to be one of the key factors affecting solar power especial PV systems according to Ayengó *et al*., (2019).

The ordinary temperature is seen to be between 22°C and 25°C. Yet the lowest temperatures seem to occur in June, July and August with values of 10°C, 11°C and 13°C respectively. All these months belong to the group 2 which is clarified better in multiple regression result below. This is the coldest period for the KwaZulu Natal region as well as in another part of the world.

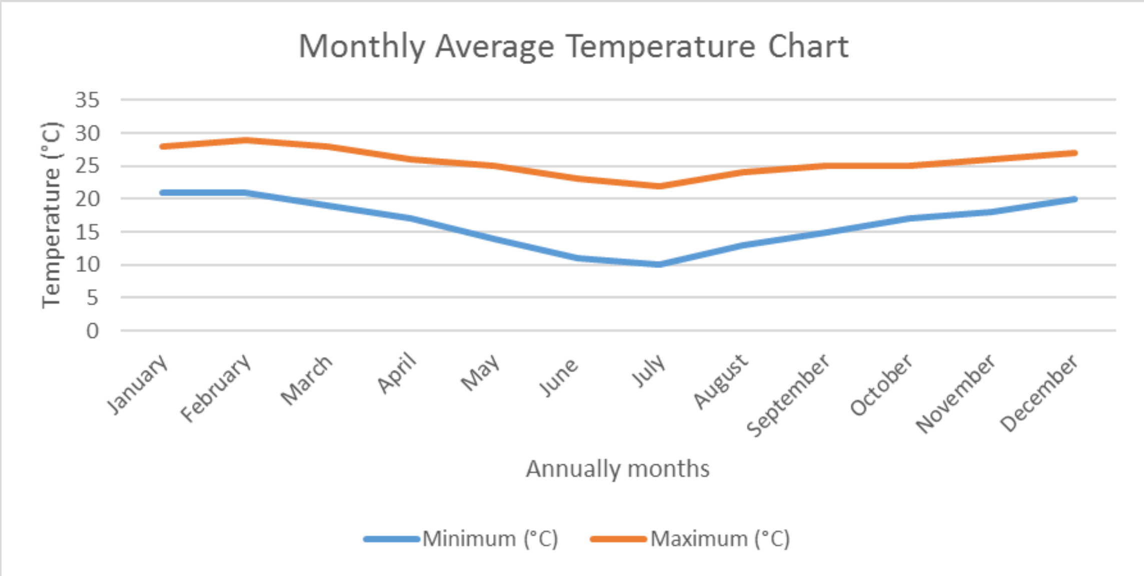

Figure 4. 5: KZN region average temperature throughout the year

There are a number of variables to be tested in the period mentioned above; the table below presents all the variables considered for statistical modelling of solar power data, through the multiple regression model. Table 4.7 demonstrates the parameters that are considered in the study, where Y represents the dependent variable (solar power production) and x indicates the independent variable (e.g. solar power consumption, temperature). A detailed description of all the variables is given in table 4.7 to facilitate understanding.

Table 4. 7: Solar variables descriptions

Variables	Description	Units
Y	Solar system production	Wh
X_1	Solar energy import	Wh
X_2	Solar energy export	Wh
X_3	Temperature/ Weather	°C
X_4	Solar Self Consumption	Wh
X_5	Solar energy consumption	Wh
X_6	Period	Months/ Days

The variables presented in Table 4.7 were obtained from the database of the Department of Renewable Energy in the eThekwini Municipality. The temperature and solar radiation data were collected directly from the historical information available in the renewable energy department. Regression analysis was then utilized to check the relationship between solar power system production and associated independent variables (Xn) presented in the table above. This will assist in decision making on solar sustainability in the KZN region. It will also help determine the impact of each independent variable. The annual data from the database was categorized according to the season of year found in South Africa using months. Table 4.8 shows the grouping of data prior to analysis to make it more understandable. There are four categories in the table below, namely: autumn, winter, spring and summer. The range of data category was specified to clearly group data for analyses in the later stage. The table below gives the changing of seasons throughout the year, which is a key dependency of solar power.

Table 4. 8: Data grouping of annual period

Data Group (DG)	**Categories**	**Range of months**
1	Autumn	March - May
2	Winter	June - August
3	Spring	September - November
4	Summer	December - February

4.5 DATA GROUPING (DG) ANALYSIS OVERVIEW AND RELATIONSHIP COMPARISON

There are four season categories which must be considered and acknowledged so as to the check adaptation of solar power throughout the changing weather patterns. Solar power is grouped using the month categories in table 4.8. The solar power parameter relationships are investigated using the scatter plot diagram for each set of parameters. The solar system parameter, which is the dependent variable, is investigated against all the independent variables (consumption, solar import, energy export, solar self-consumption and temperature).

Bewick *et al*. (2018) accepted as true that the linear relationship between two variables could be interrogated through linear regression to obtain satisfactory data. Each data group consisted of four correlation investigations. All the correlation investigations were conducted between energy consumption and one of the parameters (solar system production, solar power imported, solar power exported and solar self-consumption). It was important to investigate the correlation between the parameters to get better knowledge about the strength of the parameters. Section 5.1 summarizes the correlation between the parameters.

4.5.1 Data group 1 (DG 1): Analysis of correlation among parameters

Figure 4.6 of DG 1 investigated the correlation in energy consumption and solar system produced. The increase in solar system production showed an increase in energy consumption. The correlation between these two parameters seems not to have been strong since the R^2- value is 0.49, since it is below 0.50, the correlation between the parameters in not that strong.

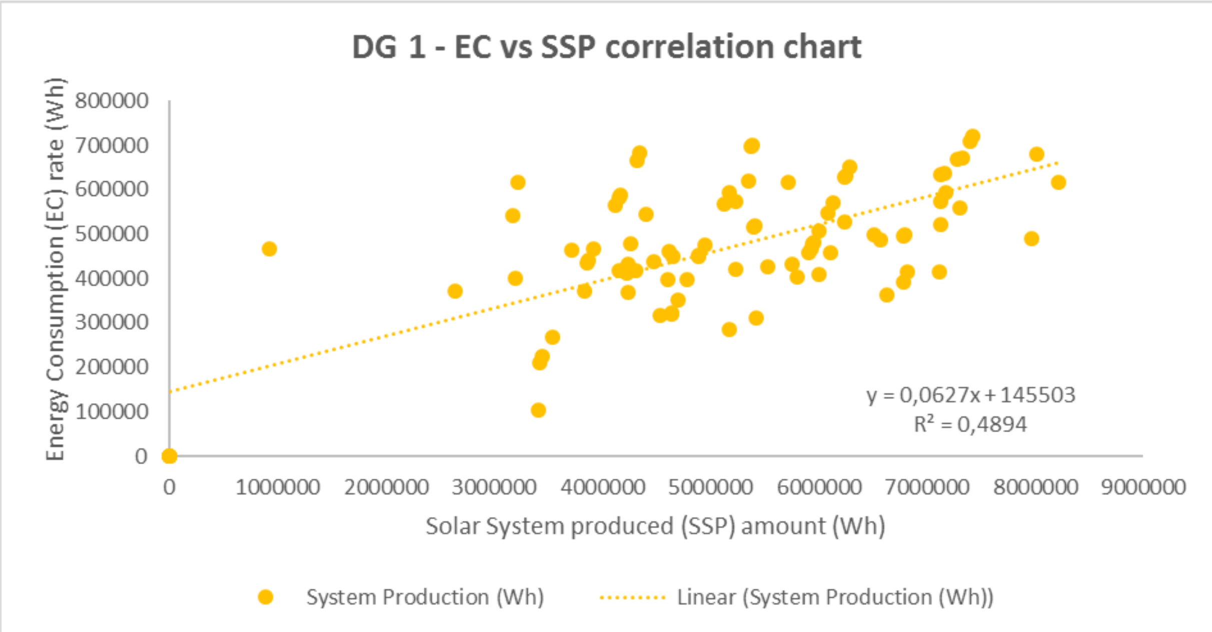

Figure 4. 6: DG 1: Investigated the correlation between EC and SSP

Figure 4.7 of DG 1 investigated the correlation between the energy consumption and the solar self-consumption amounts. The figure below shows the good relationship between them since R^2 -value has 0.57 which is above 0.50. However, it is not close to 1.0, which means it is not strong but there is a trustable relationship. An increase in the solar self-consumption amount also demonstrates an increase in the energy consumption rate.

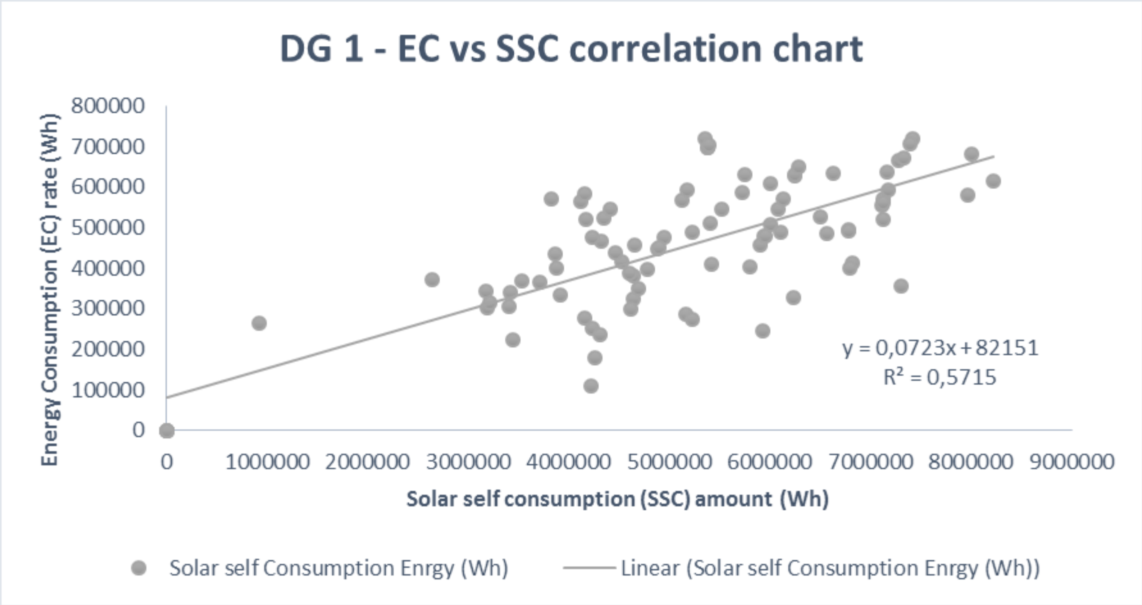

Figure 4. 7: DG 1: Investigated the correlation between EC and SSC

A strong relationship exists between the energy consumption (EC) and the solar power exported (SPE) amounts since it consists of an R^2- value of 0.76 as shown in figure 4.8. This value shows that the more solar power is exported, the more energy is consumed.

