University of Pretoria

RESEARCH REPORT

An Assessment of the South African Photovoltaic Sector within the Technological Innovation System Framework

by

Dawid Gideon LeRoux van Niekerk

Student Number: 29185034

A project report submitted in partial fulfilment of the requirements for the degree of

Master of Engineering in Technology & Innovation Management

in the

GRADUATE SCHOOL OF TECHNOLOGY MANAGEMENT, FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY, UNIVERSITY OF PRETORIA

17 November 2017

Abstract

Globally, a strong transition is taking place: conventional coal-based and nuclear energy-generating methods are being phased out as the world is advancing towards cleaner renewable energy production, triggered by increasing awareness of the threat of global warming and climate change. South Africa faces a major energy crisis and is in the process of expanding its energy infrastructure. The main challenge addressed in this study is the context of a country with a struggling economy, a high unemployment rate and widespread poverty. Photovoltaic (PV) energy could provide a long-term solution to the existing energy crisis, potentially develop and enhance local economic activity and make a significant contribution to eradicating poverty. This study investigates the strengths and potential barriers to diffusion, influencing the growth and adoption of PV energy by applying the Technological Innovation System (TIS) framework approach in the context of South Africa. Every well-functioning TIS comprises system functions fulfilling critical activities and processes that, in combination, strengthen the system. The TIS framework approach evaluates the seven core system functions, namely entrepreneurial activities, knowledge development, diffusion of knowledge, guidance of the search, market formation, resource mobilisation and advocacy/resistance to change. An exploratory case study was applied in the context of the TIS framework to evaluate the system functions and the link between them through an online questionnaire using a comprehensive sampling technique. The performance of each system function was measured using a Likert scale, whereafter the system functions were mapped graphically in order to compare their performance to one another. The extent of development of the PV infrastructure was determined by evaluating the system functions according to specific indicators relating to each function. The system functions were then mapped graphically, to indicate that the best performing functions had been calculated to be the resource mobilisation function and the market formulating function, and the worst performing functions the entrepreneurial activities function and the knowledge development function. The overall result achieved by the analysis was unsatisfactory, indicating the presence of barriers limiting the development and growth of the PV industry. Some of the most important barriers were found to be lack of funding, lack of knowledge, insufficient influence of the role of government and regulatory organisations, insufficient knowledge development, insufficient guidance, lack of advocacy and lobbying in promoting PV and insufficient knowledge shared through collaboration and networks. The study was concluded by suggesting policies targeted at removing the barriers.

Keywords: Photovoltaic, technological innovation system, diffusion, renewable and sustainable energy.

Acknowledgements

The author wishes to express his gratitude to Prof. David Walwyn for being an excellent study leader, guiding and steering him in the right direction.

Table of Contents

List of Figures

List of Tables

List of Acronyms/Definitions/Abbreviations

ESKOM	Electricity Supply Commission
GW	Gigawatt
GWh	Gigawatt Hour
IS	Innovation System
Kw	Kilowatt
Kwh	Kilowatt Hour
LCOE	Levelised Cost of Electricity
MW	Megawatt
NERSA	National Energy Regulator of South Africa
PV	Photovoltaic
R&D	Research and Development
REI4P	Renewable Energy Independent Power Producers Procurement Programme
RET	Renewable Energy Technology
RSA	Republic of South Africa
SHS	Solar Home System
TIS	Technology Innovation System
TWh	Terawatt Hour

1. Background to the Research Study

Since the discovery of electricity in 18th century, electrical power has become essential in people's daily lives. By the end of 2016 the total global electrical energy production capacity reached 24 816 Terawatt-hour (TWh) (BP, 2017). Figure 1.1 indicates a map of the global power generation production capability of the different countries around the world. According to Figure 1.1, China and the United States are the largest electricity producers in the world, producing a total of 6 015 TWh and 1 423 TWh respectively by the end of 2016 (Enerdata, 2017).

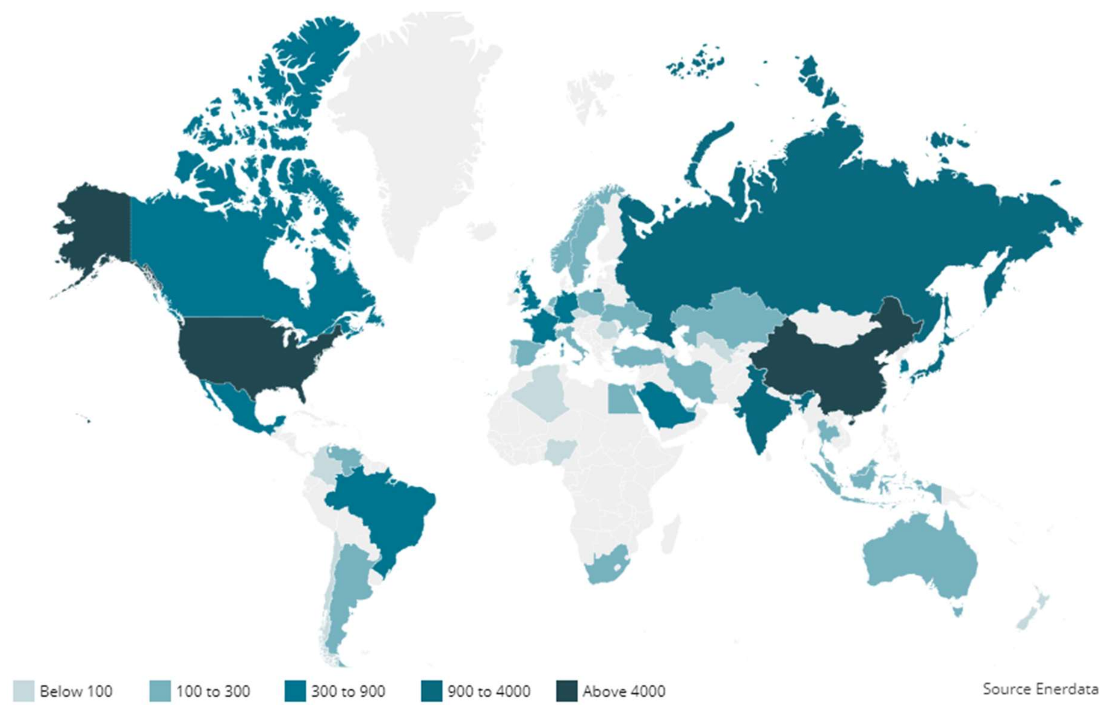


Figure 1.1: Global energy production statistics

Source: Enerdata (2017)

Table 1.1 summarises the percentage of primary energy resources used globally for 2005, 2010 and 2015. According to Table 1.1, oil, coal and natural gas are the most extensively used energy resources around the world, accounting for 32.9%, 29.2% and 23.9% of global energy consumption respectively (World Energy Council, 2016). It is estimated that the transportation industry accounts for 63% of oil consumption (World Energy Council, 2016). With electric vehicle technologies becoming an increasing reality, oil consumption might decrease in the future, creating a greater demand for electricity to power electric vehicles. The use of oil, coal and nuclear power decreased from 2010 to 2015, whereas the use of natural gas and renewable energy resources increased from 2005 to 2015 (World Energy Council, 2016).

Table 1.1: Percentage of primary resources used for generating energy

Source of Energy	2005	2010	2015
Oil	35.96%	33.49%	32.94%
Coal	28.61%	29.84%	29.20%
Gas	22.89%	23.70%	23.85%
Nuclear	5.73%	5.14%	4.44%
Hydro	6.05%	6.44%	6.79%
Wind	0.22%	0.63%	1.44%
Solar	0.01%	0.06%	0.45%
Other Renewables	0.54%	0.70%	0.89%

Source: (World Energy Council, 2016)

Thirty-one countries around the world are still producing energy from nuclear sources (Wright *et al.*, 2017). Figure 1.2 provides the total global capacity of nuclear, wind and solar power produced over a 46-year period. Figure 1.2 indicates that there was an exponential growth rate in nuclear energy production from 1970 to 1990. The annual growth rate changed to a 2.27 Megawatt (MW) per year average linear increase from 1990 to 2016. A strong transition is signified globally; conventional coal based and nuclear energy generating methods are being phased out and decommissioned and the world is advancing towards cleaner renewable energy production (Münzberg *et al.*, 2016). According to the International Energy Agency, 50% of the nuclear reactors in existence today will be decommissioned by 2040 (Wright *et al.*, 2017).

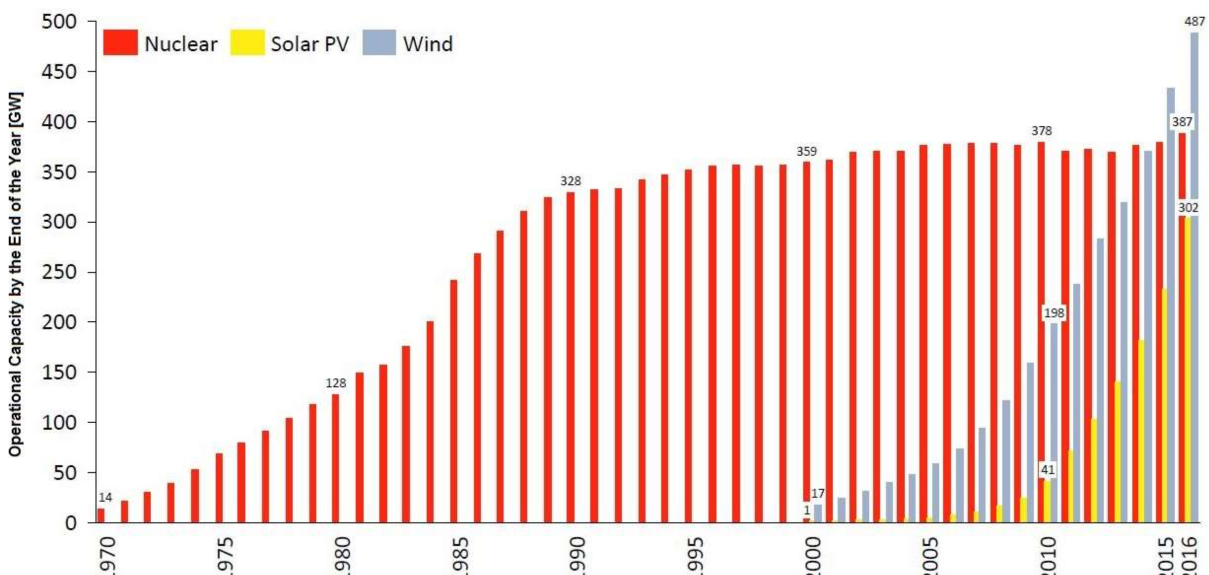


Figure 1.2: Total nuclear, wind and solar power from 1970 to 2017

Source: (Wright *et al.*, 2017)

Inverse growth and downscaling in several markets for the traditional fossil-fuel based and nuclear energy generation are indicated (IRENA, 2017c). The overcapacity and energy industry consolidation in certain countries indicate an improvement in mining techniques and technologies, causing major job losses in the fossil fuel industry (IRENA, 2017c). Policies regulating climate control and the decreasing costs of renewable energy result in added pressure on fossil-fuel based energy generation (IRENA, 2017c).

Over the past 15 years, the energy production landscape has experienced a significant change globally, with unexpected growth in the renewable energy market (Enerdata, 2017). The enormous change in the transition towards renewable energy resources was triggered by increasing awareness of the threat of global warming and climate change (BP, 2017). The growth in the renewable energy market resulted in improvement of technologies, a greater push towards a cleaner and greener environment, new methods of energy production and the reduction in the cost of renewable energy resources. The global emissions target requires the roadmap of the energy sector to reduce carbon dioxide emissions drastically by 2050 (IRENA, 2017a). In order to limit climate change below 2°C by 2050, the carbon dioxide emission levels reached in 2015 will have to be reduced by 70% globally (IRENA, 2017a). Renewable energy is becoming increasingly important in energy systems globally where the objective is to separate economic growth from increasing greenhouse gas emissions (Enerdata, 2017). Regardless of the notable effort to advance green energy production, the transition remains far too slow to meet the targeted emission requirements (World Energy Council, 2016).

The radiation potential of the sun that could be harvested on earth is much more than the current global energy requirement. The theoretical power limit that could be harvested from the sun is in the vicinity of 89 000 TW (Tsao *et al.*, 2006). This means that the estimated power that could be harvested from the radiation of the sun is more than 4 450 times the current globally installed capacity (Tsao *et al.*, 2006). Renewable energy can be defined as power produced from resources that are replenished naturally. Renewable energy resources comprise mainly wind, water, heat and solar energy generation (Saez-de-Ibarra *et al.*, 2016).

Over the past two decades solar photovoltaic (PV) generation evolved as a reliable source of renewable energy that has been adopted and used widely all around the world (Walwyn and Brent, 2014). Almost 80% of the PV capacity in existence was produced and installed during the past five years (Wright *et al.*, 2017). Since 2000, the average growth rate of the installed capacity of PV systems globally has reached approximately 40%, tallying to reach in the vicinity of 237 gigawatts (GW) towards the end of 2014 (Walwyn and Brent, 2014). Solar PV is anticipated to be the world's largest source of electrical power by the end of 2050, when it is expected to produce

16% of the total global demand (Walwyn and Brent, 2014). Figure 1.3 indicates the total global capacity of PV and wind energy added annually from 2000 to 2016. The total globally added PV installed capacity reached 71 GW by the end of 2016 (IRENA, 2017c). Figure 1.3 indicates the exponential growth rate of the PV and wind energy industry globally. The global increase in the adoption of PV is mainly due to favourable supportive policies and decreasing PV module manufacturing costs (IRENA, 2017c).

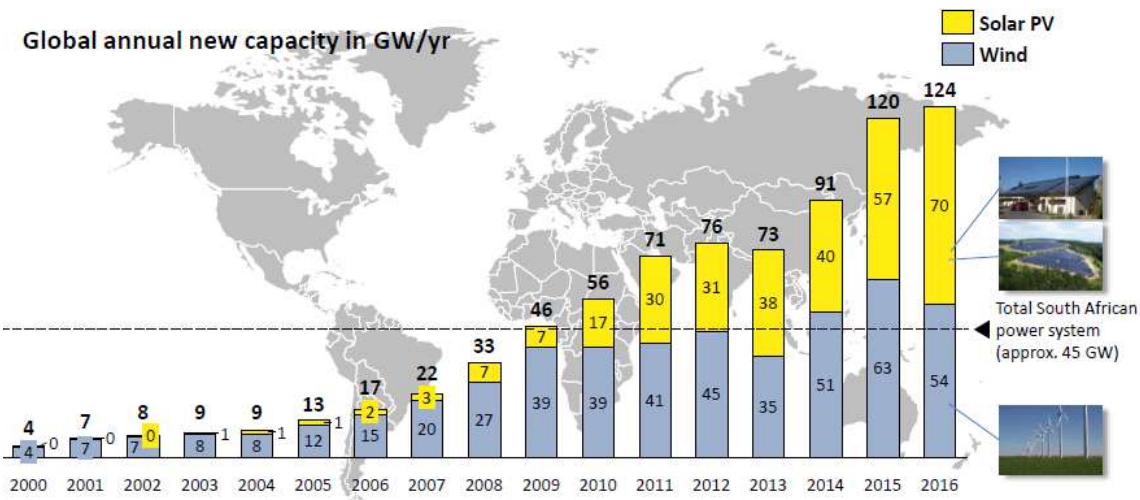


Figure 1.3: Annually added total photovoltaic and wind global capacity

Source: (Wright *et al.*, 2017)

Figure 1.4 is a map of the solar irradiation intensities of countries globally. The figure indicates that Sub-Saharan Africa, North Africa, Southwest Asia, Australia, Central America and Mexico are exposed to the highest solar irradiation. Even countries located in regions with lower levels of solar irradiation, such as East Asia, South-Asia and Europe, find it feasible to invest heavily in the solar PV market.