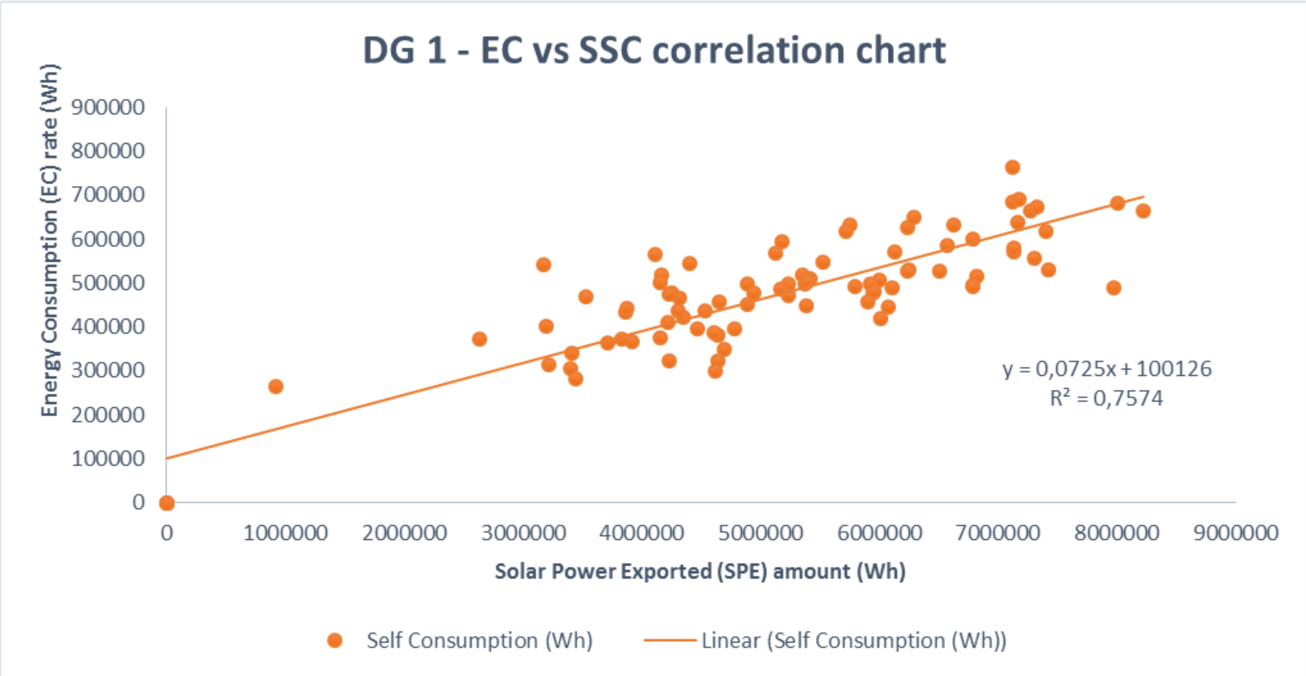

Figure 4. 8: DG 1: Investigated the correlation between EC and SC

The imported energy and energy consumption are investigated as well and the relationship between these parameters seems to be statistically significant since it has a R^2- value of 0.67. This value demonstrates a good relationship between these parameters. For every amount of solar power imported there is consumption of that imported solar power. Figure 4 better demonstrates the relationship between the parameters.

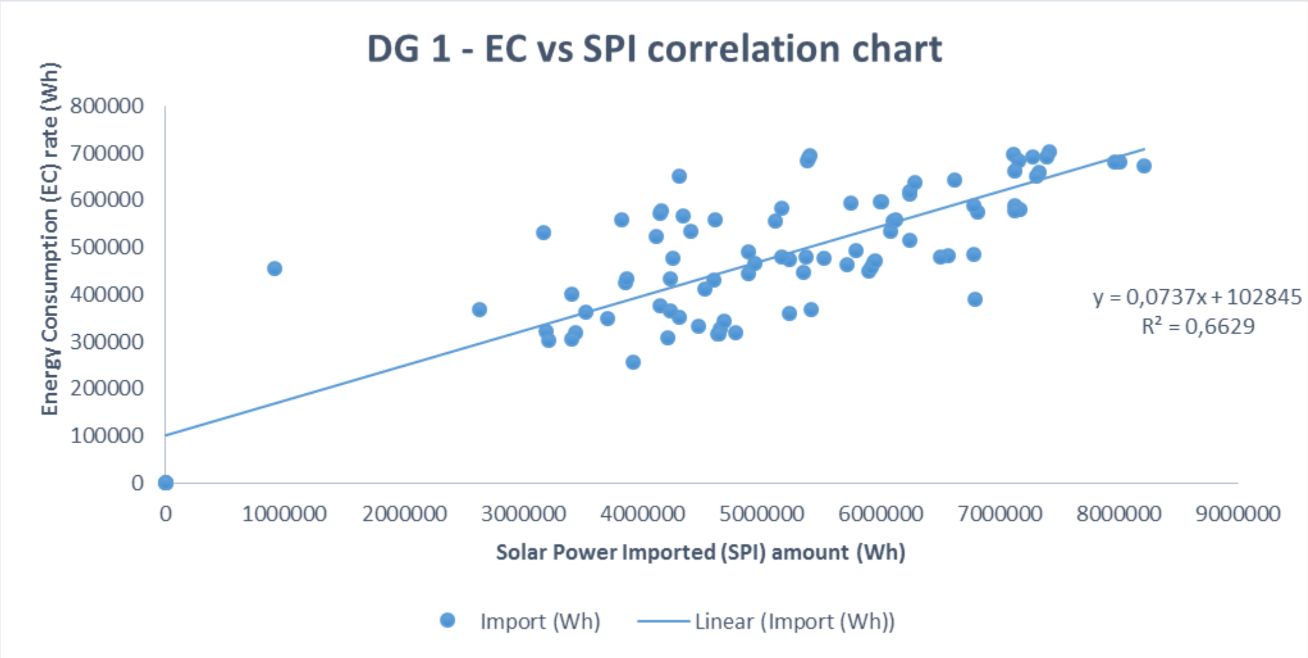

Figure 4. 9: DG 1: Investigated the correlation between EC and SPI

4.5.2 Data group 2 (DG 2): Analysis of correlation between parameters

Figure 4.10 of DG 2 investigated the relation between the energy consumption and solar system production amounts. The figure below shows the good relationship between them since the R^2 -value is 0.66 which is above 0.50. An increase in the solar self-consumption amount also demonstrates an increase in the energy consumption rate.

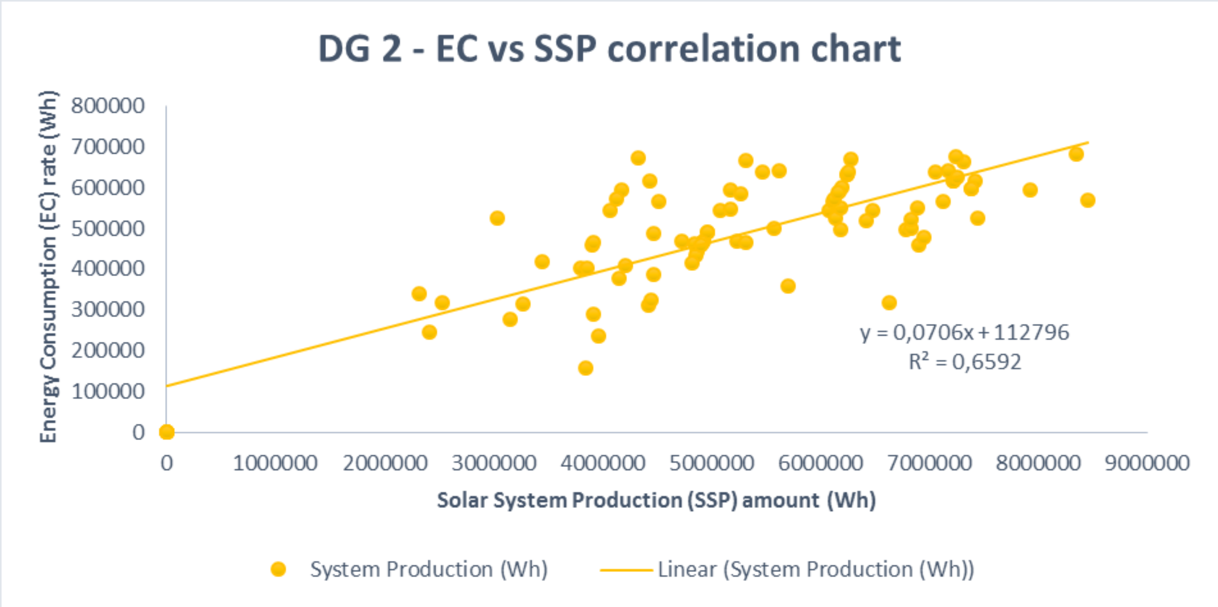

Figure 4. 10: DG 2: Investigated the correlation between EC and SSP

Figure 4.11 of DG 2 investigated the relationship between the energy consumption and solar self-consumption amounts. The figure below shows the good relationship between them since the R^2 -value is 0.67 which is above 0.50. An increase in the solar self-consumption amount also demonstrates an increase in the energy consumption rate.

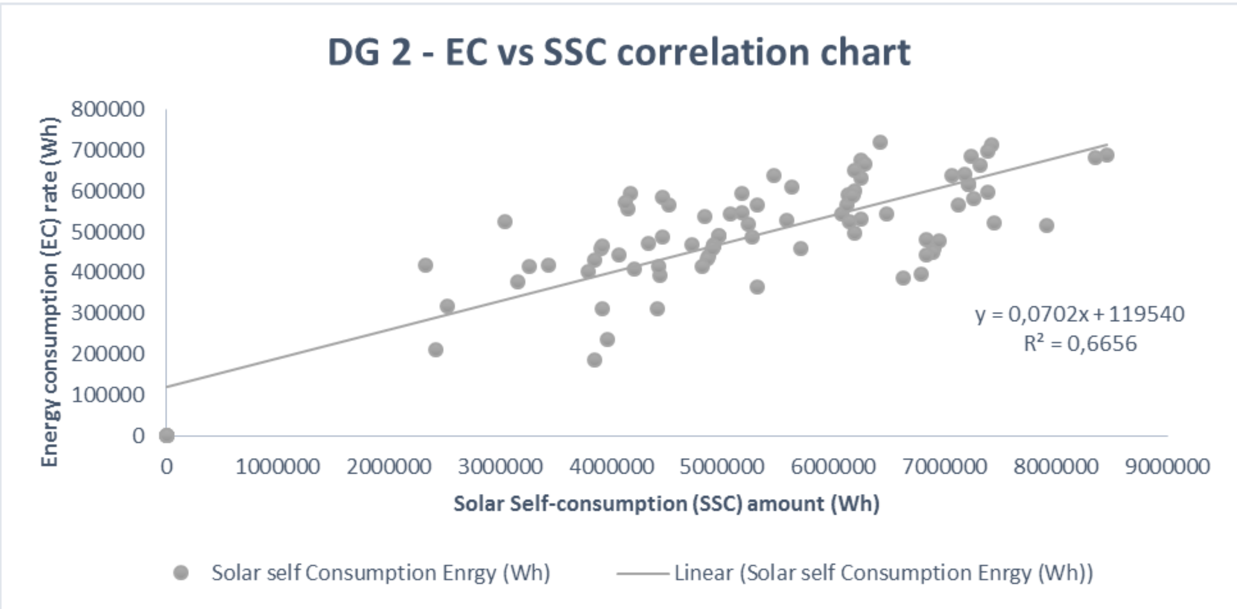

Figure 4. 11: DG 2: Investigated the correlation between EC vs SSC

Figure 4.12 of DG 2 investigated the correlation between energy consumption and solar power exported. The increase in solar system production shows an increase in energy consumption. The correlation between these two parameters seems not to be strong since the

R^2- value is 0.65; since it is below 0.50, the correlation between the parameters is not that strong.