Currently China ranks first as the biggest manufacturer of PV cells globally, producing around 80% of the PV cells. India is ranked in the second place, producing around 13% of the PV cells globally (IRENA, 2017c). The countries with the largest installed capacities are China, Germany, India, Italy, Japan, and the United States. These countries jointly use 62% of the total installed global capacity (Walwyn and Brent, 2014; IRENA, 2017c)

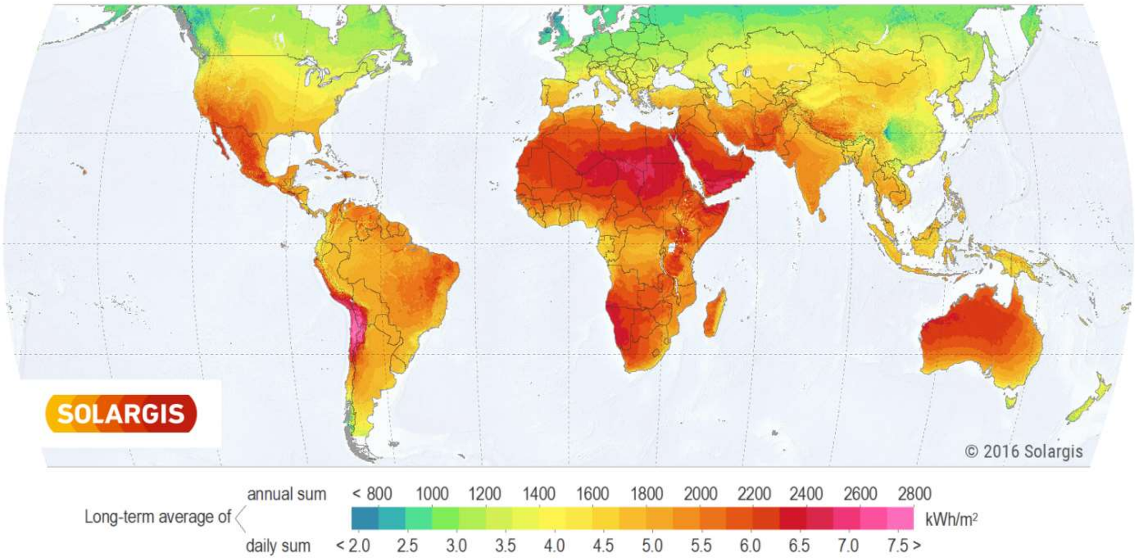


Figure 1.4: Solar irradiation world map

Source: (Solargis, 2016)

The increasing demand for energy generation from renewable energy resources contributed to 9.8 million new jobs globally towards the end of 2016 (IRENA, 2017c). The solar PV industry employed 3.1 million individuals during 2016 (IRENA, 2017c). Brazil, China, Germany, India, Japan and the United States created most of these jobs in 2016, of which 62% occurred in Asia. China is the largest installer of PV, creating 1.65 million jobs (IRENA, 2017c). In Japan and the United States respectively 37 000 and 194 000 job opportunities were created in the PV industry (Walwyn, 2016). Since 2011 the PV industry has registered the most stable employment growth compared to other renewable energy resources (IRENA, 2017c).

The annual added capacities of renewable energy resources produce significant job opportunities. Table 1.2 summarises the number of jobs in the renewable energy sector for 2012 to 2016. Table 1.2 indicates that the solar PV industry created 1.7 million employment opportunities globally within five years. Solar PV and wind energy generation are the renewable energy resources in the industry with the most consistent job growth (IRENA, 2017c). The countries creating most jobs globally in the PV industry are China, India and the United States (IRENA, 2017c). The solar PV industry increased by 50% from 2015, indicating 71 GW electricity production towards the end of 2016, creating 3.1 million jobs globally (IRENA, 2017c). The renewable energy industry has registered a significant increase in job opportunities globally since 2011 (IRENA, 2017c). Renewable energy generates more job opportunities compared to fossil-fuel based technologies, such as coal and natural gas (IRENA, 2017c).

Table 1.2: Renewable energy jobs from 2012 to 2016 globally [in thousands]

	2012	2013	2014	2015	2016
Hydropower	1 410	1 740	1 660	1 630	1 520
Other Technologies	330	380	400	400	450
Solar Heating and Cooling	890	500	760	940	830
Wind Power	750	830	1 030	1 080	1 160
Bioenergy	2 400	2 500	2 990	2 880	2 740
Solar Photovoltaic	1 360	2 270	2 490	2 770	3 090
Total Renewable Energy Jobs	**7 140**	**8 220**	**9 330**	**9 700**	**9 790**

Source: (IRENA, 2017c)

Developing countries, driven by the decreasing cost of the technologies, invest considerably more in their installed renewable energy capacity. The uptake of solar PV power generation in developing countries remains slow and the cumulative markets remain small compared to developed countries (Walwyn and Brent, 2014).

1.1. Historical Development and Current State of Electricity in South Africa

South Africa faces a major energy crisis that commenced in 2008. The crisis emerged in reaction to a combination of strong economic growth, insufficient load planning, underinvestment in additional energy-generating resources and insufficient maintenance of the existing infrastructure (Pollet *et al.*, 2015; World Energy Council, 2016). In 2008 the coal energy generation capacity could not satisfy the required demand (Krupa and Burch, 2011). The energy crisis resulted in scheduled power outages, locally known as load shedding (Roesch *et al.*, 2015). Load shedding encompassed reducing the peak power demand that was greater than the supplied capacity in order to prevent total grid shutdown (Herbst and Lalk, 2015). During 2015, the state-owned enterprise, the Electricity Supply Commission (Eskom), was forced to reduce electricity supply by up to 4 GW by implementing three stages of load shedding (World Energy Council, 2016). The South African economy suffered a great loss (in rand value) owing to power outages.

Eskom generates about 90% of the energy in South Africa from low-cost coal (Baker, 2016). South Africans rely mainly on Eskom for production, distribution and sale of electricity. South Africa currently generates energy from various resources, such as coal, gas turbines, hydroelectric power, nuclear, wind and solar sources and is the seventh largest emitter of greenhouse gases per capita globally (Herbst and Lalk, 2015). The country will contribute increasingly more to greenhouse gas emissions by installing additional coal based power stations, with a high carbon footprint, which will consequently not serve as a long-term solution to the existing energy crisis (Walwyn and Brent, 2014).

In 2014 South Africa produced 5% of its 253 TWh electricity from nuclear sources (Wright *et al.*, 2017). The South African government plans to install 9.6 GW additional nuclear capacity, at an estimated cost of $100 billion, by the end of 2030 (Wright *et al.*, 2017). Nuclear energy has an uncertain future globally, because of the inherent risks and threats posed to the environment, waste disposal issues and the likelihood of accidents, such as the Fukushima nuclear disaster (Maeda and Mori, 2011). Nuclear and fossil fuel energy will soon become obsolete, in response to international regulatory and compliance laws, such as the Paris agreement and the Kyoto Protocol, that aim at reducing greenhouse gas emissions globally (Musau *et al.*, 2017).

1.2. Research Problem

South Africa faced some challenging periods (years), due to the struggles of inequality caused by apartheid, very low economic growth, a high rate of unemployment and the ongoing struggle against poverty (Walwyn, 2016). Residents in several South African towns, villages and communities rely heavily on social grants for an income for survival (Walwyn, 2016). South Africa (with its struggling economy), has a large 26.6% unemployment rate and an average of 17.2 million social grants are being paid monthly as a means of survival in 2017 (Walwyn and Brent, 2014; SASSA, 2017). Figure 1.5 indicates the monthly social grant amounts paid over a two-year period from June 2015 to July 2016. According to Figure 1.1 the number of monthly grants paid is increasing at a simple linear regression rate.

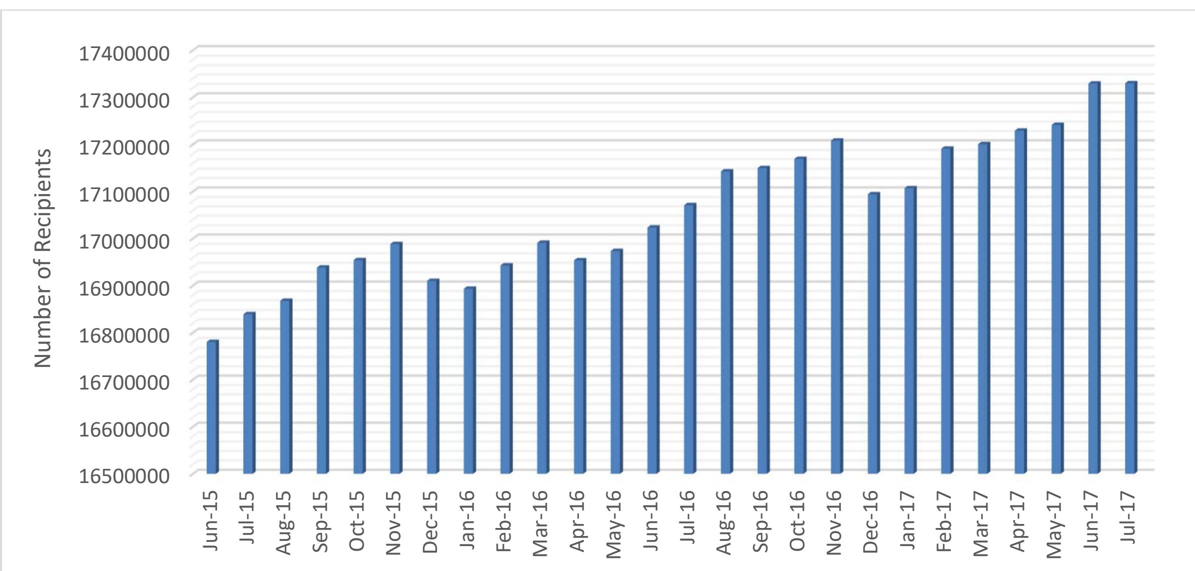


Figure 1.5: Number of social grants paid monthly in South Africa

Source: (SASSA, 2017)

Energy poverty in low-income residential areas remains a major challenge, with 40% of South Africans lacking access to basic electricity (Herbst and Lalk, 2015; Pollet *et al.*, 2015). PV energy is indicated as the ideal source of energy in view of its flexibility and could provide electrical power to communities in rural areas. Solar PV provides an attractive solution to generate employment in local communities, providing electricity to micro-communities in remote areas (Walwyn and Brent, 2014).

The world is progressing towards generating cleaner and greener energy. South Africa is partially following the tendency to produce greener energy from renewable energy resources. The South African government envisages relying predominantly on coal-based energy generation and nuclear power for the foreseeable future.

Electricity tariffs in South Africa have increased by 16% annually since 2006 (Montero, 2016). The drastic increase in energy tariffs and the global drop in renewable energy prices have led to the South African market being receptive to renewable energy solutions.

Since the discovery of electricity occurred in the 18th century, it is incomprehensible that 1.4 billion individuals globally still lack access to basic electricity (Kebede and Mitsufuji, 2017). Solar PV provides a solution by reducing energy poverty in terms of electricity in remote areas of developing countries (Walwyn and Brent, 2014; Kebede and Mitsufuji, 2017). Multiple attempts have been made to promote PV technologies in developing countries, but diffusion and uptake remain slow, especially when endeavouring to progress from conventional sources of electricity to renewable energy (Kebede and Mitsufuji, 2017).

The major challenge to be addressed in this study is the context of a country with a struggling economy, a high unemployment rate and widespread poverty. PV could provide a long-term solution to the existing energy crisis and could potentially develop and enhance local economic activity (Walwyn, 2016).

1.3. Rationale for the Study

Globally, PV energy generation grew rapidly from 1 GW in 2000 to 177 GW towards the end of 2014, with China and Germany being the global leaders in PV installations and energy generation (Pollet *et al.*, 2015). The earth receives much more radiation from the sun that could be converted into electricity than the total global energy production capacity (Guo *et al.*, 2009). South Africa should realise its market opportunity not only to alleviate the existing energy crisis, but also to benefit the economy in providing a significant number of job opportunities. South Africa has the opportunity to drive sustainable modes of green energy production by placing greater emphasis on renewable energy (Mathews and Mathews, 2016).

The development and diffusion of new technologies are influenced by a number of factors, many of which are captured by the technological innovation system (TIS) framework. Every well-functioning TIS comprises system functions. Each function fulfils critical activities and processes that, in combination, strengthen the system (Kebede and Mitsufuji, 2017). Regarding solar PV, South Africa (as a technology-receiving country) should focus on innovating and diffusing an existing technology, referred to as diffusion-based TIS (Kebede and Mitsufuji, 2017).

The South African government launched major energy programmes, pursuing the generation of more energy, but with limited large-scale effects on the national grid. With the cost of PV energy generation reducing significantly, South Africa should partner with other countries to create more sustainable modes of energy production. South Africa has the advantage of being situated appropriately for PV energy harvesting. It has a favourable climate with (on average) 300 days of sunshine a year (Solargis, 2016). It is therefore necessary to investigate the barriers to diffusion in South Africa to determine why the adoption rate of PV remains slow compared to the rest of the world and why PV energy generation is not exploited to its full potential. South Africa is currently not realising the potential of PV optimally to alleviate the existing energy crisis and to make a significant contribution to eradicate poverty.

1.4. Research Objectives and Research Questions

The preliminary investigation suggests that South Africa could establish a fully functional PV innovation system (IS). South Africa is situated in a region receiving abundant solar radiation, though PV is not utilised to its full potential. The challenge is to establish the main channels for the technological innovation of PV energy in South Africa.

A research project with the following objective is proposed to address this challenge:

"The objective of this research is to establish the barriers restricting the diffusion of solar PV, critically evaluating the TIS and the policies governing the system and from the results, develop policies in South Africa to support the TIS."

The South African population was affected at large by the recent power outages and load shedding, costing the economy millions of rands. This research intends not only to enhance the grid capacity, but also to join leading world countries in the transition to renewable energy. This research could also benefit the environment, with South Africa progressing towards much greener energy generation methods.

The proposed research questions for this study are:

- Based on the model proposed by Hekkert and Negro (2009), to what extent has the PV TIS been developed in South Africa?
- What are the present weaknesses of the TIS, particularly regarding knowledge development and knowledge diffusion within the PV TIS?
- What are the barriers that inhibit the further future development of PV TIS in South Africa?
- What policies are recommended that need to be implemented to strengthen the PV TIS in South Africa?

1.5. Key Attributes of the Study

This research study aims to focus on the PV TIS in South Africa, critically evaluating the accrual of the system functions of the TIS and to determine their relationship. The diffusion rate of PV in South Africa is directly proportional to the functionality of the TIS (Kebede and Mitsufuji, 2017).

This study offers the following contribution to literature:

- Insufficient research has been done on the evaluation of the PV TIS in the South African context, therefore this research will contribute to evaluating the extent of development of the PV TIS.
- South Africa experiences a massive energy crisis that needs be addressed; solar PV can provide a solution to the problem.
- South Africa faces a high unemployment rate and solar PV provides an opportunity for employment.
- The research intends providing policies that could be implemented to strengthen the PV TIS in South Africa and the local innovation capacity.

The study intends investigating reasons for the slow adoption rate of solar PV in South Africa, while other countries are well advanced. It aims to identify the barriers to PV diffusion and evaluate the South African PV market and industry as a TIS. The study will identify policies to be implemented to increase the diffusion of PV and functions, removing the barriers to diffusion.

2. Literature Study

2.1. Renewable Energy

Energy systems in many countries are changing towards adopting sustainable resources, causing active research to be done into developing more sustainable modes of production from renewable energy resources (Walwyn, 2016). Much of the research is aimed at the governing and promotion of the technologies by studying the different challenges and possible solutions, changing and improving relationships between different actors, building business models and evaluating business behaviour (Walwyn, 2016).

2.1.1. Renewable Energy Technologies

Over the past few years, the detrimental effect of non-renewable energy has become clear through evidence of the impact on the environment, which is currently a major global concern (Musau *et al.*, 2017). The Paris agreement and the Kyoto protocol were established for precisely this reason: to counteract and reduce greenhouse gas emissions globally (Musau *et al.*, 2017). The Paris agreement and the Kyoto protocol are essentially forcing global energy systems to adopt renewable energy technology (RET) to serve as a remedy in reducing greenhouse gas emissions (Musau *et al.*, 2017).

To date, RET diffusion has been slow owing to barriers limiting the penetration of the technologies in the energy industry (Musau *et al.*, 2017). These barriers include the cost of RETs and their impact on the environment and ecosystems (Musau *et al.*, 2017).

Table 2.1 indicates the total installed capacity of RET in different countries around the world (IRENA, 2017b). According to Table 2.1, the global RET market had a growth rate of 16.1% from 2005 to 2015, and a 14.1% growth rate for 2016 (BP, 2017).

Table 2.1: Total renewable energy capacity [in GW]

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
South Africa	0,8	0,8	0,8	0,9	0,9	0,9	1,4	2,4	3,1	4,1
Australia	10,0	10,1	10,5	11,1	12,4	13,9	14,6	15,9	17,4	18,1
Germany	36,2	40,4	47,6	56,8	67,0	77,2	85,0	92,0	99,4	105,8
N. America	197,1	207,1	219,7	231,5	242,2	264,0	271,3	286,9	305,7	329,7
China	148,4	178,0	205,2	236,3	270,9	304,7	360,8	413,0	481,1	545,2
World	**989,2**	**1058,2**	**1133,3**	**1223,1**	**1326,0**	**1444,1**	**1563,5**	**1690,2**	**1845,2**	**2006,2**

Source: (IRENA, 2017b)

Renewable energy resources can be divided into different categories: bioenergy, geothermal energy, hydropower, marine energy, solar energy and wind energy. Table 2.2 indicates the total global installed capacity of renewable energy resources by category from 2007 to 2016. According to Table 2.2, the installed capacities of hydropower and wind energy experienced 34% and 398% growth respectively over the 10-year period, whereas solar energy experienced 3114% growth over the 10-year period.

Table 2.2: Global installed renewable energy capacity by category in [GW]

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Marine Energy	0,3	0,3	0,3	0,3	0,5	0,5	0,5	0,5	0,5	0,5
Geothermal	9,1	9,5	9,9	10,1	10,0	10,5	10,8	11,5	11,8	12,6
Bioenergy	52,5	56,9	63,7	69,4	74,7	81,4	88,8	94,5	101,1	109,7
Solar Energy	9,2	15,2	23,4	40,2	71,5	101,9	139,3	176,7	224,8	295,7
Wind Energy	93,6	119,7	150,1	182,7	222,1	271,7	303,7	350,2	415,3	466,5
Hydropower	924,2	958,2	991,9	1024,6	1056,3	1089,5	1132,8	1170,1	1207,9	1243,0

Source: (IRENA, 2017b)

Since 2000, the global electricity generation mix has changed significantly with the increasing share of renewable energy resources (Enerdata, 2017). Developing countries such as Latin America, South Asia and South Africa have the potential to invest heavily in the RET market, to overtake the installed capacities of advanced developed countries (Enerdata, 2017).

The European Union progress report stated that European countries achieved 16% and 16.4% of their energy in 2014 and 2015 respectively being produced from renewable energy resources (Varda and Kuzle, 2017). The European Union intends to generate 20% of the energy it consumes from renewable energy resources by 2020 (Varda and Kuzle, 2017). It is also planning to diversify energy resources to increase energy security by avoiding dependency on only selected resources by focusing more strongly on renewable energy (and its efficiency) to decrease the effect of climate change with harmful emmisions (Varda and Kuzle, 2017).

The energy supply from RETs is associated with some form of insecurity in view of the inherent dependency on climate and environmental conditions (Varda and Kuzle, 2017). The variations in energy supply from RETs can be counteracted by maintaining stability and flexibility through diversification of renewable energy resources (Varda and Kuzle, 2017).

2.1.2. Photovoltaics

PV cells convert radiated energy from the sun to electrical power (Peter, 2011). Traditional PV cells are made primarily from silicone and function on the same basic principles as diodes and transistors (Peter, 2011). One of the major advantages of PV cells is that they do not contain any moving parts that are susceptible to wear and tear, which could possibly harm or disrupt the ecosystem (Peter, 2011). Solar PV is extremely practical for rural area electrification where it is impossible or very expensive to gain access to the electrical grid.

Currently three main characteristically different types of PV cell technologies are available on the market. These are categorised into monocrystalline, polycrystalline and thin film technologies, each with different characteristics and attributes suitable for different applications (Peter, 2011). PV cells are made up of 93% silicon wafer technology; other materials included in the manufacturing process are selenium, gallium, cadmium, tellurium, arsenic and conductive materials (Walwyn, 2016).

There are 1.4 billion people around the world that do not have access to basic electricity (Kebede and Mitsufuji, 2017). Solar energy is an excellent way of producing energy in rural areas because of easy setup and low maintenance in developing countries (Kebede and Mitsufuji, 2017). The adoption and diffusion rates of solar energy are particularly slow in developing countries. One of the main causes of this is resistance to change in the shift from conventional energy generation to renewable energy generation (Kebede and Mitsufuji, 2017).

Research and development (R&D) in the PV industry has significantly improved the technology over the past ten years, improving the efficiency of PV cells by, on average, 1.3% a year. By 2013 the efficiency of commercial PV had reached 16%; with some higher-grade PV technologies achieving efficiencies ranging between 19% and 21% (IEA, 2014). PV technology has a very long service life-span. Most of the manufacturers are able to guarantee that each cell will produce 80% of its rated power output for 25 years (Peter, 2011). PV cells thus have an expected lifetime of 25 years (Mathews and Mathews, 2016).

The cost of PV panels has decreased around 15 times since 1992 and is still decreasing because of greater volumes being manufactured, more effective use of materials and increasing global competitiveness (Walwyn, 2016). It is estimated that the average cost of PV will decrease by 35% for each doubling in cumulative production volume (Walwyn and Brent, 2014). The time it takes a solar cell to produce the total energy required to produce the cell is known as the payback period (Walwyn, 2016). The payback period is different for the different types of PV technologies; some technologies already have a payback period of less than a year (Walwyn, 2016).

The rapid decrease in the cost of solar PV is due to increased efficiencies, thinner wafer thickness and decreasing usage of materials, from 16 g/W to less than 6 g/W) (Walwyn, 2016). Commercially available solar PV cells generate power with efficiencies between 17% and 22%. Using solar PV as a renewable energy source of electricity reduces the carbon dioxide avoidance factor by 0.715 kg.CO_2/kWh (Walwyn, 2016).

The global installed capacity of PV by the end of 2015 reached 227 GW, producing around 1% of the total electricity demand (World Energy Council, 2016).

Table 2.3: Installed PV capacity in different parts of the world [in GW]

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
South Africa	0,02	0,02	0,02	0,02	0,07	0,07	0,28	1,03	1,04	1,54
Australia	0,07	0,08	0,11	0,40	1,39	2,43	3,26	4,00	5,03	5,63
Germany	4,17	6,12	10,56	17,55	25,03	32,64	36,34	38,23	39,79	40,99
N. America	1,02	1,21	1,73	3,16	5,71	9,40	13,04	16,08	24,30	36,07
China	0,10	0,14	0,30	0,80	0,33	6,80	17,50	28,05	43,18	77,42
World	**8,7**	**14,7**	**22,6**	**38,9**	**69,7**	**99,3**	**135,4**	**172,3**	**220,1**	**290,8**

Source: (IRENA, 2017b)

Figure 2.1 is a plot of Table 2.3: Installed PV capacity in different parts of the world.

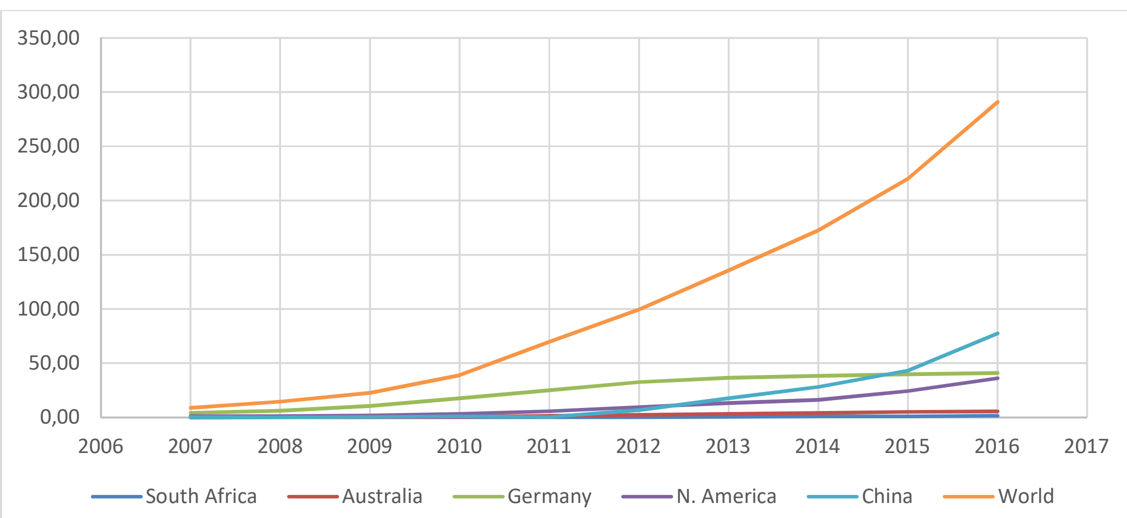


Figure 2.1: Installed PV capacity in different parts of the world in [GW]

Source: (IRENA, 2017b)

Figure 2.2 indicates the installed capacity of PV in different industries in South Africa. According to Figure 2.2, the commercial application of PV has the biggest market share, reaching almost 100 MW by 2016 (PQRS, 2016).

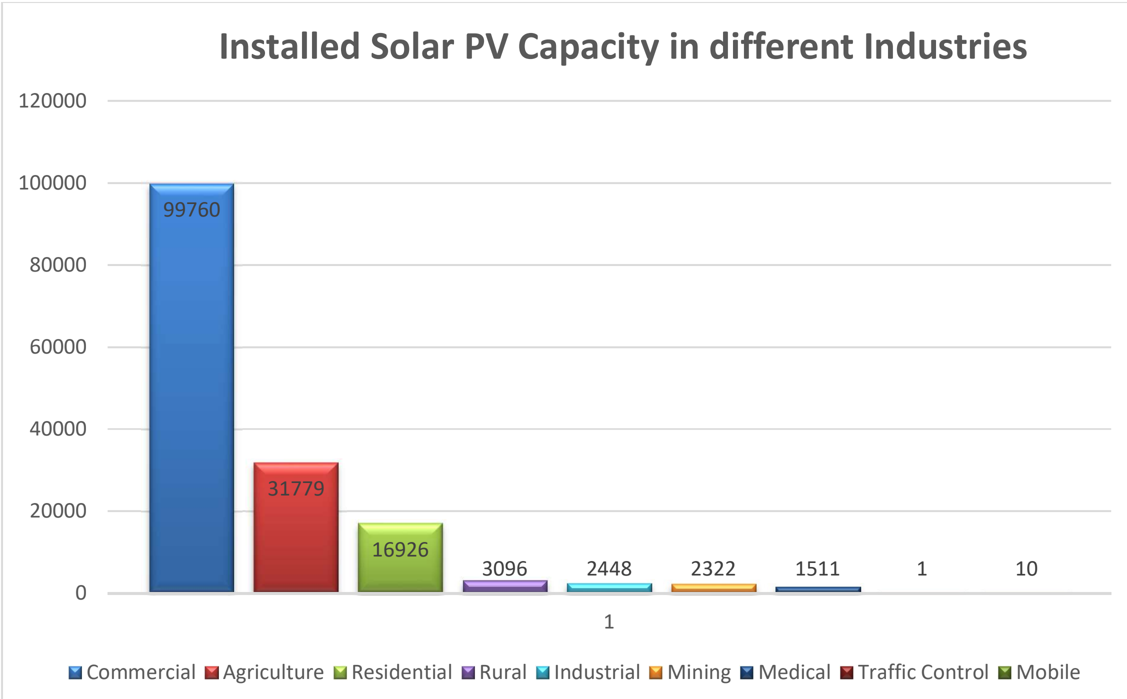


Figure 2.2: Installed PV capacities in different industries [in kW]

Source: (PQRS, 2016)

The levelised cost of electricity (LCOE) can be used as a measure to calculate and compare different sources of electricity generation (Chudy *et al.*, 2015). The LCOE calculates the average total cost of electricity over the design life of the system. It can be calculated with the following formula (Chudy *et al.*, 2015):

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where:

n = Lifetime of the system

I_t = Investment expenditure for year t

M_t = Operational and maintenance expenditure for year t

F_t = Fuel expenditure for year t

E_t = Expected energy generated for year t

r = Discount rate.

For PV systems, the fuel expenditure is zero and the investment expenditure is only for the initial investment of the plant in the first year.

Small scale energy generation (SSEG) gives residents the opportunity to use the electrical grid to store excess energy. The monthly electricity bill is calculated by subtracting the excess energy pushed back into the grid from the energy used from the electrical grid (Mathews and Mathews, 2016).

Figure 2.3 indicates the average cost of PV in South Africa from 2006 until 2015. From Figure 2.3, the cost of PV peaked during 2008 and from then onwards decreased significantly. The decreasing cost of PV are one of the main drivers in the recent increase in adoption rate of PV globally.

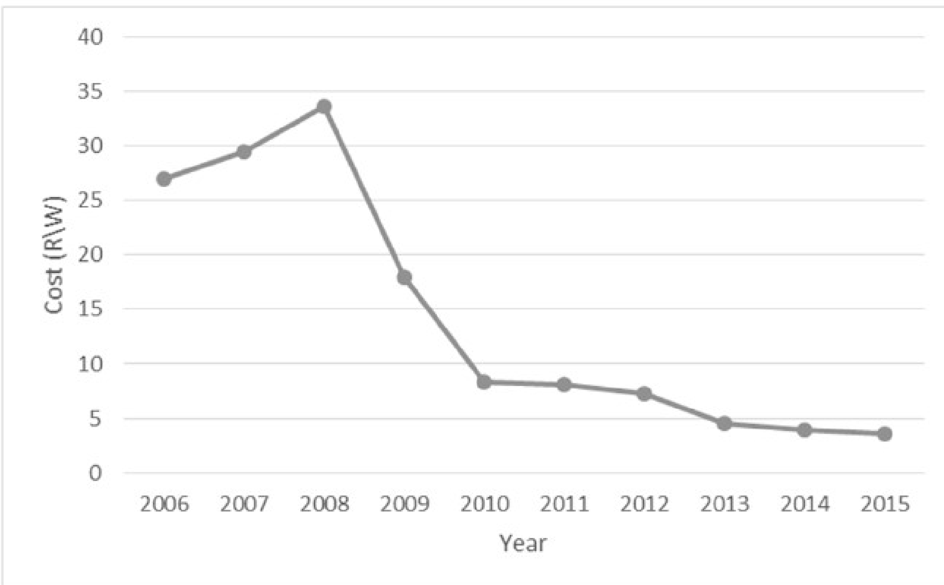


Figure 2.3: Average cost of PV globally

Source: (Mathews and Mathews, 2016)

Some countries and municipalities allow residents to feed excess energy into the electrical grid, to be bought by the energy suppliers at the cost of a pre-determined feed-in tariff, enabling residents to become prosumers (being both an energy producer or energy consumer, depending on the time of day) (Batawy and Morsi, 2016). An advantage of selling excess energy to the electrical grid is that residents could potentially generate a profit, depending on the size of the system. Another advantage of storing energy in the electrical grid is the ability to remove the battery backup system completely or reduce the size of the battery backup system, which saves on the initial investment and battery maintenance.

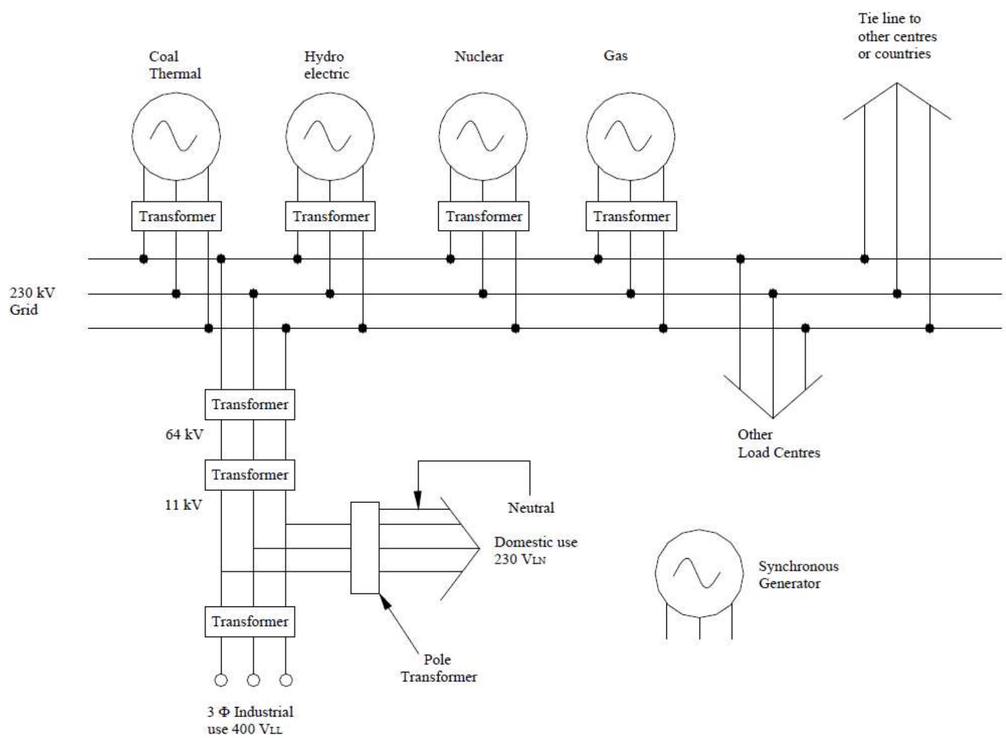


Figure 2.4: Connecting multiple power sources to the electrical grid

Source: (Fritz, 2013)

PV systems with electrical grid feed-in and battery backup are the most expensive types of systems owing to the requirement for a bi-directional inverter, inverter and battery backup. If municipalities allow excess energy to be pushed back into the electrical grid, thus eliminating the added cost of battery backup systems, PV becomes an economically viable investment (Mathews and Mathews, 2016). Electrical grid feed-in would have to be supported by smart meters, training of technicians and maintenance of the infrastructure (Mathews and Mathews, 2016). One of the biggest barriers to the adoption of PV is the high initial investment that is in some cases much more than the monthly income of some households; funding becomes critical (Mathews and Mathews, 2016). To improve the adoption rate of PV, innovative financing measures should be put in place through rebates, subsidies and eco-loans.