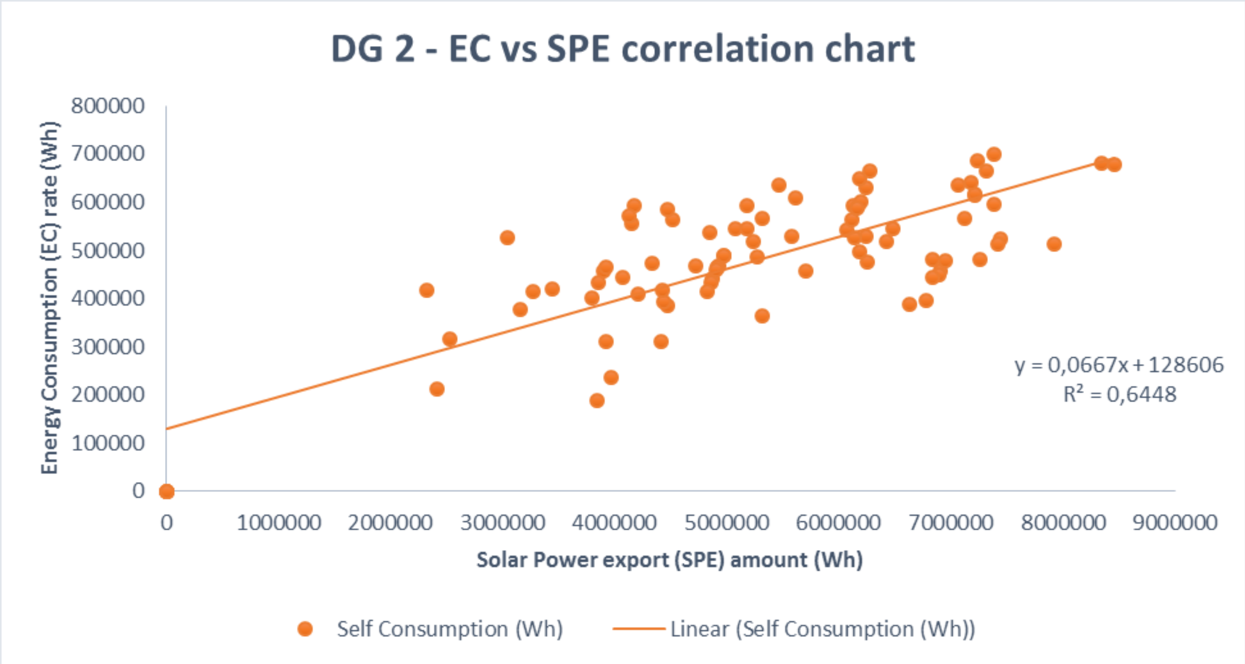

Figure 4. 12: DG 2: Investigated the correlation between EC vs SPE

Figure 4.13 of DG 2 investigated the correlation between energy consumption and solar power imported. The increase in solar system production shows an increase in energy consumption. The correlation between these two parameters seems not to be strong since the R^2- value is 0.73; since it is below 0.50, the correlation between the parameters in not that strong.

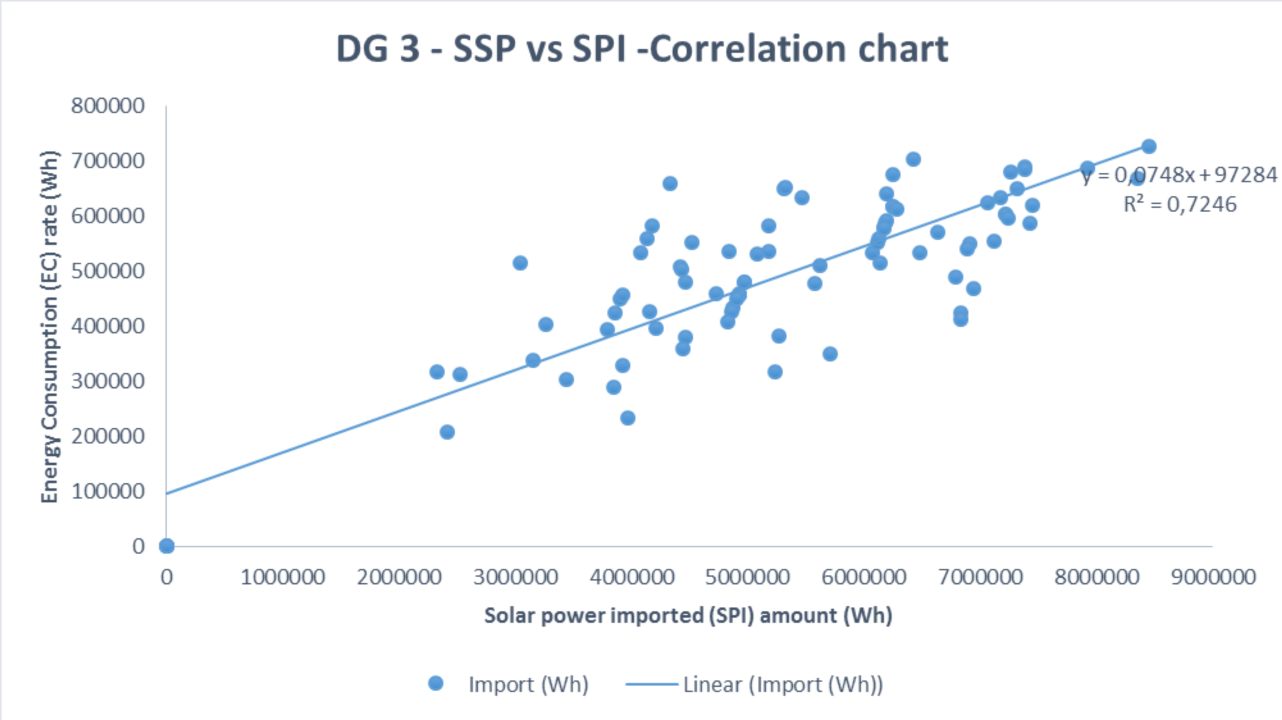

Figure 4. 13: DG 3: Investigated the correlation between EC vs SPI

4.5.3 Data group 3 (DG 3): Analysis of correlation between parameters

Figure 4.14 of DG 3 investigated the relationship between the energy consumption and solar power produced amounts. The figure below shows the good relationship between them since the R^2 -value is 0.63, which is above 0.50. An increase in solar self-consumption amount also demonstrates an increase in the energy consumption rate.

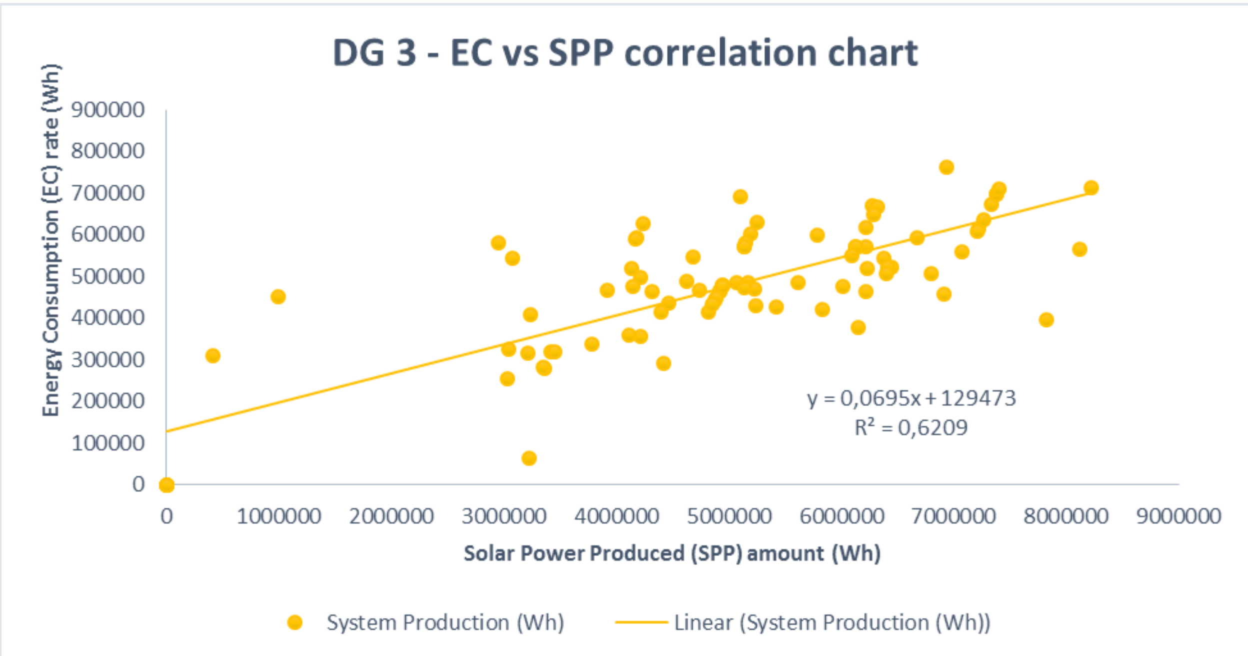

Figure 4. 14: DG 3: Investigated the correlation between EC vs SPP

Figure 4.15 of DG 3 investigated the relationship between the energy consumption and solar self-consumption amounts. The figure below shows the good relationship between them since the R^2 -value has 0.65, which is above 0.50. An increase in solar self-consumption amount also demonstrates an increase in the energy consumption rate.