Figure 2.5 indicates different types of PV system architecture connections, each with unique characteristics and attributes suitable for different applications. The most basic PV system architecture application is used to power loads directly, as indicated in $X_{3,n}$. PV systems that are connected in such a way have limited control and are only suitable for loads that require power during the day when there is sunlight available. Systems that require some means of energy storage become increasingly complicated, as indicated by $X_{2,n}$ and $X4_{,n}$ in Figure 2.5.

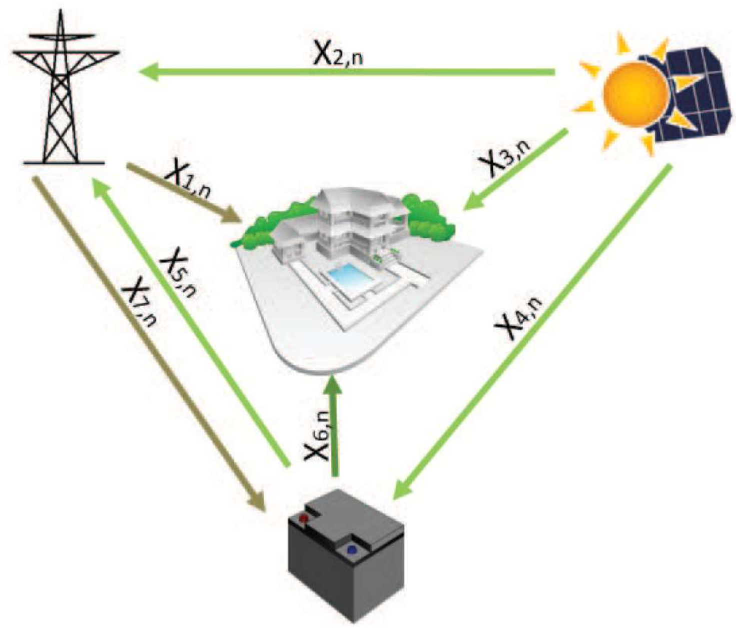


Figure 2.5: Photovoltaic system components

Source: (Münzberg *et al.*, 2016)

Solar PV system configurations can be characterised into four distinct architectures:

- PV system without energy storage
- PV system with battery backup
- PV system with electrical grid feed-in
- PV system with electrical grid feed-in and battery backup.

PV system without energy storage

The simplest PV system configuration has two essential components: solar panels and a load that has to be powered. These systems do not contain any resources for energy storage. Systems of this type of configuration have the advantage of not being complicated and are the most cost-effective initial investment. Unfortunately, this type of configuration is only suitable for applications that require power when sunlight is available. The disadvantages of this type of configuration are that excess energy is wasted, making it less efficient, and the maximum power that can be drawn from the system (at any given instance) is limited to the capacity of the PV panels. Figure 2.6 indicates the cash flow of this type of configuration; these systems typically have a payback period of 7 to 7.5 years and a remaining useful lifetime of 18 years (Mathews and Mathews, 2016).

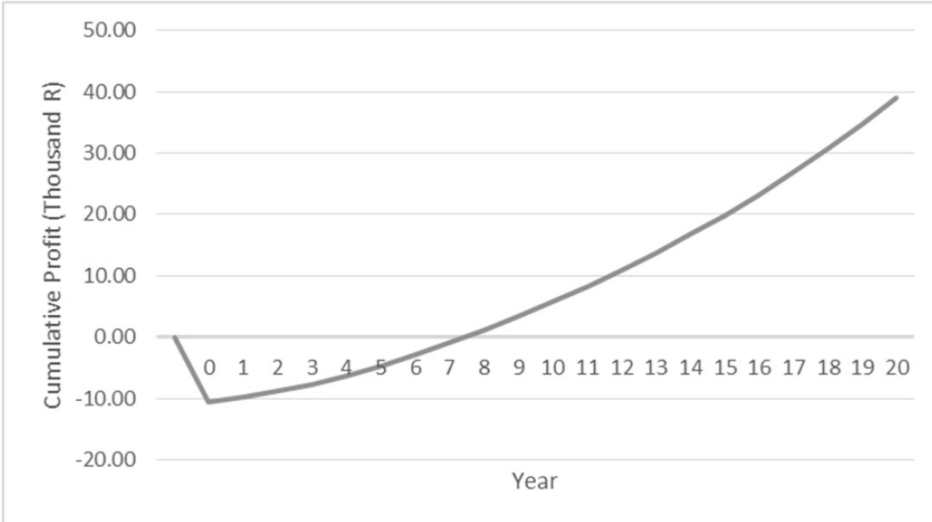


Figure 2.6: PV system without battery backup payback period

Source: (Mathews and Mathews, 2016)

PV system with battery backup

PV system applications that require power during the periods when no sunlight is available implement batteries as an energy storage medium that can supply power during those periods (Mathews and Mathews, 2016). PV systems incorporating batteries have the disadvantages of being expensive, with the initial investment in batteries often accounting for a third of the system cost (Münzberg *et al.*, 2016), and of being extremely inefficient, with efficiencies reaching in the vicinity of 30% (Fritz, 2013). Systems incorporating batteries have a 3.8 times higher initial investment cost compared to systems without energy storage (Mathews and Mathews, 2016). Batteries have an expected lifetime of about 10 years, depending on the battery technology, the number of cycles and the depth of discharge, where-after battery replacement is required (Mathews and Mathews, 2016). The maximum instantaneous power that can be drawn from the system is limited by the battery power capacity and the inverter. The payback period of a medium-sized system with this type of configuration is indicated in Figure 2.7. Figure 2.7 indicates that the batteries are replaced after 10 years of operation. Medium-sized systems with this type of configuration have an average payback period of 17.8 years (Mathews and Mathews, 2016).

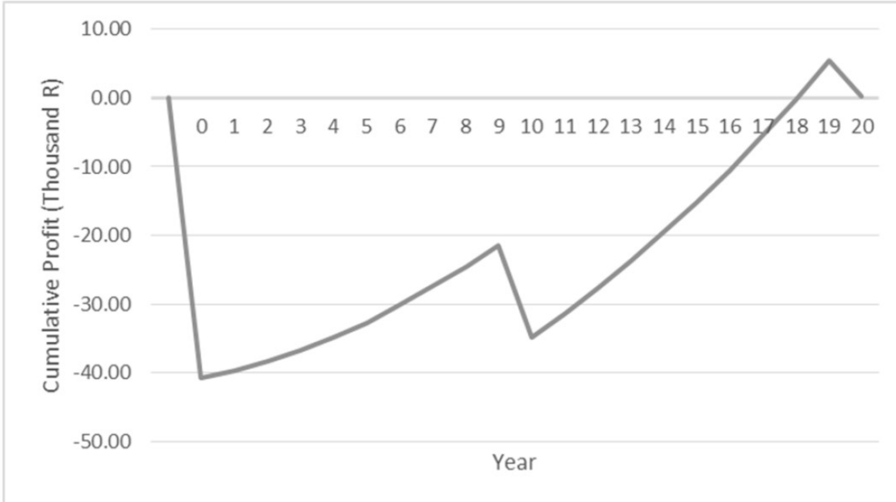


Figure 2.7: PV system with battery backup payback period

Source: (Mathews and Mathews, 2016)

PV systems with electrical grid feed-in

Energy systems that require energy storage, without the high initial investment of batteries, could be accomplished through electrical grid feed-in architectures. PV systems with electrical grid feed-in have the benefit of eliminating expensive and inefficient batteries while enjoying the advantage of energy storage capability. PV systems can become more efficient when governments and municipalities allow excess energy to be stored in the electrical grid (Fritz, 2013). Excess energy that is produced during the day is stored in the electrical grid; whenever power cannot be produced, power is drawn from the electrical grid. The maximum power that can be drawn by this configuration is limited by the municipality. Figure 2.8 indicates the cash flow of a medium-sized PV system with electrical grid feed-in configuration. The payback period of these type of systems is in the vicinity of 5.5 years (Mathews and Mathews, 2016).

The cost of batteries has decreased significantly over the past few years, encouraging more and more investors to invest in PV systems as a sound investment (Mathews and Mathews, 2016). Quite recently the Tesla motor company launched its Tesla Powerwall rechargeable lithium-ion battery backup system into the market (Mathews and Mathews, 2016). The Tesla Powerwall is an energy storage solution for homes and businesses that is competitively priced at $350/kWh with options of 7 kWh and 10 kWh capacities available (Mathews and Mathews, 2016).

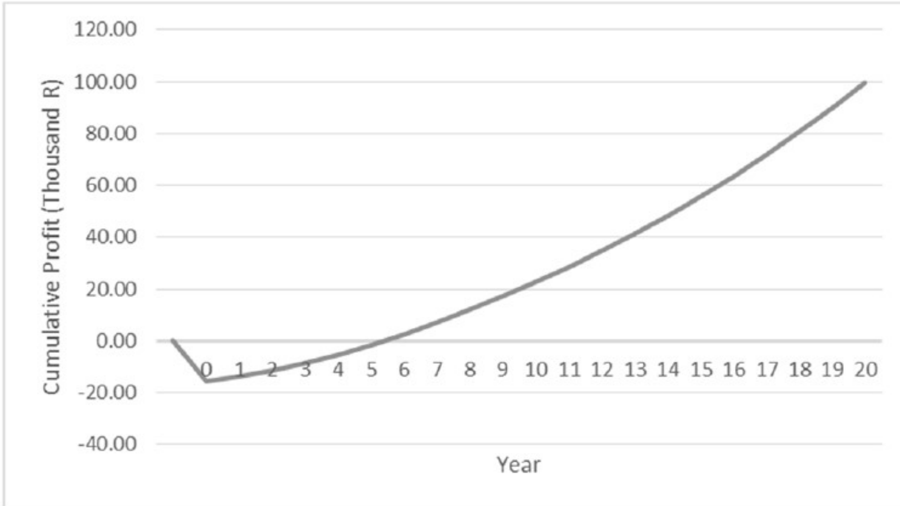


Figure 2.8: PV system with electrical grid feed-in payback period

Source: (Mathews and Mathews, 2016)

2.1.3. Photovoltaics in South Africa

The South African electrical grid is still in a critical state and several energy and energy efficiency programmes have been launched by the South African government to address the crisis. These programmes place special focus on renewable energy in order to develop a greener and more sustainable economy (Pollet *et al.*, 2015). South Africa has experienced some growth in the PV industry over the past six years, with a total installed cumulative capacity of 1.5 GW power by the end of 2016. The massive increase in the adoption of PV energy is largely due to the contribution of the Renewable Energy Independent Power Producers Programme (REI4P), which has successfully procured 6.3 GW power in the first bidding round from 92 independent power producers. The REI4P target is to install 17.8 GW renewable energy power by the end of 2030 (Walwyn and Brent, 2014); wind and solar PV would contribute an estimated 53% and 36% respectively to the renewable energy mix (Walwyn, 2016). The goal of the REI4P is to balance the needs for low energy cost against job creation, job protection (in the mining and fossil fuel industry), social wages in urban areas and social development in rural areas (Walwyn, 2016).

The Integrated Resource Planning (IRP) programme for energy, which was launched established in 2011 to establish the electricity expansion plan, focused on strategising the long-term expansion goals in South Africa for 2050 (Wright *et al.*, 2017). The IRP is taking into account least-cost planning principles in order to meet the expected future demand by comparing different possible future energy sources (Wright *et al.*, 2017). Communities that are located within a 50 km radius of the IRP projects will benefit from the projects because of the government initiative that requires these projects to engage with the local communities regarding socio-economic development and enterprise development over the next 20 years. It is estimated that the fourth round of the bidding for all renewable energy in South African will produce an estimated 26 246 full-time work opportunities (IRENA, 2017c).

South Africa has the advantage of being one of the countries that receives the highest solar irradiation around the world, with levels ranging between 4.38 kWh/m^2 and 6.43 kWh/m^2 (Solargis, 2016). Despite the fact that South Africa has abundant solar irradiation, it relies predominantly on carbon-based power generation for electricity (Zawilska and Brooks, 2011). Figure 2.9 indicates the solar irradiation for different regions throughout South Africa. According to Figure 1.4, the global solar irradiation map of the world serves as proof that South Africa is appropriately located to innovate PV fundamentally into the infrastructure of the national energy grid (Solargis, 2016).

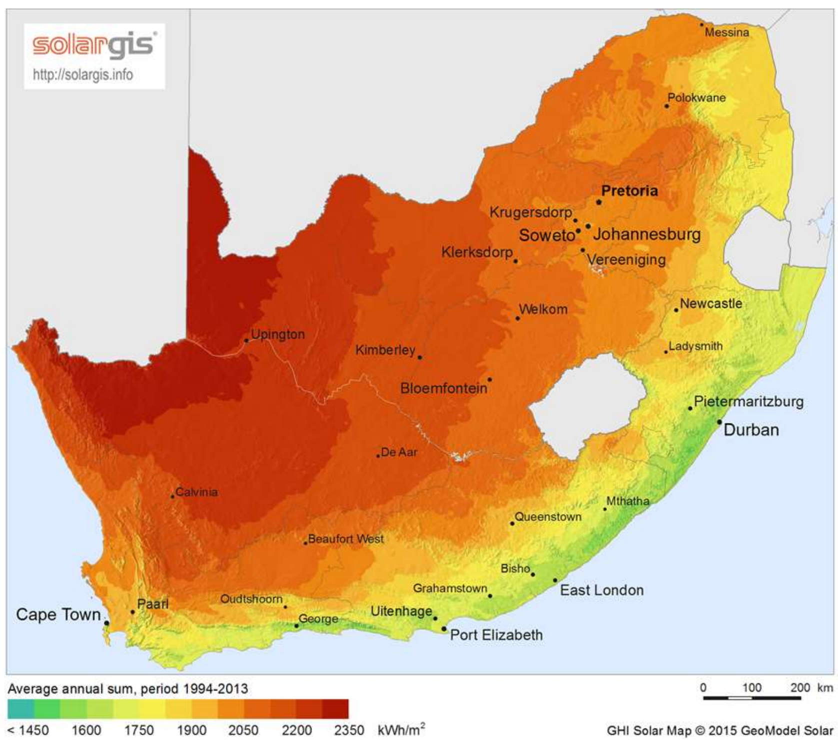
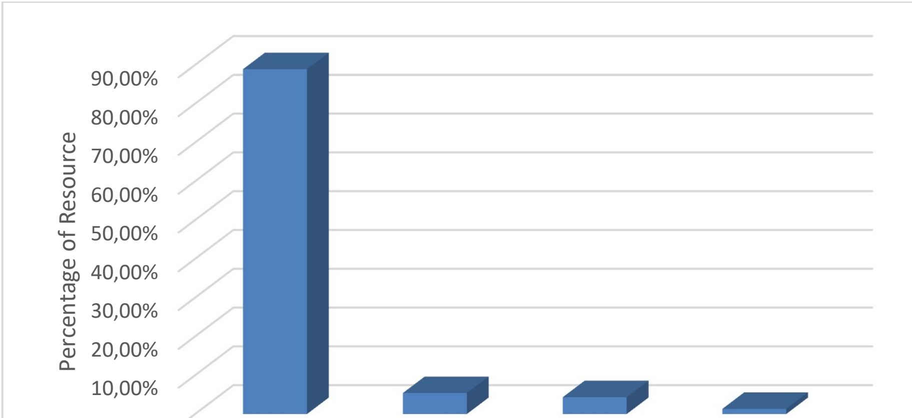


Figure 2.9: Solar irradiation map of South Africa

Source: (Solargis, 2016)

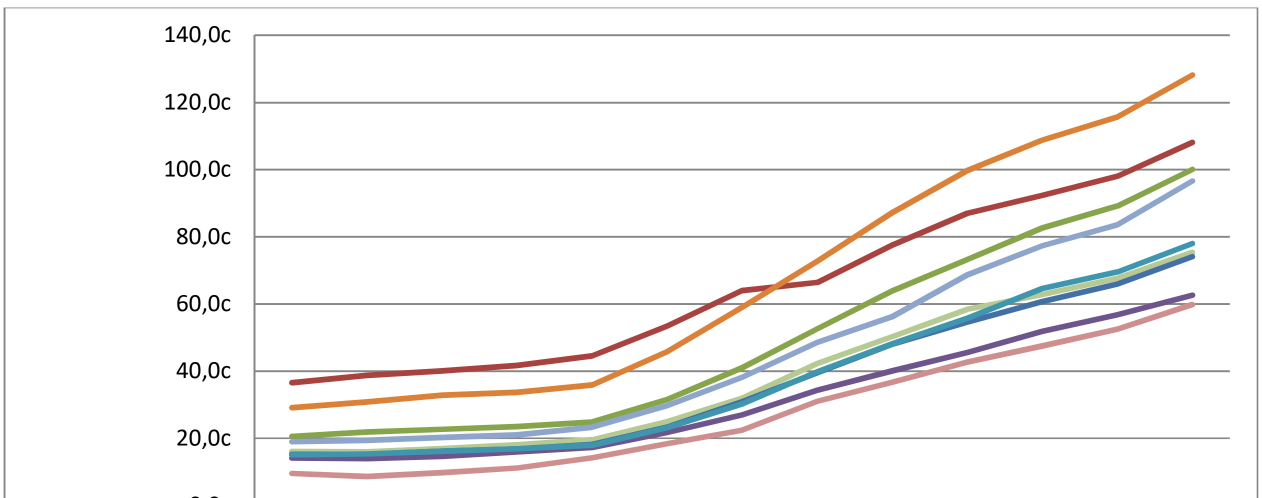
Solar PV has been a topic of discussion over the past few years in South Africa because of the ongoing energy crisis, high levels of solar irradiation intensities/levels in the country and the global reduction in the cost of PV, which is still decreasing, making PV much more appealing than previously (Chudy *et al.*, 2015). It is difficult to compare the effect PV will have on the LCOE owing to the abundant coal that can be mined relatively inexpensively in South Africa (Chudy *et al.*, 2015).



	Coal	Natural Gas	Nuclear	Hydro
Series1	88,90%	5,42%	4,34%	1,34%

Figure 2.10: Primary sources of electricity in South Africa

Source: (Mathews and Mathews, 2016)



	2003	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
Average price	16,1c	16,0c	17,0c	18,1c	19,6c	25,0c	31,9c	42,2c	50,3c	58,5c	62,8c	67,6c	75,4c
Authorities	15,2c	15,2c	16,1c	16,9c	18,2c	23,3c	30,8c	39,5c	48,0c	54,6c	60,7c	65,9c	74,1c
Residential	36,6c	38,7c	40,1c	41,7c	44,6c	53,4c	64,0c	66,4c	77,5c	87,0c	92,4c	98,1c	108,1c
Commercial	20,6c	21,9c	22,7c	23,5c	24,9c	31,6c	41,0c	52,6c	63,9c	73,2c	82,7c	89,2c	100,1c
Industrial	14,2c	14,0c	14,6c	16,0c	17,3c	21,7c	27,0c	34,3c	40,1c	45,6c	51,8c	56,8c	62,6c
Mining	15,1c	15,4c	16,2c	16,9c	18,0c	23,1c	30,2c	39,8c	48,1c	55,7c	64,7c	69,5c	78,0c
Agriculture	29,1c	30,8c	32,9c	33,7c	35,9c	45,8c	59,0c	72,7c	87,2c	99,7c	108,7c	115,7c	128,2c
Traction	19,0c	19,4c	20,3c	21,0c	23,3c	29,8c	38,2c	48,6c	56,2c	68,7c	77,3c	83,6c	96,6c
International	9,6c	8,6c	9,8c	11,1c	14,2c	18,5c	22,5c	31,0c	36,7c	42,7c	47,6c	52,6c	59,8c

Figure 2.11: Average cost of electricity history per industry in South Africa

Source: (Eskom, 2016)

The average cost of solar PV panels in South Africa is around R10 per watt (Walwyn, 2016).

South African citizens can generate up to 100 kW power unregulated through small-scale rooftop solar systems. This technology is still in an early stage in South Africa (Walwyn, 2016). At present no regulatory processes have been implemented for these small systems (Walwyn, 2016). The National Energy Regulator of South Africa (NERSA) is in the process of preparing regulations to regulate net metering that will allow South Africans to feed electricity into the electrical grid (Walwyn, 2016).

Small-scale energy producers in Cape Town municipality district and Nelson Mandela Bay metropolitan municipality district can sell power to the municipalities by feeding power back into the electrical grid. The Nelson Mandela Bay metropolitan municipality purchases excess energy from independent power producers for the same price as the selling price. Cape Town municipality, on the other hand, purchased energy from independent power producers for R0.5699/kWh in 2015/2016 and R0.6147/kWh in 2016/2017 (prices are VAT exclusive) (Cape Town Government, 2016; Walwyn, 2016).

There is still too little emphasis on renewable energy resources in South Africa and there is insufficient diversity of energy resources and energy producers, with limited involvement of the private sector in the production of energy (Kebede and Mitsufuji, 2017). The diversification of energy production by the REI4P programme from independent power producers is still a critical issue that has to be addressed to alleviate problems associated with energy being generated on only a limited number of sites (Walwyn, 2016).

The inherent risk of relying on a single entity for electricity can be diversified by allowing PV systems to act as energy generators and push energy into the electrical grid (Fritz, 2013).

In many parts of the world the initial investment cost of PV systems is approaching grid parity (Fritz, 2013). South Africa can be on the verge of a social revolution; innovative and favouring policies should be implemented to create bigger markets (Fritz, 2013).

During a study conducted in 2016 on the feasibility of PV systems in South Africa, it was proved that investment in a 3 kW PV system by a private investor is uneconomical, at a purchase price of double the then average cost of electrical grid electricity (Walwyn, 2016). PV systems that produce less than 3 kW will produce energy at a cost more than double the cost of electricity from the electrical grid; systems that produce more than 3 kW become much more feasible.

Solar home systems (SHS) or rooftop solar technology is gaining popularity in only a handful of countries around the word, Australia being the leading country in producing 15% of its total demand through SHS. The term prosumer is used to define systems/users that produce excess power during the day, storing the energy in the national grid and using the excess energy during hours that the PV system cannot generate power (Walwyn, 2016). Excess energy that is stored in the electrical grid is compensated for with a feed-in tariff that could generate an income for residents.

Factors Influencing the Photovoltaic Industry

There are many factors that have an effect on solar radiation; these include the time of day, weather, seasonality, air pollution, El Niño and climate change due to global warming (Fluri, 2009). Figure 2.12 indicates how solar radiation is affected by the earth's atmosphere (Fluri, 2009).

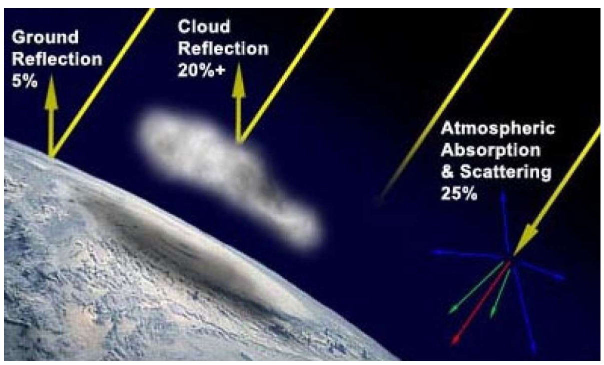


Figure 2.12: Effects of the atmosphere on solar radiation

Source: (Fluri, 2009)

The automation of operations, maintenance and production of PV are factors that need to be taken into consideration; they may decrease the number of jobs in the renewable energy industry (IRENA, 2017c).

This global competitiveness of low-cost PV modules could pose a risk to manufacturers in the European Union and force them out of business (IRENA, 2017c). In order for renewable energy and job creation to continue increasing, stable and favourable policies need to be established to support the technologies (IRENA, 2017c).

Manufacturers of certain technologies in other sectors/industries limit the growth of the PV industry (Kebede and Mitsufuji, 2017). Batteries, for instance, are used widely in the automotive industry but the production of batteries, specifically for the PV industry, remains limited (Kebede and Mitsufuji, 2017). This is mainly because batteries in the PV industry are primarily used in the private PV industry, which is possibly why manufactures find joining the PV market unattractive (Kebede and Mitsufuji, 2017).

A PV system is a very good investment, especially in view of the 16% average annual increase in the price of electricity in South Africa over the past 10 years (Eskom, 2016). The cost of a PV system is strongly dependent on three factors: political decisions, interaction and the size of the market (Münzberg *et al.*, 2016). The increasing implementation and adoption rate is inversely proportional to the cost of a PV system; higher production rates and progress ratios consequently lead to decreases in the cost of PV, making it much more feasible (Münzberg *et al.*, 2016).

Incentives are required to accelerate the local manufacturing and assembly of PV panels, strengthen the skills and capability of local science and technology systems and support processes that advance the adoption of PV technology (Walwyn, 2016).

South Africa is a late follower in comparison with leading countries in PV such as Germany and China. South Africa has not contributed much in terms of R&D of PV technologies and therefore South Africa is classified as a PV technology-receiving country that mostly relies on imports (Kebede and Mitsufuji, 2017). The R&D function of the PV TIS in the South African context does not contribute to new knowledge but rather improves the rate of absorption in the South African market.

2.2. Renewable Energy and Job Creation

2.2.1. Context and National Need

Table 2.4 indicates the companies with the biggest expenditure on public infrastructure. Eskom was at the top of the list of 722 public sector organisations, accounting for R73 billion of the R284 billion capital expenditure being spent on the electricity infrastructure (Stats SA, 2017a).

Table 2.5 indicates the quarterly employment statistics of South Africa over a period of two years. Table 2.5 indicates that the South African economy experienced a 2.2% increase in the unemployment rate over the last two years, resulting in almost 6.2 million people being unemployed by the end of June 2017 (Stats SA, 2017b).

Table 2.4: Organisations with biggest public-sector expenditure

Rank	Organisation	Amount	Percentage
1	Eskom	R 73,0 billion	25,7%
2	Transnet	R 33,6 billion	11,8%
3	Johannesburg municipality	R 8,9 billion	3,1%
4	SANRAL	R 8,5 billion	3,0%
5	Department of water affairs	R 7,6 billion	2,7%
6	eThekwini municipality	R 6,7 billion	2,4%
7	PRASA	R 6,1 billion	2,1%
8	Cape town municipality	R 5,9 billion	2,1%
9	Telkom	R 5,8 billion	2,0%
10	Water trading entity	R 5,1 billion	1,8%
11	Tshwane municipality	R 5,1 billion	1,8%
12	Ekurhuleni municipality	R 4,3 billion	1,5%
13	Kwazulu-Natal: transport	R 4,3 billion	1,5%
14	Property management trading entity	R 3,8 billion	1,3%
15	SAPS	R 3,0 billion	1,1%
16	Rand water board	R 2,9 billion	1,0%
17	Western Cape: transport and public works	R 2,9 billion	1,0%
18	Kwazulu-Natal: education	R 2,4 billion	0,8%
19	SABC	R 2,2 billion	0,8%
20	Gauteng: Education	R 2,2 billion	0,8%

Source: (Stats SA, 2017a)

Table 2.5: South African employment statistics [in thousands]

	Jul-Sep 2015	Oct-Dec 2015	Jan-Mar 2016	Apr-Jun 2016	Jul-Sep 2016	Oct-Dec 2016	Jan-Mar 2017	Apr-Jun 2017
Population aged between 15 and 64 years	36 113	36 272	36 431	36591	36 750	36 905	37 060	37 218
Labour force	21 246	21 211	21 377	21179	21 706	21 850	22 426	22 277
Employed	15 828	16 018	15 663	15545	15 833	16 069	16 212	16 100
Unemployed	5 418	5 193	5 714	5634	5 873	5 781	6 214	6 177
Not economically active	14 867	15 061	15 054	15412	15 044	15 055	14 634	14 941
Unemployment rate	**25,5%**	**24,5%**	**26,7%**	**26,6%**	**27,1%**	**26,5%**	**27,7%**	**27,7%**
Employment to population ratio	**43,8%**	**44,2%**	**43,0%**	**42,5%**	**43,1%**	**43,5%**	**43,7%**	**43,3%**
Labour force participation rate	**58,8%**	**58,5%**	**58,7%**	**57,9%**	**59,1%**	**59,2%**	**60,5%**	**59,9%**

Source: (Stats SA, 2017b)

Table 2.6 indicates the number of people who are employed by the different industries in South Africa (Stats SA, 2017b). According to Table 2.6, the utilities in industry provide the lowest number of job opportunities compared to other industries.

Table 2.6: Employment by industry [in thousands]

Industry	Apr-Jun 2016	Jan-Mar 2017	Apr-Jun 2017
Agriculture	825	875	835
Mining	447	447	434
Manufacturing	1 712	1 790	1 799
Utilities	111	145	148
Construction	1 388	1 505	1 395
Trade	3 136	3 207	3 265
Transport	862	965	954
Finance and other business services	2 220	2 378	2 395
Community and social services	3 544	3 569	3 560
Private households	1 296	1 319	1 311

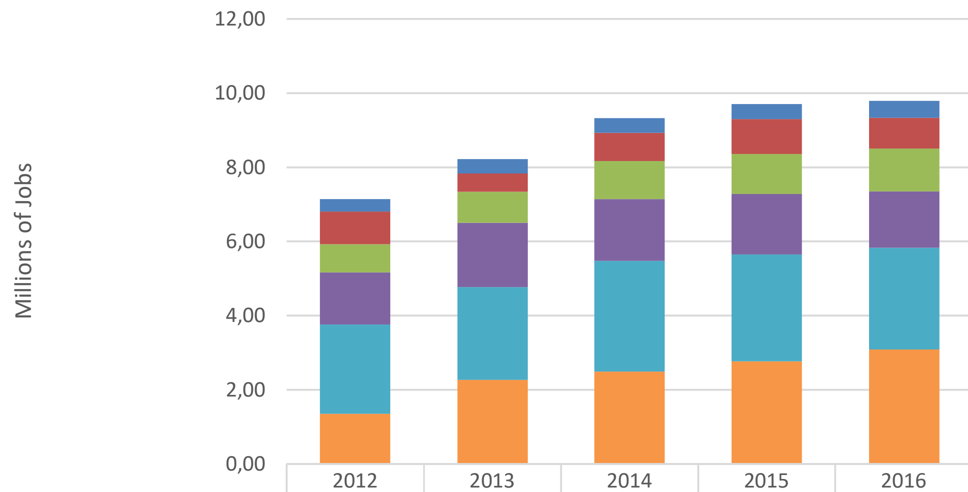
Source: (Stats SA, 2017b)

Comparing Table 2.5 with Table 2.6 shows that the industry with the biggest capital expenditure employs the least amount of people.

2.2.2. Job Creation Potential of Renewable Energy

By the end of 2016, the renewable energy industry indicated a 1.1% increase from 2015 in the number of people employed, reaching 9.8 million people employed by the end of 2016. Figure 2.13 indicates the number of people employed by the different technologies in the renewable energy industry (IRENA, 2017c). Supportive policies and the falling cost of renewable energy account for the increase in employment in the renewable energy industry.

In the past two years a moderate growth rate was maintained in the renewable energy industry, whereas traditional energy resources experienced a decrease, resulting in major employment cuts globally (IRENA, 2017c).