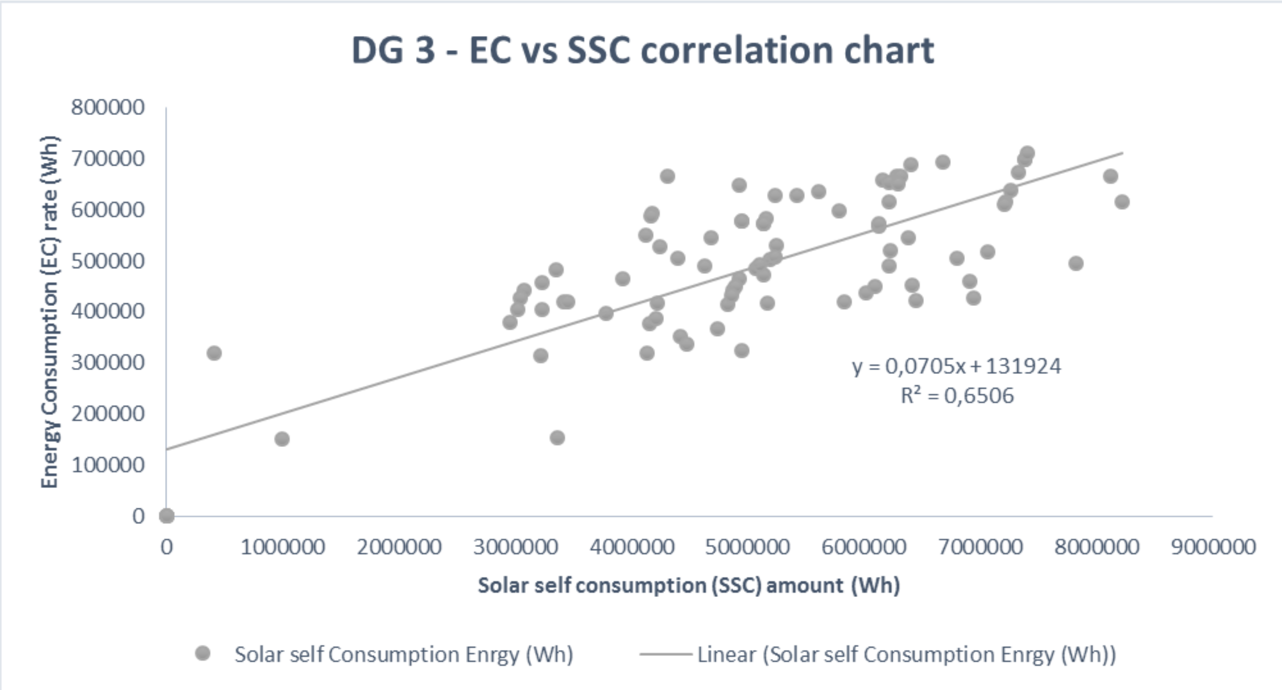

Figure 4. 15: DG 3: Investigated the correlation between EC and SSC

Figure 4.16 of DG 3 investigated the relationship between the energy consumption and solar self-consumption amounts. The figure below shows the good relationship between them since the R^2 -value has 0.65, which is above 0.50. As it above the minimum expectation by almost 0.15, we have confident in the correlation of these two variables. An increase in the solar power exported amount also demonstrates an increase in the energy consumption rate.

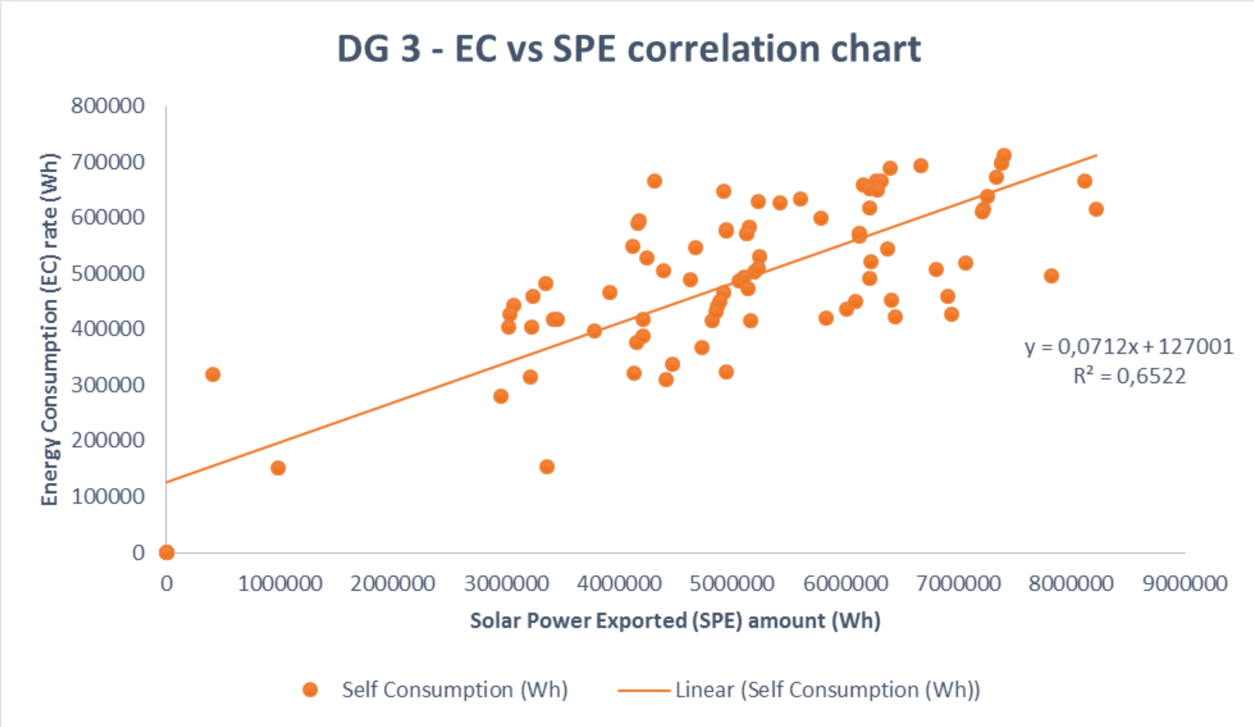

Figure 4. 16: DG 3: Investigated the correlation between EC and SPE

Figure 4.17 of DG 3 investigated the relationship between the energy consumption and solar power imported amounts. The figure below shows the good relationship between them since the R^2 -value is 0.66, which is above 0.50. An increase in the solar self-consumption amount also demonstrates an increase in the energy consumption rate.

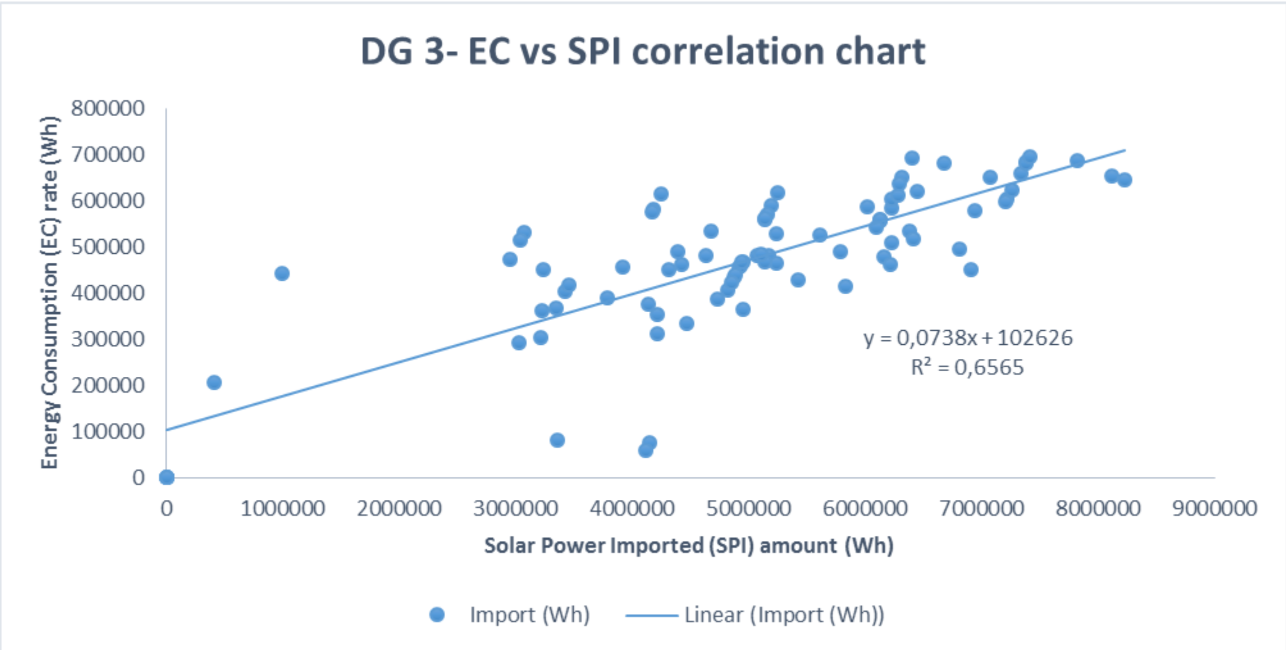

Figure 4. 17: DG 3: Investigated the correlation between EC and SPI

4.5.4 Data group 4 (DG 4): Analyses of correlation among parameters

Figure 4.18 of DG 4 investigated the relationship between the energy consumption and solar power produced amounts. The figure below shows there is not a strong relationship between the parameters since the R^2 -value is 0.54. An increase in the solar self-consumption amount also shows an increase in the energy consumption rate.

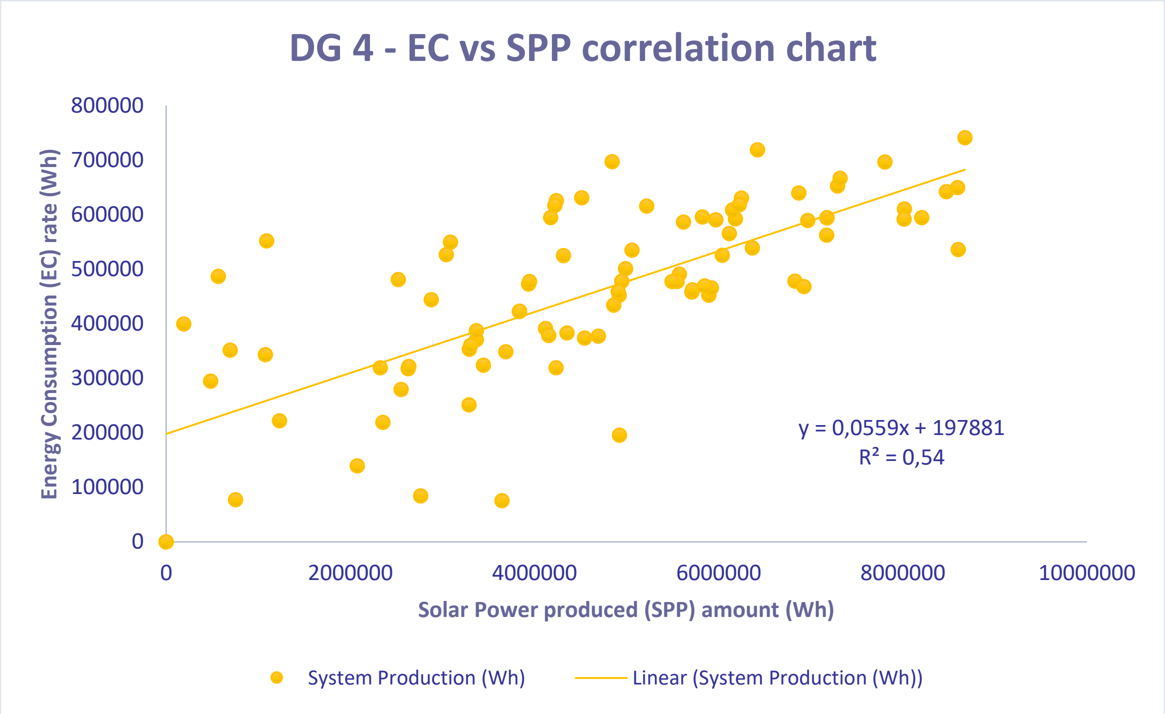

Figure 4. 18: DG 4: Investigated the correlation between EC and SPP

The solar self-consumption energy and energy consumption are investigated as well and the relationship between these parameters seems to be strong as well since it has a R^2- value of 0.67. This value demonstrates a good relationship between these parameters. Figure 4.19 below better demonstrate the relationship between the parameters.

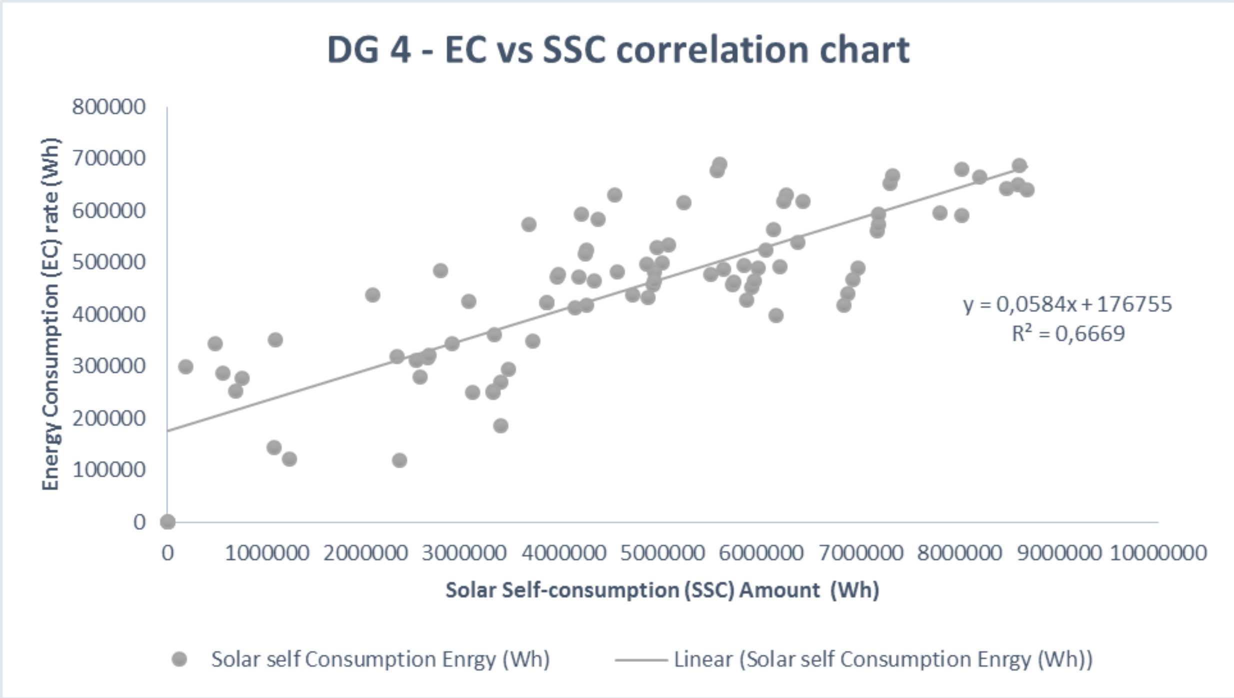

Figure 4. 19: DG 4: Investigated the correlation between EC and SSC

The relationship between energy consumption and solar power exported are investigated. The graph below demonstrates a strong relationship between the two parameters. The slope of the graph is seen to be growing by 0.057 at all points and shows a high relationship of parameters. Furthermore, the systematic calculated R^2- value predicts a high level of solar power, as the r^2- value is above 0.5 and is 0.67. However, most relationships show a positive r^2-value that is more than 0.5.

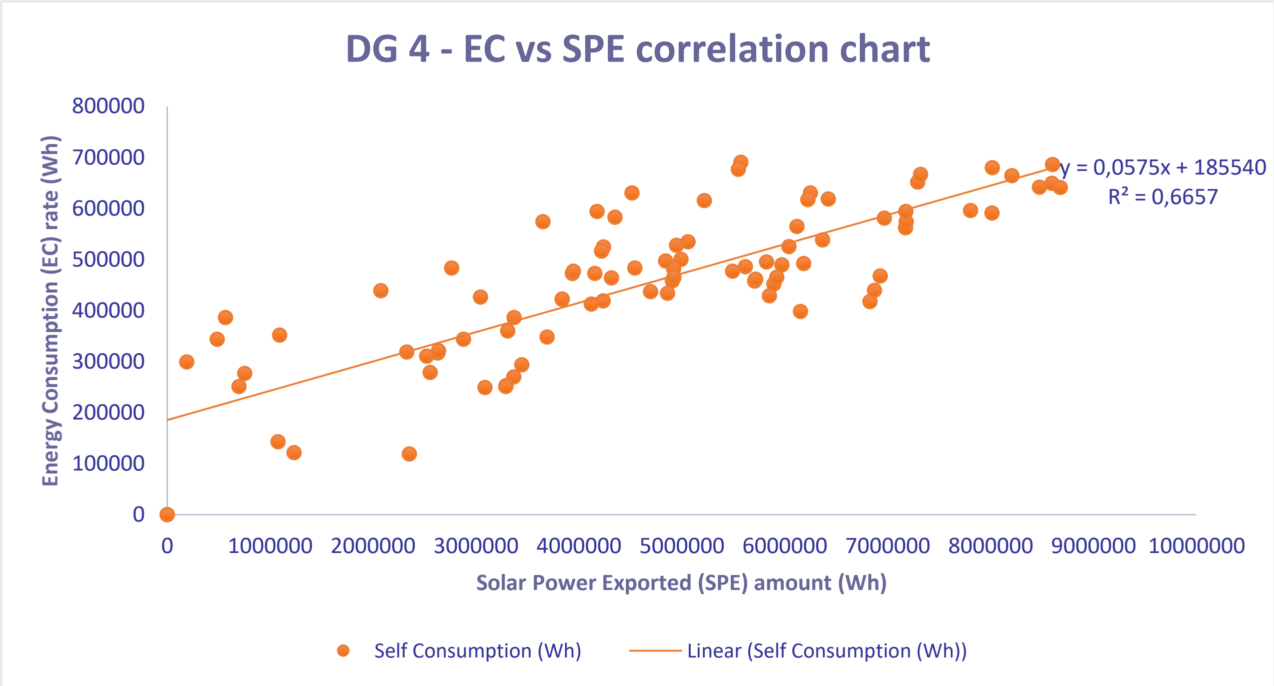

Figure 4. 20: DG 4: Investigated the correlation between EC and SPE

The relationship between energy consumption and solar self-consumption of DG 4 presented below shows a slight drop compared to the others. Their r^2- value is found to be 0.537, which is high risk compared to the others, but it is above the minimum expected value. However, the relationship is seeming to be existing, but not stronger than the other parameters compared before in the DG 4.

The y-intercept shows positive growth of 0.0583 of all points, even though it is a small growth, but it shows a positive relationship between the parameters.

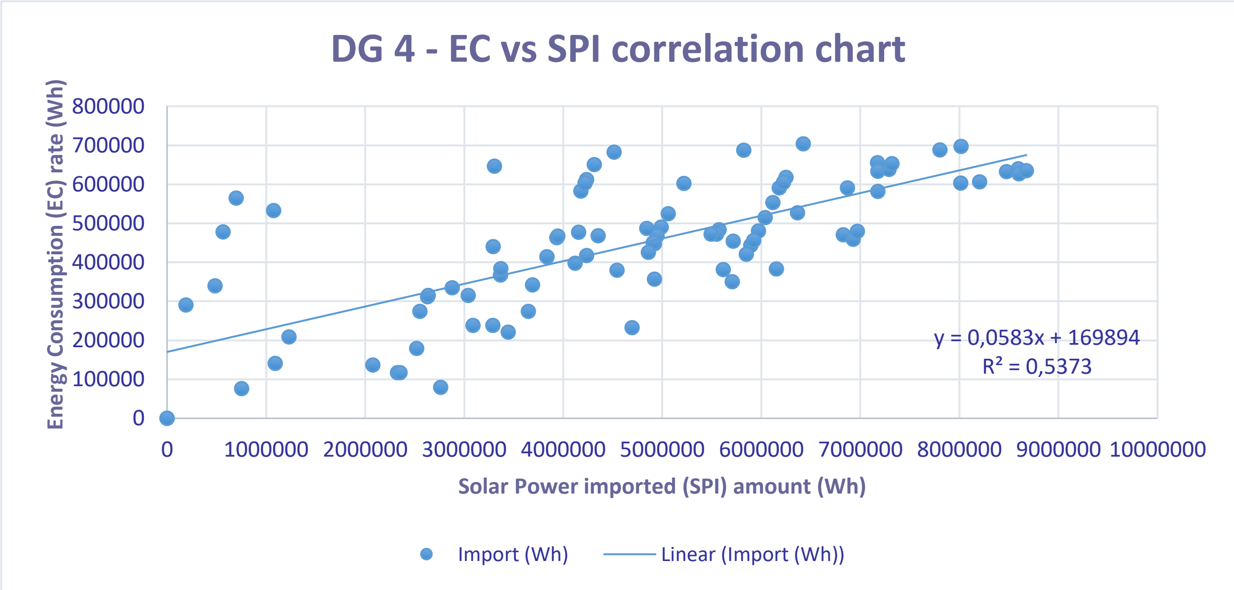

Figure 4. 21: DG 4: Investigated correlation between EC and SPI

The reason for outlining the data grouping throughout is to demonstrate the performance between the parameters during the different seasons and weather conditions. This assisted mostly in understanding the correlation between the parameters for different seasons of the year. Data grouping 1 (DG1) was the only data grouping that did not show a solid correlation of the r^2-value of 0.49 between energy consumption (EC) and solar system production (SSP). Nevertheless, all the other parameters in the all the data groupings (DG2, DG3 and DG4) showed good correlations between each other as they all had r^2-value above 0.50.

4.6 APPLICATION OF MULTIPLE REGRESSION MODEL

The major purpose of applying the multiple regression model is to predict solar power production according to certain numerous solar power routines as well as trying to predict the solar power performance in the region of KZN.

Based on multiple regression data, the observed variables all seem to have a high level of significant values as all independent variables consist of $P < 0.05$ as it was explained in chapter 3. Table 4.9 clearly demonstrates the significance of each independent variable. The unpresented variable below, such as temperature, did not meet the significance requirement of 5% or less.

Table 4. 9: Independent variable significance indication (P < 0.05)

Variables	***P-value***
Intercept	0,002174135
Consumption (Wh)	0,000759062
Import (Wh)	0,000216778
Export (Wh)	0,043602569
Solar self-Consumption Energy (Wh)	0,040754731

In summary, table 4.10 demonstrates that:

• All the clarifying parameters remain statistically significant.

• They all have positive coefficients which display each clarifying variable as a greater percentage associated with a higher level of solar power production.

• For every 1 Wh increase in the Wh of solar self-consumption and over, there will be an increase of 1.36%, 44.25%, 16.67% and 15,54% in the predicted value of consumption, import, export and solar production respectively.

Table 4. 10: Coefficient table of all solar power variables

Solar power Variable	***Coefficients***
Intercept	42603.780
Consumption (Wh)	0.0136
Import (Wh)	0.4425
Export (Wh)	0.1667
Solar self-consumption (Wh)	0.1554

*Dependent variable: solar power production (Wh).