	2012	2013	2014	2015	2016
Other Technologies	0,33	0,38	0,40	0,40	0,45
Solar Heating and Cooling	0,89	0,50	0,76	0,94	0,83
Wind Energy	0,75	0,83	1,03	1,08	1,16
Large Hydropower	1,41	1,74	1,66	1,63	1,52
Bioenergy	2,40	2,50	2,99	2,88	2,74
Solar Photovoltaic	1,36	2,27	2,49	2,77	3,09

Figure 2.13: Global renewable energy jobs

Source: (IRENA, 2017c)

2.2.3. Job Creation Potential of Photovoltaics in South Africa

The PV industry offers an average estimated 30 jobs per MW power capacity installed (Walwyn, 2016). In South Africa these jobs mainly involve assembling, installing and maintaining the PV modules and in some factories assembling imported PV cells (Walwyn, 2016). The REI4P conforms to the criteria that force projects to add value along the value chain. To date the programme has not been very successful (Walwyn, 2016).

Table 2.7: Employment per installed capacity of PV

	2012	2013	2014	2015	2016
Solar energy [MW]	101 900	139 300	176 700	224 800	295 700
People employed by the PV industry	1 360 000	2 270 000	2 490 000	2 770 000	3 090 000
Global jobs in PV per MW installed	**13,3**	**16,3**	**14,1**	**12,3**	**10,4**

Source: (IRENA, 2017c; IRENA, 2017b)

2.3. National Systems of Innovation

2.3.1. National System of Innovation Conceptual Framework

During the late 1980s the national system of innovation conceptual framework was introduced in the study of science, innovation and technology; the framework suggested that the primary goal of the research system was innovation (Godin, 2009). The national system of innovation was created for the purpose of studying and analysing the innovative capacity of different countries in order to establish the effect globalisation and trends have on the development of science and technology (Godin, 2009). The national IS emphasised that the relationship and interaction between different sectors, such as the environment, governments, universities, industries, etc., influence and ultimately determine the innovative performance of the system and firms operating within the system (Godin, 2009). The relationship and interaction between different entities, such as education, regulatory bodies, financial institutions, etc., contribute to the development and diffusion of knowledge in the system (Godin, 2009). One of the primary concerns of the national system of innovation is the development, distribution and application of knowledge (Godin, 2009). The national IS indicated that the overall performance of an IS does not depend on the individual performance of entities, but on the interaction, knowledge distribution and knowledge utilisation between them (Godin, 2009).

The knowledge economy is a concept that was first introduced in the 1960s and re-emerged in the 1990s (Godin, 2009). In order for a system to be efficient, the accessibility and distribution of knowledge become essential and increase the number of innovative opportunities (Godin, 2009). The efficiency and rate at which new knowledge is produced, diffused and used serve as extremely relevant performance indicators in evaluating the National System of Innovation (Godin, 2009).

The generation, transfer and practical implementation of new knowledge is a necessary condition for innovation (Saari and Haapasalo, 2012). Figure 2.14 indicates different elements that affect knowledge transfer. According to Figure 2.14, the knowledge transfer framework is dependent on relationships and links between different people, organisations and institutions (Saari and Haapasalo, 2012).

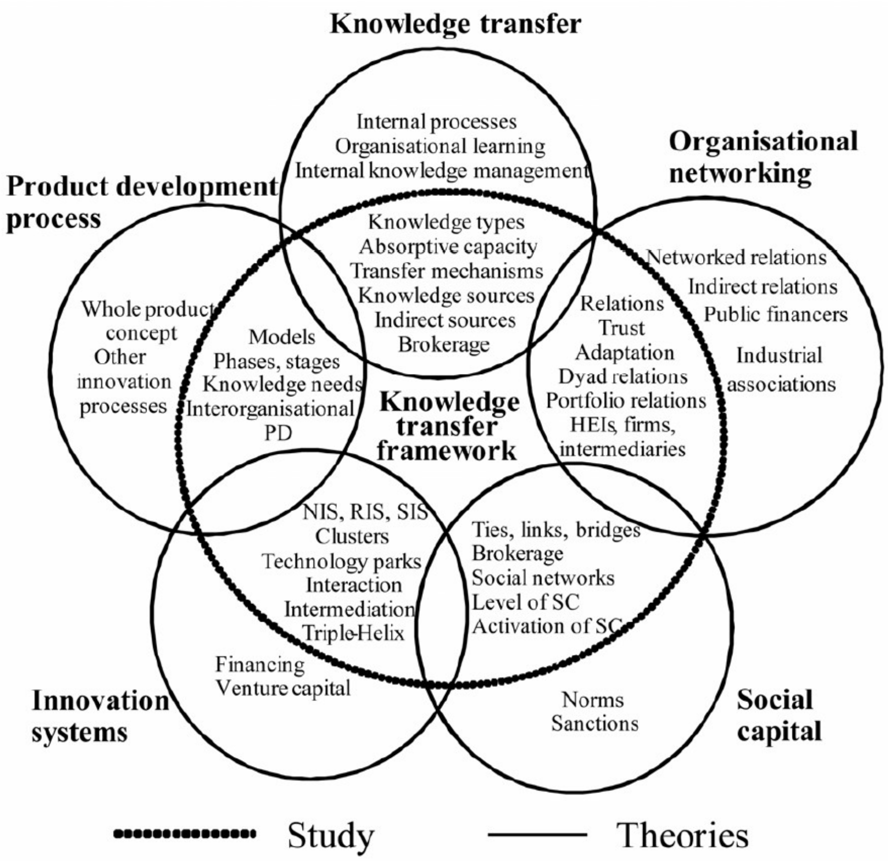


Figure 2.14: Knowledge transfer framework

Source: (Saari and Haapasalo, 2012)

Science parks, or research parks, are purposely built establishments that employ specialised professionals for the purpose of generating new knowledge, usually in close proximity to businesses and knowledge-based institutions (Saari and Haapasalo, 2012). The purpose of these establishments is to increase the wealth and wellbeing of the community by promoting a culture of competitiveness and innovation by stimulating and managing the flow of knowledge and technology, assisting with the establishment and growth of innovation-based organisations and providing value-added services with state-of-the-art facilities (Saari and Haapasalo, 2012). These establishments manage the flow of information between knowledge-based institutes (universities and R&D institutions), different companies in the industry and markets (Saari and Haapasalo, 2012). Science parks aim at assisting firms with structural changes in different regions, technological development and innovation activities (Saari and Haapasalo, 2012).

Innovation occurs when explicit and tacit knowledge is available for specific scientific and technological use; this is usually trapped inside organisations and institutions (Saari and Haapasalo, 2012). Technology parks assist industries with knowledge transfer between different actors, organisations, networks and services in local innovation during product development processes (Saari and Haapasalo, 2012). Product development processes have various stages where different kinds of knowledge are required and knowledge transfer becomes essential (Saari and Haapasalo, 2012). The product development phase establishes which information is necessary for the specific stage (Saari and Haapasalo, 2012).

Social capital is defined as social networks and personal relationships between people and knowledge transfer that occurs within societies and industries (Saari and Haapasalo, 2012). Social capital can act as an enabler that encourages collaboration between organisations or it can be a hindrance (Saari and Haapasalo, 2012). Social links and strong ties between people are extremely important and greatly influence interactions, contracts and negotiations between firms (Saari and Haapasalo, 2012). Inter-organisational networking is heavily dependent on technology parks, local IS and social capital for knowledge transfer to occur (Saari and Haapasalo, 2012).

The absorptive capacity of a firm is dependent on the receiver's ability to capture and exploit the transferred knowledge (Saari and Haapasalo, 2012). The person receiving knowledge could also act as a hindrance in knowledge transfer because of inexperience, narrow-mindedness and lack of expertise (Saari and Haapasalo, 2012). Knowledge transfer relies on trust within relationships and compensation policies and can be limited by mutual intent (Saari and Haapasalo, 2012).

Tacit knowledge resides within individuals; it can be increased through learning processes that include training, research, observation, coaching, working in groups, working with networks of people, recording history, etc. (Saari and Haapasalo, 2012). Tacit knowledge could be transferred through technology, moving people and changing the structure of an organisation, working with experts, brainstorming and recording and observing critical events (Saari and Haapasalo, 2012). Explicit knowledge can easily be transferred between individuals and organisations (Saari and Haapasalo, 2012).

R&D has an effect on the learning curve of organisational learning processes where greater expenditure on R&D usually leads to steeper learning curves, resulting in greater knowledge absorption capacity and improved innovation (Saari and Haapasalo, 2012).

The elements that affect knowledge transfer are shown in Figure 2.15. Knowledge transfer is initiated through enablers, which include the IS (technology parks, actors, structures, regional networks, national networks and connections to sectorial ISs) and social capital (regional and national networks and links to other locations and connections to sectorial ISs) (Saari and Haapasalo, 2012). According to Figure 2.15, enablers form the base of knowledge transfer and are evaluated on the IS level (Saari and Haapasalo, 2012). Knowledge required for different phases of product development is transferred to the process through inter-organisational networking (Saari and Haapasalo, 2012).

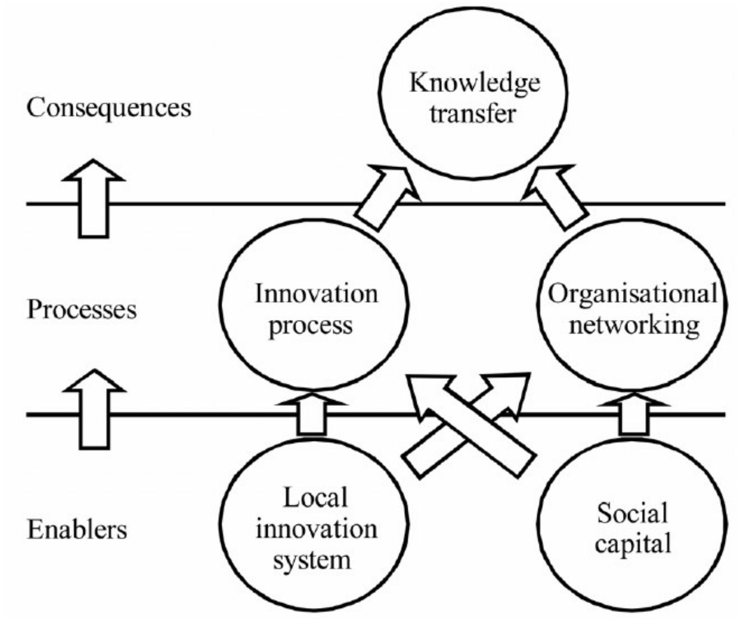


Figure 2.15: Elements affecting knowledge transfer

Source: (Saari and Haapasalo, 2012)

ISs cannot be assessed purely on the number of patents patented over a period of time or on the R&D expenditure, because these do not measure the use of knowledge (Godin, 2009). Godin stated in his study on national ISs that there is an urgent need to develop new and innovative performance indicators for the establishment of science and technology policies (Godin, 2009).

Earlier IS approaches were used rather in the sense of social and natural sciences by explicitly relating general systems theory to IS, but this has not been addressed in a systematic manner (Hekkert and Negro, 2009). The characteristics of a system, in the strict sense, is that its sole purpose is to perform a specific function (Hekkert and Negro, 2009). Early researchers concluded that the primary goal of an IS approach is to contribute to the development and diffusion of an existing or emerging technology (Hekkert and Negro, 2009). The success of an emerging technology's IS is dependent on the sub-functions of the system, which enable it to be developed and to grow (Hekkert and Negro, 2009).

The IS framework approach has enormous potential in contributing to insight into the understanding of different processes of innovation; it could also be applied in the sustainable and renewable energy technologies and has become well recognised for innovation studies (Hekkert and Negro, 2009). The IS framework is used as a guideline by many organisations globally as an analytical framework in establishing science and innovation policies.

During the process of technological change, changes in the existing IS co-evolve with new and emerging IS, emphasising the criticality of obtaining insight into the dynamics of the system (Hekkert *et al.*, 2007). The traditional IS analysis framework, which considers only the structure of an IS, is considered inadequate and has to include the broader aspect of a number of processes that contribute to the performance of a well-functioning IS (Hekkert *et al.*, 2007).

An IS can be evaluated on three levels: the type of technology, the sector or industry it falls into and the national level of penetration or geography of the innovation (Kebede and Mitsufuji, 2017). The goal of any IS is to create/develop, diffuse and exploit the new innovation and the information/knowledge that was created.

2.3.2. Technological Innovation Systems

Ever since the study of ISs was introduced, it attracted the attention of researchers and policy makers globally (Kebede and Mitsufuji, 2017). During the 1990s, TIS researchers moved their focus from static structures to exploring and analysing the dynamics of a system (Markard *et al.*, 2015). ISs can be analysed based on technology, industry and geography, with the basic goal of developing, diffusing and using the technology and knowledge about it (Kebede and Mitsufuji, 2017). The study of an IS can be used as a framework to analyse and construct the technology in focus while it is being built to ensure that it emerges as the policy makers and governing bodies intended (Kebede and Mitsufuji, 2017).

Many IS approaches have been developed over the years and can be used as analytical frameworks and policy toolboxes; the different IS framework approaches that have been developed are the national, sectoral, regional and technological innovation systems (Edsand, 2016). The TIS approach can function on a national, sectorial and regional level (Edsand, 2016). Johnson and Jacobsson first introduced the system functional approach to analyse the implementation and development of a TIS in 2001 (Edsand, 2016). The performance of the system functions can be analysed to identify the elements causing barriers to the development of the system and conversely the elements that accelerate the development of the system (Edsand, 2016). In the past study of the TIS framework was only undertaken in the context of developed countries. Recent studies have indicated that the TIS framework approach can also be applied to the context of developing and late-coming economies (Kebede and Mitsufuji, 2017).

Each and every technology in existence today is unique and characteristically different in system structure and its ability to develop and diffuse (Hekkert and Negro, 2009). The success of diffusion of a technology is directly proportional to the functionality of the TIS supporting the technology (Hekkert and Negro, 2009). The TIS framework approach, introduced by Heckert *et al.*, have been used by a number of scholars and researchers globally in studying socio-economic change and renewable energy technologies (Hekkert and Negro, 2009). A TIS can be distinctly classified into two categories: R&D-based TIS and diffusion-driven TIS (Kebede and Mitsufuji, 2017).The purpose of a TIS is to "satisfy the strong need to influence both the speed and direction of innovation and technological change" (Hekkert *et al.*, 2007).

In 1991 Bo Carlsson and Rikard Stankiewicz defined a TIS as "a dynamic network of agents interacting in a specific economic or industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology" (Kebede and Mitsufuji, 2017).

Jochen Markard and Bernhard Truffer defined a TIS as a "set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product" (Kebede and Mitsufuji, 2017).

Hekkert *et al*. defined a TIS as "the set of actors and rules that influence the speed and direction of technological change in a specific technological area" (Hekkert *et al.*, 2011). It is therefore critical to analyse a TIS in order to evaluate which functions, structures and processes are in place (or non-existent) and if there are any obstructions/obstacles that can be removed.

The co-evolution of socio-technological change and a TIS implies that emerging technologies are applied in the context of the TIS and the growth of a TIS influences the success or failure rate of the technology (Hekkert and Negro, 2009). With the maturity of a technology comes the proportional growth of the TIS in response to new knowledge that is being developed, increasing size and density of networks, new market entrants and arrangements or agreements that are established (Hekkert and Negro, 2009).

The TIS framework has attracted great attention over the past few years and is used extensively for new and emerging technologies to study their development, progression and maturity (Markard *et al.*, 2015). The TIS framework focuses on the dynamics of an IS and the understanding thereof in order to evaluate the performance of the system and identify barriers and shortcomings that might improve the system performance (Markard *et al.*, 2015). The TIS framework is used to design policies and derive recommendations to ensure the technology is developed and utilised to its full capacity and potential (Markard *et al.*, 2015).

TIS is aimed at innovation processes to maximise the development, diffusion and use of the technology (Hekkert and Negro, 2009). In order to study and evaluate the performance of a TIS, all the factors that influence the system need to be identified and taken into account (Hekkert and Negro, 2009).

Diffusion of a TIS can be defined as the way the network of actors, organisations and institutions interact in order to build innovative capacity and increase the adoption rate; in combination the system functions contribute to the diffusion of the technology and further improvements (Kebede and Mitsufuji, 2017). Despite numerous attempts to measure the performance of the system functions for a specific technology, the level of diffusion remains the best indicator (Kebede and Mitsufuji, 2017).

The concept of IS stretches far beyond R&D in developing new technologies or proof of concepts, which is often neglected by researchers (Kebede and Mitsufuji, 2017). In order to understand successful IS economic growth, all the functions of the system should be taken into consideration, such as demand, entrepreneurial activities, supporting functions, knowledge development, business formulation, etc. (Kebede and Mitsufuji, 2017).