Even though the linear relationship is indicated by the coefficients of independent variables, it does not give any sign of the strong point of each association. The correlation coefficient can only give the confidence interval.

Based on the correlation coefficient outcome, it suggests a very strong relationship between the solar power production and the solar power factor (consumption, import, export and solar self-consumption). The coefficients of determination of solar power production (Y) with R^2-

value of 0.75 remained adequate to encounter the solar power consumption, for instance. Table 4.11 demonstrates the all regression statistical model. The actual strong relationships of solar production regression between solar consumption, solar power imported, solar power exported, and solar self-consumption suggests that the application of the solar power production to solar power factors is even more suitable for reliably signifying the degree of solar power sustainability.

Table 4. 11: Summary of the multiple regression

Regression Statistics	
Multiple R	0,868
R Square	0,753
Adjusted R Square	0,750
Standard Error	82,290

With four predictors together with a constant, there is a coefficient of determinant of almost 75% of the variation in solar power production in the region of KwaZulu-Natal. Fortunately, there are no exponential terms in equations, as exponential terms are considered to be more complex especially if the number of exponential terms keeps on rising (Karamavus and Ozkan, 2019).

The theoretical model is:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + bx_4 + \varepsilon \quad (4.4)$$

The projected model is:

$$\mathbf{Y = 42603{,}780 + 0{,}0136x_1 + 0{,}4425x_2 + 0{,}1667x_3 + 0{,}1554x_4 + \varepsilon} \quad (4.5)$$

As all coefficient gradients are positive, the slope shows a positive increase. The gradient of this line from solar consumption, import, export and solar self-consumption is 0,0136, 4425, 0,1667 and 0,1554 respectively, which designates that for an increase of one month in a year the predictable increase in solar production (Wh) is 0,0136, 4425, 0,1667 and 0,1554 units. The predicted solar production for each month, the following table provides values for each first day of the month so as to be able to make future predictions of solar power production.

Table 4. 12: Random sampling date for daily solar production for prediction. (Ntshalintshali, 2016)

Time	Consumption (Wh)	Import (Wh)	Export (Wh)	Solar self- Consumption Energy (Wh)
01/03/2018	921884	456171	265713	265713
01/04/2018	4407863	533687	544176	544176
01/05/2018	0	0	0	0
01/06/2018	6477863	533687	544176	544176
01/07/2018	5077863	531687	544176	544176
01/08/2018	3921884	456171	465713	465713
01/09/2018	6377863	533687	544176	544176
01/10/2018	3921884	456171	465713	465713
01/11/2018	0	0	0	0
01/12/2018	564123	477656	386467	286467
01/01/2019	7177863	633687	574176	574176
01/02/2019	8603008	626985	686023	686023

In the calculation below, the number of days was extracted from the previous solar power data to manage the prediction of the future solar power production. The y is used to present solar power production as the dependent variable.

Solar power prediction calculation:

$\mathbf{Y_1}$ = 42603,780 + (0,0136×921884) + (0,4425×456171) + (0,1667×265713) + (0,1554 × 465984) = **373705 Wh**

$\mathbf{Y_2}$ = 42603,780 + (0,0136×4407863) + (0,4425×533687) + (0,1667×544176) + (0,1554 × 544435) = **514027 Wh**

$\mathbf{Y_3}$ = 42603,780 + (0,0136×0) + (0,4425×0) + (0,1667×0) + (0,1554 × 0) = **42604 Wh**

$\mathbf{Y_4}$ = 42603,780 + (0,0136×6477863) + (0,4425×533687) + (0,1667×544176) + (0,1554 × 544176) = **542138 Wh**

$\mathbf{Y_5}$ = 42603,780 + (0,0136×5077863) + (0,4425×531687) + (0,1667×544176) + (0,1554 × 544176) = **522213 Wh**

Y_6 = 42603,780 + (0,0136×3921884) + (0,4425×456171) + (0,1667×465713) + (0,1554 × 465713) = **<u>447803 Wh</u>**

Y_7 = 42603,780 + (0,0136×6377863) + (0,4425×533687) + (0,1667×544176) + (0,1554 × 544176) = **<u>540778 Wh</u>**

Y_8 = 42603,780 + (0,0136×3921884) + (0,4425×456171) + (0,1667×465713) + (0,1554 × 465713) = **<u>447803 Wh</u>**

Y_9 = 42603,780 + (0,0136×0) + (0,4425×0) + (0,1667×0) + (0,1554 × 0) = **<u>42604 Wh</u>**

Y_{10} = 42603,780 + (0,0136×564123) + (0,4425×477656) + (0,1667×386467) + (0,1554 × 286467) = **<u>370580 Wh</u>**

Y_{11} = 42603,780 + (0,0136×7177863) + (0,4425×633687) + (0,1667×574176) + (0,1554 × 574176) = **<u>605571 Wh</u>**

Y_{12} = 42603,780 + (0,0136×8603008) + (0,4425×626985) + (0,1667×686023) + (0,1554 × 686023) = **<u>658014 Wh</u>**

Where,

Yn – represents solar power production in monthly day.

The y intercept is 42604 Wh; this simply means that if the line was predicted back to zero solar consumption, solar imported, solar exported and solar self-consumption, then the solar produced value would be 42604 Wh.

To summarise the above calculations, a predictive chart was created to give a better review of solar production in the region of KZN annually. The minimum solar power that could be produced is 42608 Wh as indicated in fig.4.22 in months 3 and 4 respectively. The minor decrease in solar power production is predicted to be in months 2, 6 and 8 at 5.6%, 3.9% and 3.9% respectively. The factors that seem to have a major effect are solar radiance and temperature. The increase is expected in months 1, 3, 5, 9, 10, 11 and 12 at 0.5%, 100%, 1.7%, 100%, 29.2%, 19% and 23%. However, there are months where there is no increase nor decrease such as in months 4 and 7.

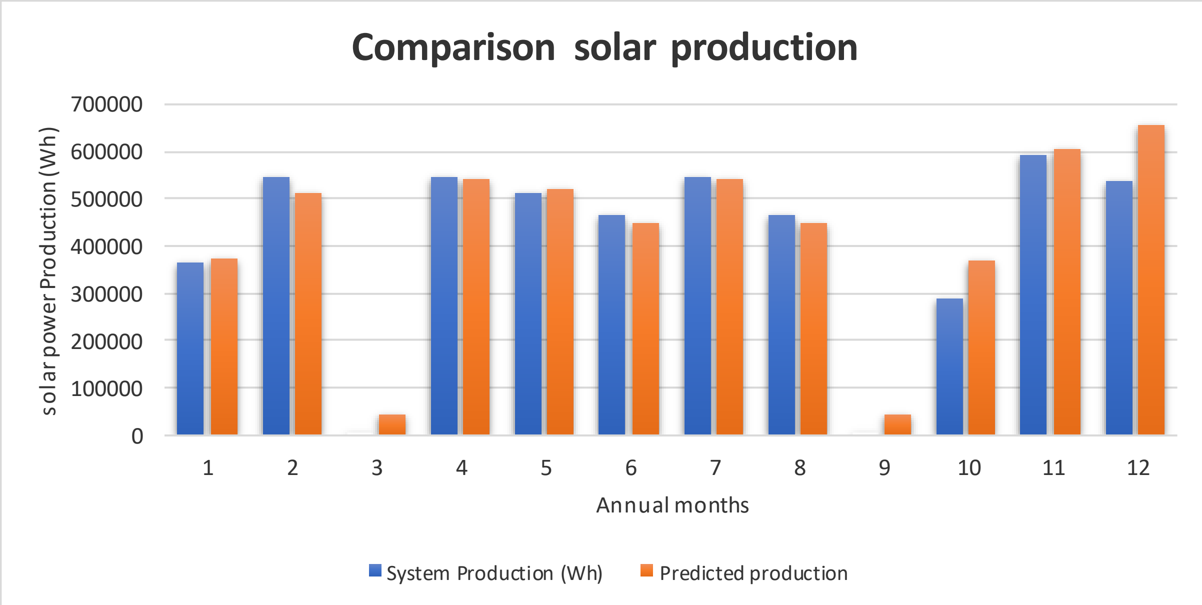

Figure 4. 22: Comparison of solar power production

The expected performance of solar power in the region of KwaZulu-Natal is graphically summarised in fig.4.24. The summary shows the next 360 days of solar power production using the same period as the database (March to February). The performance of solar power production as per the data grouping (DG) scale shows that solar power production varies according to solar availability. The solar power production at a small scale (100 MW) is summarised based on the four data grouping. Solar power production (Wh) in the DG 1 shows that almost 32% of solar power could be produced in this term. This brings confidence that electricity can be produced using solar power to generate electricity for household activity without any negative effects such as load shedding or unreliability signs. The solar power production drop is expected in DG 2 and DG 3 as predicted earlier in the study. Fig.4.23 shows that solar power production in DG 2 and 3 will be almost 26% and 27% respectively. The last solar power production in DG 4 in expected to be 38%; this is a high level of solar production that can be produced in a region according to the data gathered.

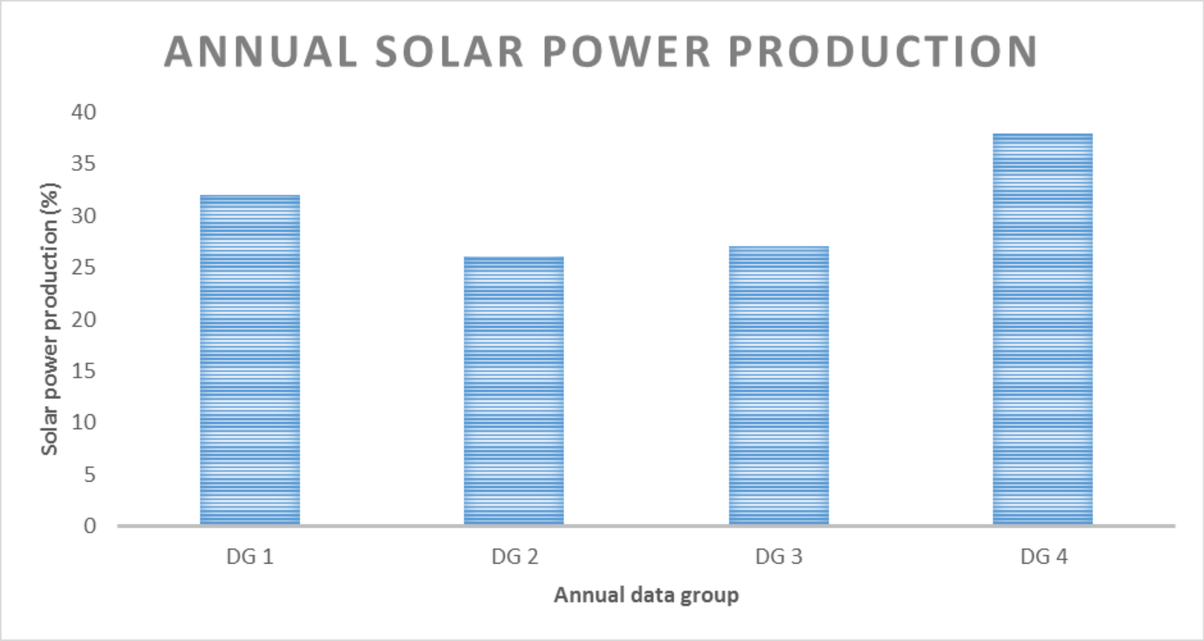

Figure 4. 23: Annual solar power production as per data grouping

4.7 SUMMARY

The response from the data analyses presented in this chapter include all the analysing tools used in the study. The data indicates a positive growth of solar power production in the region of KwaZulu-Natal. Tools such as the root cause analysis were used to investigate the challenges facing solar power sustainability. The positive outcome for RCA shows that a number of factors such as the environment, financing of solar and technology understanding need to be given attention, since they are seeming as major challenges in solar power growth.

In parallel with the root cause analysis, a cost benefits analysis was conducted to evaluate the financial challenges in implementing solar power in the region of KwaZulu-Natal. The CBA revealed that implementation of solar power on as small a scale as possible should be undertaken. The return on investment could also be seen at an early stage almost within 5 years of implementation of solar power. The investment [amount] would also double within a period of 10 years after the solar power project launch date. This also gives assurance to the government's national development plan of increasing the renewable energy projects by 2030. The financial benefit of implementing solar power in the region is best outlined through the CBA.

The statistical position of solar power in the region was also conducted in the form of multiple regression of solar power data received from the database of eThekwini municipality. The prediction of solar power sustainability in the region also shows good results since it has 0.75 of R^2. This reveals that solar power in the region will be sustainable throughout the year. The analysed results together with the study as a whole will be concluded in the following chapter, to give the study outcome and position of KZN when it comes to solar power.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

Chapter 4 dealt with the findings and analyses. In this chapter an overview of the outcomes of the study is given and the results are cited to answer the research questions introduced in chapter one. Furthermore, the study concludes with recommendations based on the findings and results analyses of the research.

5.2 CONCLUSION

A level of solar available in the region of KwaZulu-Natal provided the motive to investigate solar sustainability in the region. Part of this study acknowledges previous writings on renewable energy, in particular solar power. The outcomes reveal the necessity to conduct a regional study on solar power to investigate the sustainability of solar power in the KZN region. The literature reviewed also indicates that there is a relationship between solar availability and power solar production.

The quality of the solar system in KZN assures better solar power production in the region of KZN. As solar technology continues to develop, the feasibility of increasing costs was analysed in accordance with regional solar needs.

The literature referenced in this study clearly indicated that there is a relationship between productivity and quality. Results from the studies in this research further revealed that there is a positive correlated relationship between productivity and quality. This has enabled the researcher to answer the research questions as outlined in Chapter 1.

5.3 STUDY RECOMMENDATION

This section presents the recommendations that conclude the study. Figure 5.1 represents the sources of the recommendations. All the contributors in the source of recommendations diagram have been analysed in depth in the study in order to generate quality recommendations.

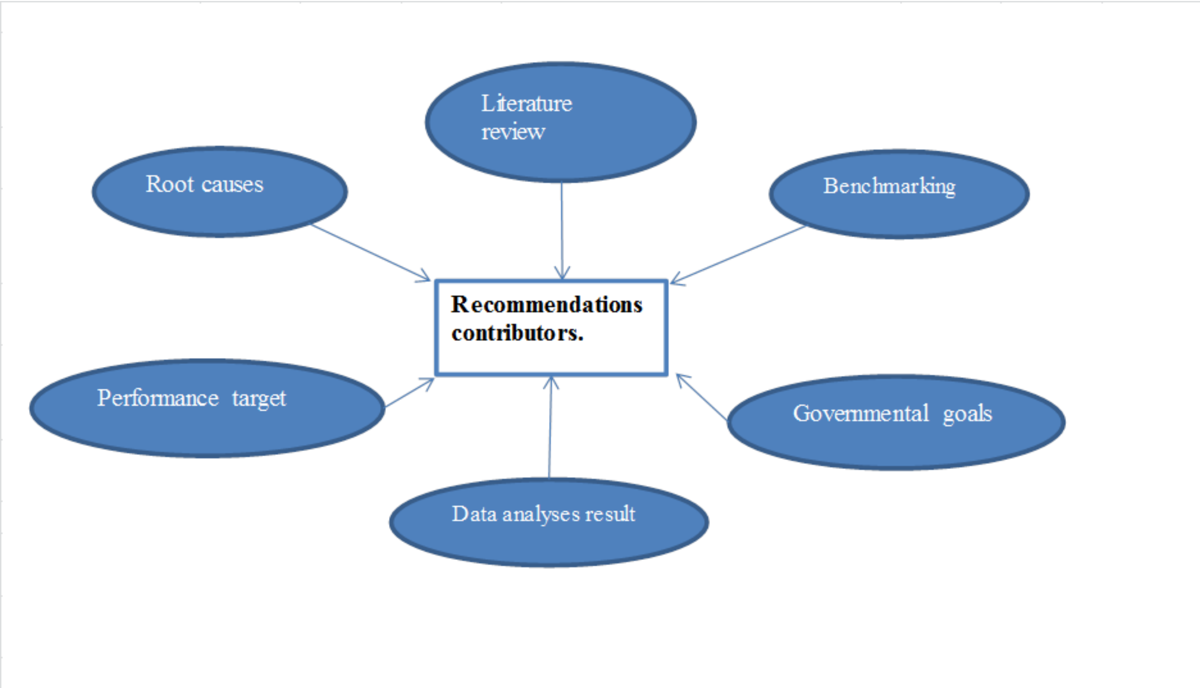

Figure 5. 1: The sources of the recommendations

5.3.1 Economical, Methodological and Environmental (EME) framework Analysis of measured solar challenges

Figure 5.2 was developed to overcome the solar power unsustainability in the KZN region. This solar power framework was developed utilising all the sources of the recommendation input in fig.5.1.

Figure 5.2 proposes the path from potential solar power factors to better solar performance in the region. This framework is divided into three sections (input, process and output). All the major inputs are introduced in this section and are explained here. The economic advantages of solar power give direction to the aspects of the solar power system to be funded. If funding of solar power in the region is directed to SP technology depreciation and SP technology implementation costs, the sustainability of solar energy could be easily achieved.

5.3.2 Economic breakdown of solar power in the region of KZN

SP technology depreciation – the funding will focus more on the age of solar technology in order to keep it up to the required standard. The standard of the solar power system will be ensured by means of a proper maintenance plan. Equipment, such as the solar panels, need to be kept in good shape to avoid premature failure of the system. Panels are affected by dust and corrosion that occurs during solar power supply. On the other hand, the battery duration is affected by the chemicals in it. Therefore, it would be more beneficial if funds were directed at dealing with the critical solar contributors that can easily collapse the solar system.

SP technology cost - the cost will be directed to the implementation of solar power. The technology has to be the latest technology to ensure the efficiency of the solar power system. The technology upgrade will cost slightly more, but it will reduce the costs budgeted for SP technology depreciation.

5.3.3 Methodological breakdown of solar power in the region of KZN

The main reason why the research had to overlook at the solar power methodology is the potential solar power have and the less increasing of its implementation of solar power from small scale to large scale to KZN region. At this stage the KZN region can function best on a small scale. The other reason was to eliminate investment risks due to the incorrect method being carried out. The cost of a solar power system will be reduced if the correct methodology is used. The proposed reduction in solar power costs can be achieved through looking into two aspects of solar:

1. **Solar power research and development** – this aspect can benefit the region since there will be a better understanding of the technology required in the KZN region. It will prepare the solar power system organisers for future technology and increase the opportunity to develop relevant technology for the region rather than benchmarking against developed countries like Germany. There is nothing wrong with benchmarking, but it needs to be remembered that other countries are using technology that suits their solar radiance and temperature. This creates an opportunity for solar power products with superior performance to be manufactured once the relevant parameters have been analysed.
2. **Solar power training and financing policy** – this will assist in reducing implementation time and the waste of solar power material, provided training be maximized through proper training policies to ensure proper skills transfer for renewable energy as whole in the region level. This process will need to be guided by policies directed towards renewable energy such as solar power. For example, a solar power financing policy should be developed since the author was unable to access such a policy for the KZN region in the course of his research for this study. Both SP research and development as well as SP training and financing policy could help reduce the premature collapse of the SP system.

Danev *et al*., (2012) believed that there was a lack of training in technologies such as solar water heating (SWH) installation and maintenance. Training in installation and maintenance of such strategic technology needs financial support and proper policies in order to expand to a larger scale.

5.3.4 Environmental breakdown of solar power in region of KZN.

Since there is high level of concern regarding greenhouse gas emission across the world, it is recommended that environmental controls be put in place to assist developing regions such as KZN in proper planning when it comes to solar implementation. There is a need to reduce the negative impact of solar energy production. The CO_2 emissions measure can play a prominent role in making the world feel more confident about solar energy as a viable alternative to fossil fuel energy.