Technology diffusion is the rate at which new technologies or ideas spread and the way in which they are adapted (Hekkert *et al.*, 2011). Technology diffusion is strongly dependent on the market or people and their willingness to change, as well as the adoption of new technologies, as indicated in Figure 2.16. The socio-cultural barrier forms limit the diffusion of TIS (Kebede and Mitsufuji, 2017). Studies over the past decades have proven that innovation is a collective activity, which should be viewed as a larger system (Hekkert *et al.*, 2011). The success factors of an IS are strongly influenced by the flow of the technological innovation and research information between academic institutions, private and public firms, government, the technology industry and the market (Hekkert *et al.*, 2011).

The success of a well-functioning TIS is supported by system functions that are the key processes and activities supporting the system (Kebede and Mitsufuji, 2017). Most of the TIS in existence today contain some form of barrier(s) that prohibits the diffusion of the technology into the market and industry. In order to remove the barriers that hinder diffusion, it is necessary to create, develop and implement policies that ensure all the system functions are in place and that the correct connections are established between them (Hekkert *et al.*, 2011).

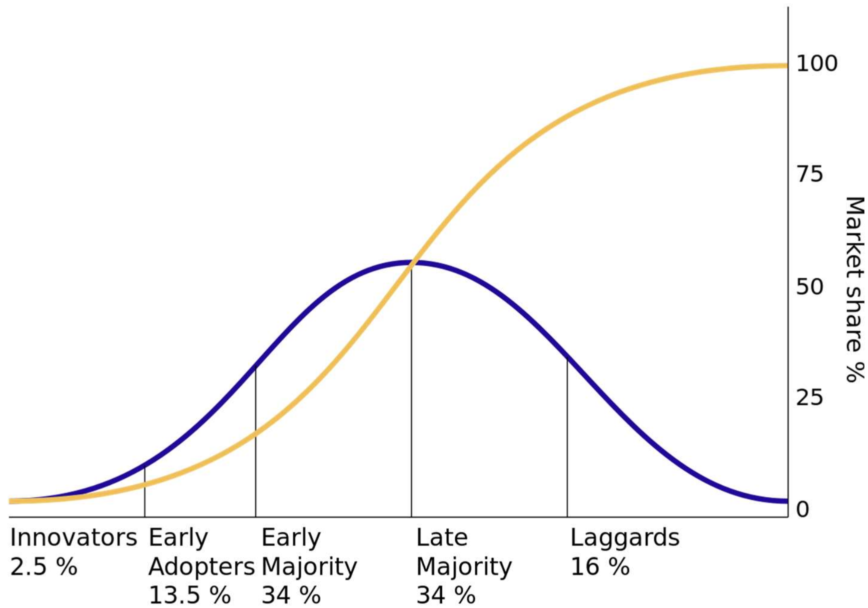


Figure 2.16: Technology diffusion life cycle

Source: (Mordechai, 2015)

There are two distinct phases of a TIS: the formative phase, which is characterised by uncertainty and high risk, and the growth phase (Kebede and Mitsufuji, 2017). A TIS cannot be evaluated solely by its diffusion rate; this is because the extent and rate of diffusion are dependent on a variety of different factors affecting the technology (Kebede and Mitsufuji, 2017). The diffusion rate can only serve as an indicator for a specific technology, indicating if it is moving in the right direction (Kebede and Mitsufuji, 2017).

Diffusion of technology could be effected through the implementation of supportive policies, ensuring that all the restrictions, obstacles and limitations are removed that limit the adoption of the technology in focus (Hekkert *et al.*, 2011). Researchers have to launch a proper investigation before any policies can be created, establishing what the strengths and weaknesses of the technology are and investigating which factors, functions, structures and processes are required to support the technology (Hekkert *et al.*, 2011).

National and local government can play an important role in the diffusion of a new technology. Governments are responsible for the design and implementation of policy instruments that support the welfare of citizens and protect markets from failure (Kohler *et al.*, 2012). Government intervention can be targeted at three main focus points: market, mission and cooperation paradigms (Christian Kohler, 2012). Governments have intervened in the development of many major industries in countries and provided funding in these areas. Examples are found in education, healthcare, water and sanitation, energy, the military, telecommunication, etc., where the government has a very huge impact on the future of technologies and industries. R&D is an extremely expensive phase of product development, which does not always yield desirable results and could take years (Kohler *et al.*, 2012). Small companies and private firms cannot afford major R&D because of the expense and tedious time frame. Government can intervene in certain industries by providing fiscal incentives and pushing the industries towards their mission-oriented objectives (Kohler *et al.*, 2012). Governments are also responsible for creating links in specific industries, leading to firms collaborating with one another, sharing their knowledge and expertise and moving towards creating an open innovation strategy. The term open innovation is used where firms develop beyond the borders of their capabilities by collaborating with other companies, knowledge providers and suppliers by building synergy to create a project that would otherwise be impossible with their own resources (Christian Kohler, 2012).

Policies can establish links for technology transfer between institutions, where knowledge is created, and the industry, where the knowledge is applied (Christian Kohler, 2012). Supportive policies allow knowledge to flow easily from where it is created to the industry, where the knowledge is applied and implemented, increasing the time to market significantly and resulting in advancement of technology within an industry (Kohler *et al.*, 2012). Another advantage is that the creation of this policy creates environments, markets and circumstances that encourage spin-off and start-up companies and increases the number of technology innovations.

To increase the amount of innovation in a country, governments could promote industries and technologies that are in line with the technology roadmap by offering incentives, support and funding for R&D in particular fields (Christian Kohler, 2012). All technologies (and firms that develop them) face challenges and obstacles towards innovation. Establishing policies optimises the time required to innovate technologies (Kohler *et al.*, 2012).

The functionality of the system functions is influenced by the characteristics, relationships and interactions among the different components in the system (Hekkert and Negro, 2009). In some cases the components of a TIS are shared between a number of different ISs (Hekkert and Negro, 2009). The system functions can be defined as the set of components that contributes to the performance of the system (Hekkert and Negro, 2009). Although there are distinct differences between different technologies, every TIS can be distinctly characterised by four basic structural building blocks that form the pillars of any IS, supporting the technology (Hekkert *et al.*, 2011; Kebede and Mitsufuji, 2017):

- Actors: The actors of a TIS contribute to the development and diffusion of a technology; these include private and public firms, small to medium enterprises, universities, institutions, users, individuals, technology developers, technology adopters, consumers, financers and governments (Kebede and Mitsufuji, 2017).
- Networks: The networks of a TIS refer to the connection, networking and relationships among the different actors supporting and influencing the technology. These include political networks, organisational networks, university and industry networks, user and supplier networks, research institute networks and political networks (Kebede and Mitsufuji, 2017).
- Institutions: Institutions comprise the policies, standards, legislation, procedures and principles that regulate and control the interactions of the firms, institutions and individuals involved in the technology (Kebede and Mitsufuji, 2017). Institutions have an important role to play in the development and diffusion of a technology. Lack of institutional support may cause barriers to diffusion of technology (Kebede and Mitsufuji, 2017).
- Technology: This refers to the practical development of a technology and the interaction with the intended infrastructure (Kebede and Mitsufuji, 2017). The technology can act as an enabler or a hindrance for the activities of actors within the IS (Hekkert *et al.*, 2011).

In an article entitled "Functions of an Innovation System", Heckert *et al*. defined each process as performing a different function and hence labelled the different processes as functions of an IS (Hekkert *et al.*, 2007). Heckert *et al*. identified seven distinctly different system functions or key processes of ISs that address the performance and functionality of the IS (Hekkert *et al.*, 2007):

- Entrepreneurial activities,
- Knowledge development,
- Knowledge diffusion/exchange,
- Guidance of the search,
- Market formation,
- Resource utilisation/mobilisation, and
- Creation of legitimacy or counteracting resistance to change.

<u>Function 1: Entrepreneurial Activities</u>

Entrepreneurial activity forms the basis of any IS and is an essential component for the satisfactory functioning of the TIS (Hekkert *et al.*, 2007). Entrepreneurs and innovation are interdependent; innovation cannot occur without the presence of entrepreneurs (Hekkert *et al.*, 2007). Therefore it is critical to ensure networks are established for the different functions to co-exist within the TIS (Hekkert *et al.*, 2007). Entrepreneurs envision and generate new innovation, business activities and opportunities by taking advantage of new and existing information and translating or combining it into different applications, networks and markets (Hekkert *et al.*, 2007). Learning is achieved through experimentation and proof of concepts to increase knowledge and understanding of the technology under different circumstances and in different environments (Kebede and Mitsufuji, 2017). The information learned in entrepreneurial activities is used to test possible applications, measure achievable performance, determine feasibility, develop business proposals, evaluate and test the reaction of stakeholders and realise market potential (Hekkert *et al.*, 2007).

Entrepreneurial activities in general entail high-risk endeavours with a high level of uncertainty; this is due to ambiguous market potential, inadequate knowledge about the technology and indefinite potential for different applications of the technology (Hekkert *et al.*, 2007). Entrepreneurial activities initially begin with high risk; thereafter risk is reduced through positive experimentation results and knowledge development (Hekkert *et al.*, 2007). Entrepreneurial activities include evaluation of a technology and envisioning its market potential. An entrepreneur can realise the potential and possible applications of technologies, thereafter exploiting it to its full potential. Entrepreneurs constantly have to take advantage of existing, new and arising technologies in order to achieve a competitive advantage and develop business opportunities (Hekkert *et al.*, 2007). In some instances, entrepreneurs perform multiple functions within the system, but preferably not all of them (Hekkert *et al.*, 2007).

Entrepreneurial activities serve as an indication of the performance of an IS; if entrepreneurial activities are lagging behind, a problem is most probably occurring within one of the other functions (Hekkert *et al.*, 2007). This is supported by the fact that entrepreneurs are dependent on other functions and cannot serve all the functions by themselves. Entrepreneurial activities are affected by the six other functions of the TIS (Hekkert *et al.*, 2007). On the contrary, if functions 2 to 7 are well-established, entrepreneurial activities will follow (Hekkert *et al.*, 2007).

The number of entrepreneurs actively present in an IS is the primary indicator of the performance of the system (Hekkert *et al.*, 2007). Entrepreneurial activities can be evaluated by mapping the number of actors within the industry, the number of firms joining the industry, the number of experiments on new technology and the number of new projects being launched (Kebede and Mitsufuji, 2017). Studies of entrepreneurial activities indicated that the root cause of problems associated with this function can in most cases be traced to problems occurring within the other six functions (Hekkert *et al.*, 2007). Mapping entrepreneurial activities gives an indication of the number of entrepreneurs getting involved in the technology, or moving away from it (Hekkert *et al.*, 2007).

Function 2: Knowledge Development

Knowledge development could be considered as the heart of any IS (Hekkert *et al.*, 2007). Knowledge is the most fundamental resource in TIS and modern economies (Hekkert *et al.*, 2007). The whole innovation process is built on the ability of the IS to generate, absorb and apply new knowledge (Hekkert *et al.*, 2007). Mechanisms of learning form the core of any IS, which cannot exist without R&D and knowledge being created (Hekkert *et al.*, 2007). Knowledge can be created and developed by researching the technology, socio-economic change, markets and technical aspects regarding the technology (Kebede and Mitsufuji, 2017). The outcome of knowledge development is information on technologies, resulting in new technologies being developed and innovation occurring (Kebede and Mitsufuji, 2017). Without knowledge, it would be impossible to understand and accurately predict the behaviour and performance of a TIS.

The creation and development of knowledge entail studying the theory of operation and laws of physics supporting the technology and testing that theoretical results are aligned with practice (Kebede and Mitsufuji, 2017). Theory testing is extremely important and should be aligned with practical results in terms of predictability, repeatability and quantifiability (Kebede and Mitsufuji, 2017). Practical experimentation results that do not align with theoretical calculations are indicative of wrong assumptions being made and the technology not being fully understood (Kebede and Mitsufuji, 2017). Learning activities for an emerging technology take place mostly through experimentation (Kebede and Mitsufuji, 2017).

Before attempting to analyse the knowledge development function, it is key to understand where the knowledge comes from, at what rate knowledge is developed and what type of firms or institutions are part of the knowledge development phase (Kebede and Mitsufuji, 2017). Knowledge development measures how many resources are put into learning and creating knowledge. The knowledge development function could be evaluated through bibliometric analysis, feasibility studies, market research and assessment, evaluation and testing, the number of articles and publications published, number of patents patented, number of R&D projects and learning curves by calculating the number of R&D projects and the amount invested in R&D over a period of time (Hekkert *et al.*, 2007; Kebede and Mitsufuji, 2017). The evaluation of this function is accomplished by determining the amount of learning that takes place through feasibility studies, testing new models, market readiness research, etc., indicating the performance of TIS (Hekkert *et al.*, 2007). Patents are usually an indicator of how much research is being done and the quality of the research being produced (Hekkert *et al.*, 2007).

Function 3: Knowledge diffusion

Knowledge diffusion entails the extremely important aspect of learning taking place and knowledge being shared through interaction and networking between actors within the industry (Kebede and Mitsufuji, 2017). Networks are affected (positively or negatively) by the amount of information that is transferred and exchanged (Hekkert *et al.*, 2007). Knowledge that was created, without being transferred to the industry, will affect the development and diffusion of the TIS negatively (Hekkert *et al.*, 2007).

Coalition with R&D institutions is critical for the success of innovation and the rate at which it takes place. The rate at which innovation can be created is strongly dependent on the availability of knowledge (Hekkert *et al.*, 2007). Networks within a TIS provide the communication channels through which knowledge can be exchanged and diffused between the different actors within the network. It is critical for any IS that actors with different backgrounds interact with one another to share information and ideas.

The level of knowledge diffusion can be indicated by the number of workshops and training courses that take place, number of entrepreneurs and users attending workshops, the number of conferences and seminars and the number of promotion campaigns being launched, as well as mapping the amount of communication between knowledge creators, developers, network size and intensity over time (Kebede and Mitsufuji, 2017). Further indicators are the type of networks and the number of networks that exist (Hekkert *et al.*, 2007). Emphasis should be placed on the level of communication between actors within the network. Policy decisions on standards and long-term goals should be implemented based on the latest information and technological insights of the system (Hekkert *et al.*, 2007). Diffusion through networks allows learning through interaction and learning through adoption to take place (Hekkert *et al.*, 2007).

Function 4: Guidance of the Search

Functions 2 and 3 are concerned with mechanisms of knowledge creation, learning and knowledge transfer, whereas guidance of the search is concerned with shaping and steering the direction in which the technology should move. Guidance of the search can be regarded as the process selection function (Hekkert *et al.*, 2007). When new technology or new knowledge of an existing technology becomes available, it is important that there is specific focus and that emphasis is placed on certain parts of the technology, else there might be insufficient resources to cover all the different research areas or focus points (Hekkert *et al.*, 2007). Technology change does not occur naturally, but has to be steered in a direction by influencing R&D priorities with the guidance of the search function (Hekkert *et al.*, 2007).

Guidance of the search refers to goals, policies, promises, needs or expectations of the actors that the emerging technology should accomplish and clarifies the goals and objectives indicating what needs to be accomplished by the emerging technology (Hekkert *et al.*, 2007).

The guidance of the search function has to adhere to technology users' specific needs and is therefore responsible for the visibility and clarification of the system (Hekkert *et al.*, 2007). Guidance of the search specifies certain goals that need to be reached within a period by the TIS, thereby initiating the momentum of the system. The momentum of the system could be initiated by government to reach a specific goal after a period, indirectly specifying the number of resources that will be required to reach that goal (Hekkert *et al.*, 2007).

Guidance of the search can be implemented or enforced by the local government, the industry and market demand (Hekkert *et al.*, 2007). In some cases, guidance of the search is influenced by exchanging knowledge and ideas between different actors, technology producers and technology users (Hekkert *et al.*, 2007). Emphasising the benefits of a proposed technology often leads to greater stimulation of the technology (Hekkert *et al.*, 2007).

Guidance of the search can be evaluated through the mapping of different formulating policies, rules and regulations established, specific targets, goals and expectations that need to be achieved, the amount of interest gained by the technology and the number of publications and articles published stating the pros and cons, possible applications and the expectations of the technology (Hekkert *et al.*, 2007; Kebede and Mitsufuji, 2017).