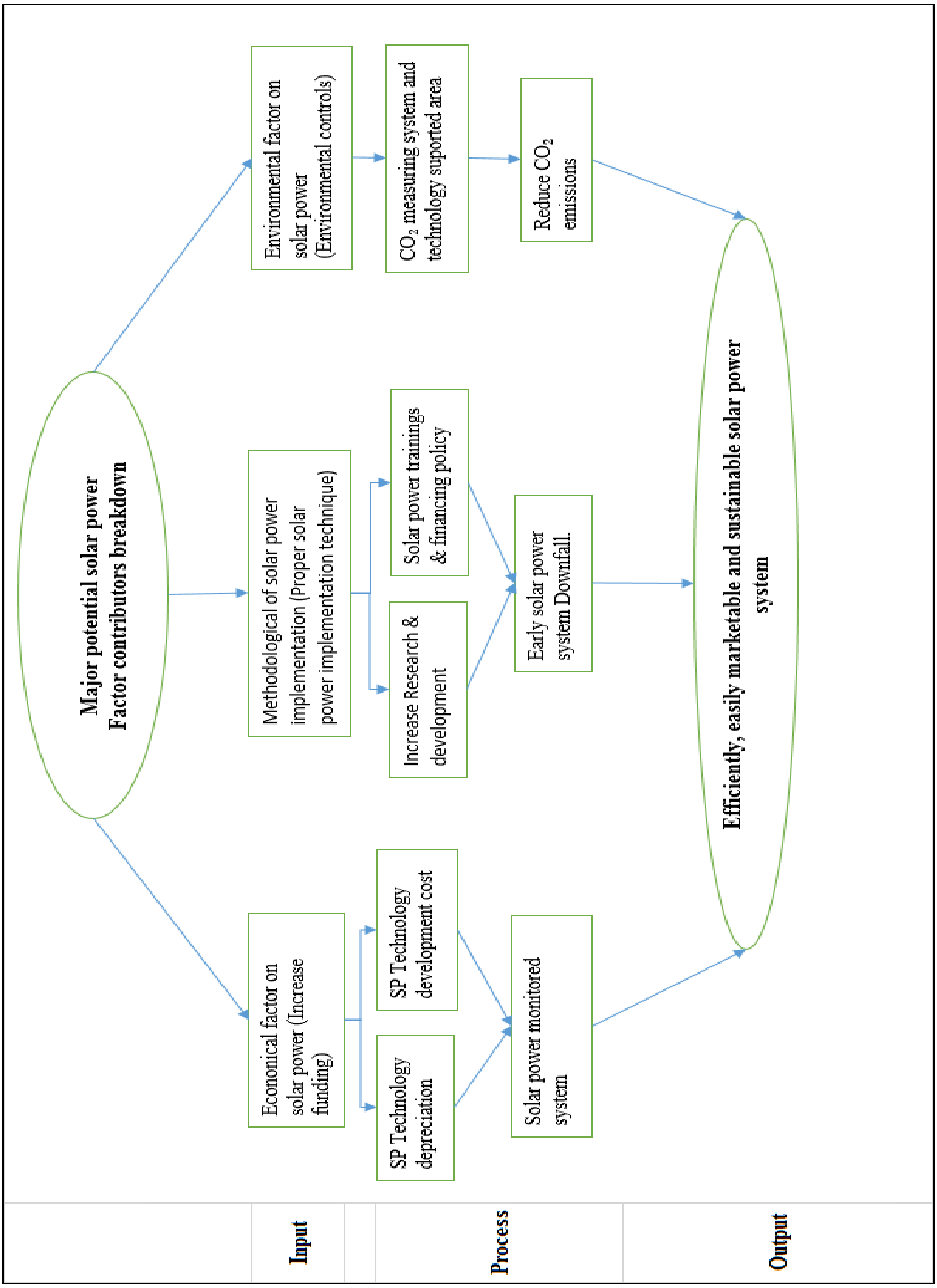

Figure 5. 2: Solar power (SP) sustainability analysis framework for KZN

5.4 RESEARCH QUESTIONS ASSESSMENT

The study was guided by a number of questions that prompted the author to pursue an investigation into solar power. A review of the study will indicate whether the direction taken by the study was significant and whether all the questions were answered or received an appropriate response. The following questions will enhance understanding of each of the study objectives.

- **What are the root causes of the unsustainability of solar power in the KZN region**?

The study analyses the root causes of solar power sustainability in the KZN region, using the cause and effect diagram. The prime solar power contributors were also discussed in relation to solar power. The following contributors were found to play a major role in solar power sustainability:

- **Man** is one the main contributor to solar power unsustainability since he lacks the very necessary skills to develop and understand the relevant technology recommended for the KZN region. This introduces the major challenge of time delay as more time has been requested to study solar power energy systems.

- **Environment** was given a brief overview to demonstrate the aspects that challenge the solar power system during the implementation phase. All delays are briefly discussed for technological aspiration in the region. As this study gave an overview of the KZN region where a solar PV system had been installed, an environmental analysis was used to provide a better understanding of the technology. A study of the local environment was also used to calculate the cost effectiveness of technology in the KZN region.

- **Method** is key when it comes to solar power implementation. A brief analysis of method is also given under the cause and effect overview. Solar power implementation methods were benchmarked to compare the region of KwaZulu-Natal with, for example, Germany.

- **Material** to create a solar power system that will be sustainable due to the structure and quality of the material used was reviewed. The material used for solar power will determine the duration of the solar power system's existence under different weather conditions. However, weather conditions prevalent in KZN were not analysed in the study.

- **What are the implementation processes with regard to implementing solar power in the region and are these processes effective?**

During the root cause analysis of solar power in the KZN region, the process of implementation was also discussed in detail. A financial analysis was also used to indicate the cost effectiveness of all the processes. However, a process flow did not form part of the study analysis.

- **What are the cost benefits related to solar power energy that can be implemented in the KZN region?**

The study revealed that solar power can be cost effective in the region of KwaZulu-Natal as long as proper measure are put in place to make it sustainable. Furthermore, the cost benefit analyses (CBA) that was conducted in the study to analyse solar power demonstrated that implementation of solar power in the KZN region would yield financial benefit. However, this financial benefit would only be realised after five years and would rely on an initial investment. Solar power investment can be classified into three categories namely small, medium and large.

Small investment is when the region plans to implement solar power on a small scale. The advantage here is that it can be easily monitored, and sustainability is guaranteed. The obvious benefit is that solar power implemented on a small scale could yield financial benefit at an early stage. Medium scale solar power implementation also only needs low financial investment and it can be easily monitored to ensure sustainability. Large scale implementation of solar power needs large investment and is not easily monitored. The advantage of implementing solar power on a large scale is that demand can be met easily.

- **What is the solar power system integration flexibility from a technological and environmental point of view?**

It was found that solar power, especially the solar PV system is more flexible than any other solar system which led countries such as Germany to prefer the solar PV system as an alternative energy provider. The technology is the major variation in the solar power system since it is subject to change now and again. Therefore, the study revealed that implementation of a solar power system relies on solar power technology. The matter of solar power systems is still in the developmental stage in South Africa as whole.

The environmental control measures that are proposed in the framework will assist in reducing GHG emissions in the preferred solar power technology. There is a national development plan proposed by government that outlines plans until 2029. This report clearly states that solar power in the region can be utilised without experiencing environmental damage.

- **How long it will it take the KZN region to implement a successful and sustainable solar power system?**

Based on a solar power implementation scale, a statistical analysis was conducted to check solar power performance in the KZN region. Solar power implementation shows a regression figure of 75%. This guarantees proper solar power production in KZN region. Although we don't know how long it will take, the prediction paints a bright future in solar production. Figure 5.4 indicates temperature variations between KwaZulu-Natal (KZN) and Western Cape (WC). The two compared provinces demonstrate high levels of solar temperature which gives certainty to solar power production throughout the year. From January to December, KwaZulu-Natal shows higher solar temperatures then the Western Cape.

In January KZN had an average temperature of 24°C, while Western Cape experienced 22°C. The lowest temperatures were experienced in the month of July with an average temperature of 16°C in KwaZulu-Natal and 13°C in Western Cape. This guarantees successful solar power production in the KZN region as all months experienced higher temperatures then the Western Cape which already has successful solar power projects in operation.

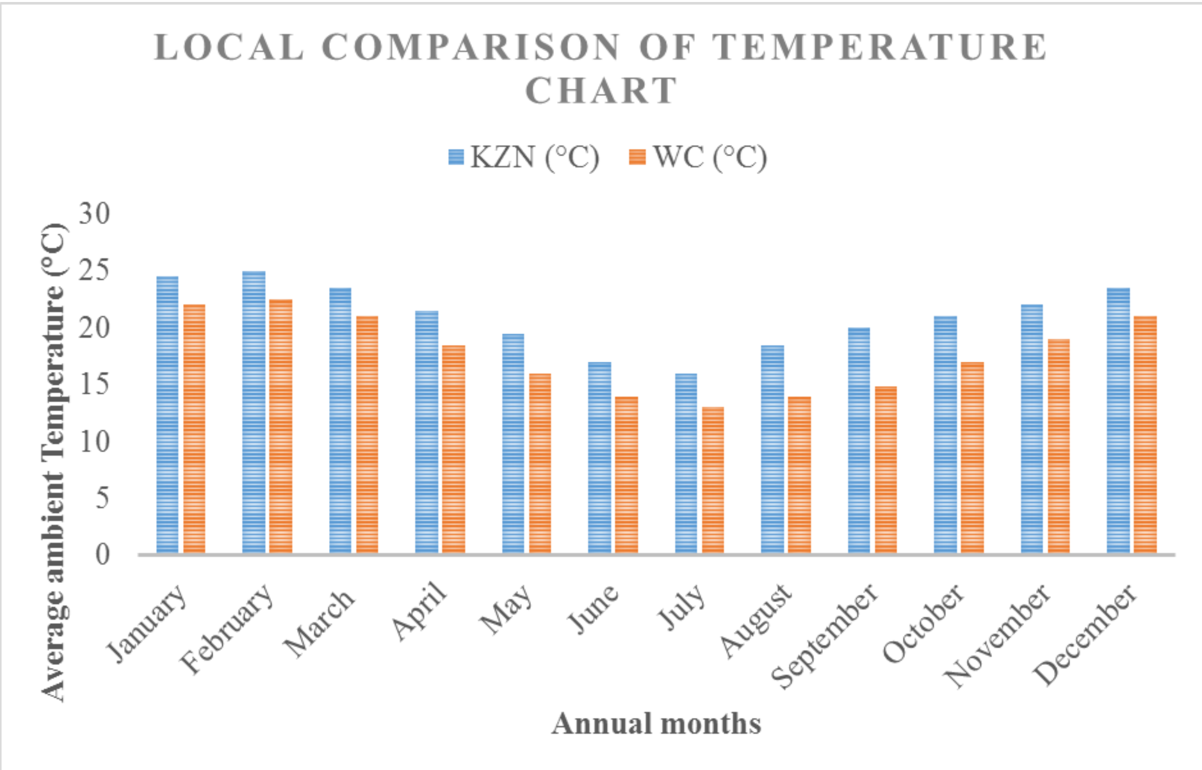

Figure 5. 3: Temperature comparison between KZN and WC (Danev *et al*., 2012)

5.5 RESEARCH OBJECTIVES SUMMARY

The root causes of solar power unsustainability were discovered in the region of KZN using the special tool for determining the root causes. There are indulgences (such as the solar power policy gap) that are hindering implementation of solar power in the region that eThekwini municipality needs to deal with. According to the root cause outcome solar power sustainability relies on SP policing, SP financing, SP technology controlling and understanding. Monyei *et al*., (2018) agreed that some solar power problems exist because of policy fall-out.

The solar power root causes concluded that solar power installation was not growing as in other provinces such as the Western Cape. Financial support appeared to be the main obstacle to solar power installation as was outlined in the study. If solar power continues to be unsustainable in eThekwini municipality, the well-known impact will be increased energy demand and lack of sponsors to give financial support. The solar power financing will continue to depend on governmental support. As solar power implementation is not trusted by many citizens of eThekwini region, marketing of this commodity needs to be vastly improved. Strategic marketing will lead to improved solar power education.

In the study, an EME framework was developed to deal with the unsustainability of solar power in the region. This is a model that will assist in eliminating the major causes of solar power failure in the KZN region such as solar power policy fall-out.

5.6 SUMMARY CONCLUSION

The importance of solar power sustainability in the region of KwaZulu-Natal, is the major contributor in dealing with renewable energy in the region. The growth of solar power depends on its sustainability. The outcomes of this solar power unsustainability investigation highlighted, among other things, a lack of education on solar power.

Solar power can be manageable in the region of KwaZulu-Natal in light of the literature reviewed and the results of this study. The gap in solar power sustainability was caused by many factors that were identified using the root cause, cost benefit and regression analyses. These techniques were used to analyse the situation in the KZN region.

In this chapter a recommendation was made to overcome the issue of solar unsustainability in the region of KwaZulu-Natal. The EME framework was used to address the unsustainability of solar power in the region.

5.7 FUTURE RESEARCH

The literature clearly tells us that implementation of renewable energy (solar power) in South Africa is still way behind from other countries such as Germany, China and the USA. Solar power has been found to be a promising alternative energy supply in South Africa. The research revealed that solar power has potential in the KZN region, but more research needs to be done in the field of solar power sustainability in rural areas, where electricity in not where to be found. More research is outstanding in financing solar power technologies that dramatically changing. Furthermore, is the solar power technology transformation still needs to be investigated further.

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