Function 5: Market Formation

Market formation refers to where markets are created and has an impact on the growth of the technology (Kebede and Mitsufuji, 2017). An emerging technology can only be successful if there is sufficient market demand for the technology. Without market demand, the technology needs to be innovated further or a market needs to be created (Kebede and Mitsufuji, 2017).

New technologies are often characterised by slow initial markets and adoption rates in the transition from existing technologies (Kebede and Mitsufuji, 2017). Actors within the industry have be made aware of the new technology through the knowledge development function and knowledge diffusion function before the potential of the technology can be realised and expectations can be set by the guidance of the search function (Hekkert *et al.*, 2007). This can be accomplished through incentives that produce favourable outcomes for the adoption of the new technology, such as tax exemptions/deductions through rebates and favourable policies and niche markets (Hekkert *et al.*, 2007).

Markets can be enhanced through innovative methods that act as a stimulus for the technology to be adopted, through favourable policies and temporary niche markets (Hekkert *et al.*, 2007).

Markets can be evaluated by mapping the various stimulants responsible for creating a market for the specific technology (Hekkert *et al.*, 2007). This includes the existence of subsidiaries, incentives, tax exemptions, rebates and standardisation of the technology in selective markets (Hekkert *et al.*, 2007; Kebede and Mitsufuji, 2017).

Function 6: Resource Mobilisation

Resource mobilisation is concerned with the number and type of resources required for the successful development of an IS (Hekkert *et al.*, 2007). Resource mobilisation is responsible for the allocation of human capital, investors, material management and financial aid (Hekkert *et al.*, 2007). Resource mobilisation consists of three types of resources: financial resources, human resources and physical resources (Hekkert *et al.*, 2007). Financial resources entail the different methods of funding that could be provided for the IS; these could be in the form of investors, subsidiaries, government incentives, tax deductions, venture capital, etc. (Hekkert *et al.*, 2007). Physical resources are the resources required to create the technology, which include the tools, materials, machinery, etc. The TIS is heavily dependent on finance and human capital that act as enablers for the development and production of new knowledge and the innovation of the system. Without resources, it is impossible to develop the TIS further.

Resource mobilisation can be evaluated by mapping the number of financial grants and loans companies and institutions use for R&D on the specific technology, funding available for the improvement of the technology, the number of educational programmes presented and launched in the specific technology field and adequate knowledge transferred to the required phase of development (Kebede and Mitsufuji, 2017). Resource mobilisation can be indicated by calculating the financial funding that is available for R&D programmes to generate knowledge for the specific industry. Another indicator is to establish if the actors, within the industry, have sufficient access to resources that help with the creation, development and implementation of the technology (Hekkert *et al.*, 2007).

Function 7: Creating Legitimacy and Counteracting Resistance to Change

Creating legitimacy of a new technology is a challenging task through which advocacy and support from stakeholders need to be established (Kebede and Mitsufuji, 2017). In order for a new technology to become part of or be viewed as a valid replacement of an existing technology, it is often necessary for the technology to become part an incumbent regime or it has to outperform and overthrow it completely (Hekkert *et al.*, 2007). New technology is often opposed by existing systems and should counteract the resistance when it is initially released. Counteracting resistance to change is challenging during the initial development phases of a new technology, especially from existing systems (Hekkert *et al.*, 2007).

The function that creates legitimacy and counteracts resistance to change can be measured by mapping the number of lobbying and advocacy programmes through the growth and conduct of interested parties (Kebede and Mitsufuji, 2017). Changes in the market result in changes that need to be applied to the TIS (Kebede and Mitsufuji, 2017). Technology and market demand change continuously and therefore the TIS should be closely monitored to compensate for these changes; this includes the nature of the change and at which rate change is taking place (Kebede and Mitsufuji, 2017).

2.3.3. Technological Innovation Systems Approach and Photovoltaic Systems

The development and diffusion of PV innovation in countries are strongly related to the TIS that controls the surroundings of the technology. The level of development, diffusion and implementation/use of a technology is strongly influenced by the TIS and its supporting functions concerning the technology (Kebede and Mitsufuji, 2017). The TIS framework was, to a large extent, created for advanced economies but studies have shown that it could be applied to lagging and late-follower economies (Kebede and Mitsufuji, 2017). South Africa could be regarded as a late follower in the adoption of PV, not contributing very much to the development of PV. The South African PV market only started adopting PV as recently as 2008 when the energy crisis emerged (Kebede and Mitsufuji, 2017).

The performance of an IS could be evaluated by evaluating the system functions subject to the opinion of different experts, researchers and key stakeholders within the industry (Hekkert *et al.*, 2007) There is currently no formal set of measurements, techniques and guidelines by which the system functions can be evaluated; instead a Likert scale can be used to compare the functions with one another to establish which function performs inadequately (Hekkert *et al.*, 2011). The functional pattern, showing how well the functions serve the system, can be mapped graphically by studying the dynamics of each function individually (Hekkert and Negro, 2009). The system functions are regarded as the intermediate variables between the structure of the elements and the performance of the system (Markard *et al.*, 2015). The functional analysis of a TIS could indicate the root cause of functional weakness within the system (Markard *et al.*, 2015).

In order to evaluate and understand a TIS successfully, it is important to include the demand side of the technology, which includes entrepreneurial activities and business formulation (Kebede and Mitsufuji, 2017). For technology-receiving and less developed countries the focus should be on building capabilities, diffusion and utilisation of the technology (Kebede and Mitsufuji, 2017).

Structural weaknesses within the system could be removed through policies, improvements and corrections once the weaknesses are identified, enabling the system to reach maximum performance (Markard *et al.*, 2015). Structural weaknesses can reside both internally on the level of the TIS or externally at the sectoral and national levels of the system (Markard *et al.*, 2015). Structural elements need to be taken into consideration in the context of the TIS because they contribute to the functional approach to the framework (Markard *et al.*, 2015).

A socio-cultural barrier has to be overcome for diffusion of PV, especially in technology-receiving countries (Kebede and Mitsufuji, 2017). Other factors that restrict diffusion are institutional barriers that should provide working policies and incentives (Kebede and Mitsufuji, 2017). Challenges in the PV industry are lack of knowledge, lack of collaboration between actors and the high cost of systems (Kebede and Mitsufuji, 2017). Lack of institutional support is a fundamental barrier to diffusion of technology ISs. This may include lack of a working policy and incentives (Kebede and Mitsufuji, 2017).

The TIS framework has been criticised by a number of scholars over the years and numerous suggestions have been made on how to improve it (Markard *et al.*, 2015). Some of the criticism received concerned the context of the TIS, system description, policy recommendations, politics and transitions (Markard *et al.*, 2015). Overall the TIS systems framework approach is regarded by several sources in literature as a validated framework on which to base the evaluation of an IS (Walwyn, 2016).

Challenges to PV TIS in most parts of the world are the high cost of initial investment, lack of knowledge and information, lack of training and lack of collaboration by firms, institutions and major stakeholders (Kebede and Mitsufuji, 2017).

The slow diffusion and adoption rate of PV in South Africa is the result of various barriers that prohibit proper diffusion (Münzberg *et al.*, 2016). Evaluation of the functions of the TIS in the subsequent chapters will determine what these barriers restricting the rate of diffusion are.

Much research into PV and TIS has been done in leading countries. None of the literature available covers South Africa, therefore there is a gap in the literature to evaluate the current South African PV TIS critically in order to establish what hinders or prohibits the diffusion of PV.

The functions are interrelated; if any single factor is weak, the overall performance of the system will be weakened. New ideas are often being tried and tested in function 1; the new knowledge is transferred from function 2 to function 3, which gives an indication to function 4 on the degree of its certainty, which in turn creates the possibility and expectations in function 4 (Hekkert *et al.*, 2007). This generates the momentum and direction of the system which in turn changes the dynamics of the system (Hekkert *et al.*, 2007). It is important to evaluate the system as a whole because the functions interact and support one another. The level to which the functions should be implemented is proportional to the development phase of the innovation system. In different phases of an innovation system, there will be different functions that feature in that particular phase (Hekkert *et al.*, 2011).

3. Conceptual Model

3.1. Introduction

Each and every TIS in existence is unique in its structure and ability to develop and diffuse (Hekkert and Negro, 2009). The success of diffusion of a technology is directly related to the TIS that supports the system (Hekkert and Negro, 2009). The TIS framework focuses on the dynamics of the system to develop an understanding of the performance of the system (Markard *et al.*, 2015). The TIS framework can be used to identify critical areas from which policies and recommendations can be derived to ensure that the technology is developed to its full potential (Markard *et al.*, 2015). This chapter focusses on the proposed model used in the study to evaluate the status of the TIS supporting the South African PV industry.

3.2. Theories, Models and Methods

The conceptual model proposed by Heckert *et al*. will be used in the study to evaluate the status of the PV TIS in the context of South Africa critically. Every TIS in existence functions in a completely distinct way, regardless of the similarity between systems. TISs in different regions differ from one another because of cultural differences and geographical location, emphasising the necessity to measure how innovation systems are functioning and performing for a given technology at a given location (Hekkert *et al.*, 2011).

Figure 3.1 indicates the basic structural components of a TIS, which are made up of the actors, institutions and networks supporting the technology. The functions of a TIS are sometimes referred to as 'key processes of the innovation system'; these functions operate as supporting processes of the structural components (Hekkert *et al.*, 2011). According to Figure 3.1, the system components are indicative of those at present active in the system, whereas the system functions are indicative of how well components are interacting and performing their specific tasks (Hekkert *et al.*, 2011).

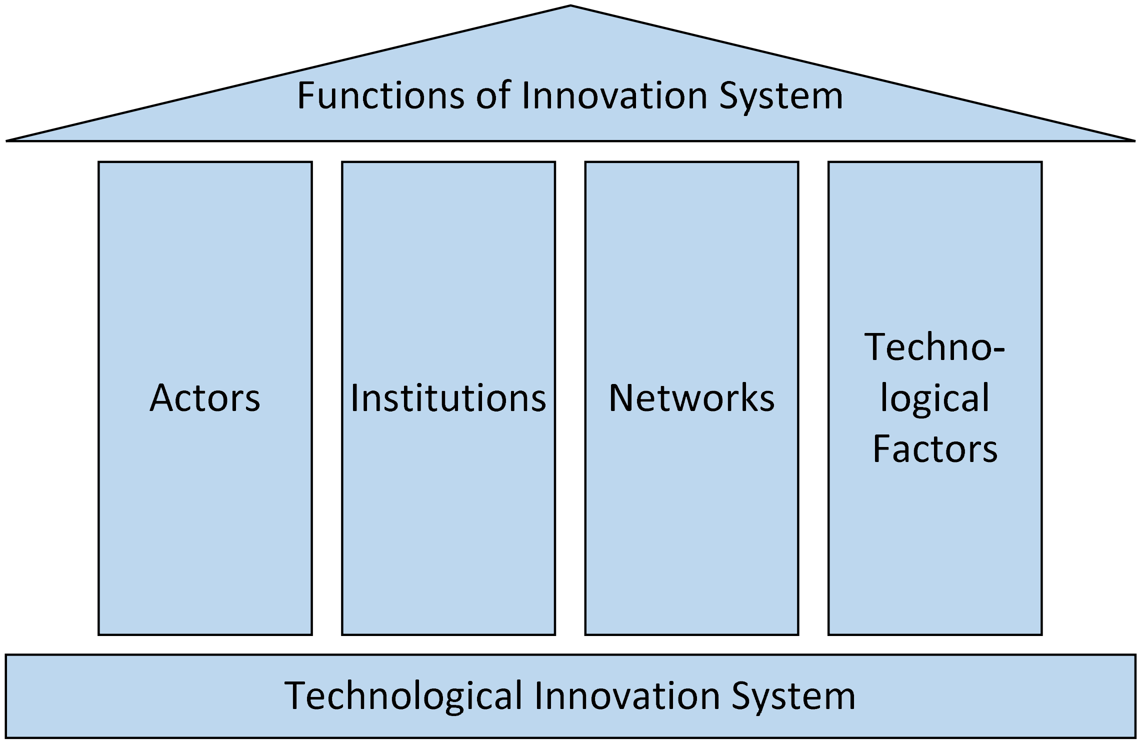


Figure 3.1: Technological innovation system structure and components

Source: Adapted from (Hekkert *et al.*, 2011)

3.2.1. Components of a Technological Innovation System

Every TIS could be characterised by four different components or structural building blocks, as indicated in Figure 3.1. These components are the actors, institutions, networks and technology that are always present in any system (Hekkert *et al.*, 2011)

Actors involve all the entities within the system that are directly or indirectly contributing to the development, growth and utilisation of the technology (Hekkert *et al.*, 2011).

Institutions involve the policies and regulations that are influenced and enforced by regulatory bodies and authorities (Hekkert *et al.*, 2011).

Networks involve the networks and relationships that allow knowledge to be shared between different actors within the system, which is a necessary condition for innovation (Kebede and Mitsufuji, 2017).

Technological factors involve a specific technology in which the direction and trajectory are important in what it wishes to accomplish (Hekkert *et al.*, 2011).

The four pillars of the component structure, as indicated in Figure 3.1, can be determined and evaluated by answering the questions stipulated in Table 3.1 (Hekkert *et al.*, 2011)

Table 3.1: Evaluating TIS structural components

System Component	Research Question
Actors	• Who are actors within the system? • Is there sufficient market demand? • Is the need for education met?
Institutions	• What are the policies and regulations that are influenced and enforced by regulatory bodies and authorities? • Are there any intermediary organisations guiding knowledge transfer and collaboration?
Networks	• Is there sufficient networking between different actors?
Technological factors	• What is the required direction and technological trajectory for the technology? • What are the technological factors involved?

Source: Adapted from (Hekkert *et al.*, 2011)

3.2.2. Functions of a Technological Innovation System

The TIS framework distinguishes between seven different system functions that support the structural components of a system. The TIS framework approach places much more emphasis on the system functions because they are much more evaluative in character than the system components (Hekkert *et al.*, 2011). In order to understand the functionality of the system, it is critical to identify and understand how the four pillars of the TIS interface or connect with the seven functions. These functions comprise entrepreneurial activities, knowledge development, knowledge exchange, guidance of the search, market formation, resource mobilisation and counteracting resistance to change (Hekkert *et al.*, 2011).

F1 - Entrepreneurial activities form the basis of and are an essential component for the good-functioning of an IS; innovation cannot occur without the presence of entrepreneurs (Hekkert *et al.*, 2007).

F2 - Knowledge development involves the mechanisms of learning and is the most fundamental resource in ISs and modern economies. ISs are built on the system’s ability to generate and create new knowledge, the absorption capacity of knowledge and the ability to apply and implement new knowledge practically (Hekkert *et al.*, 2007).

F3 - Knowledge diffusion involves the way in which knowledge can be shared and diffused through networks between different actors within the industry (Kebede and Mitsufuji, 2017).

F4 - Guidance of the search is concerned with shaping and steering technology into a clear, visible and specific direction. Technological change does not occur naturally; the guidance of the search function should intervene by influencing R&D priorities and allocating resources to satisfy user-specific needs and demands (Hekkert *et al.*, 2007).

F5 - Market formation has an impact on the growth and maturity of a technology, ensuring sufficient markets and demand (Kebede and Mitsufuji, 2017). The market formation function can create and grow markets through innovating stimulus that helps with the adoption of the technology (Hekkert *et al.*, 2007).

F6 - Resource mobilisation is responsible for the allocation of resources required for the successful development of a technology and IS (Hekkert *et al.*, 2007).

F7 - Creating legitimacy and counteracting resistance to change are responsible for establishing advocacy and support from key stakeholders. Counteracting resistance to change opposed to new technology is often a daunting task, requiring the new technology to become part of or to outperform an existing system completely (Hekkert *et al.*, 2007).

The importance of each system function is different for the different phases of development. To determine which function is causing a barrier limiting the diffusion of the system, it is important to establish in which phase of development the system is (Hekkert *et al.*, 2007). The seven functions of a TIS are required to be heavily interrelated with one another (Hekkert *et al.*, 2007).

3.2.3. Steps to Analyse a Technological Innovation System

The TIS should be analysed by specialists, experts and key stakeholders who have extensive knowledge about the technology and are currently active within the system (Hekkert *et al.*, 2011). This is because of the effect of geographical location on the innovation and diffusion of a specific technology, making quantitative assessment and benchmarking of leading countries difficult or impossible to compare; therefore the best way to evaluate the system would be by means of a number of different expert opinions in the technological field (Hekkert *et al.*, 2011). Figure 3.2 indicates the five steps necessary to perform when a TIS is being analysed (Hekkert *et al.*, 2011).

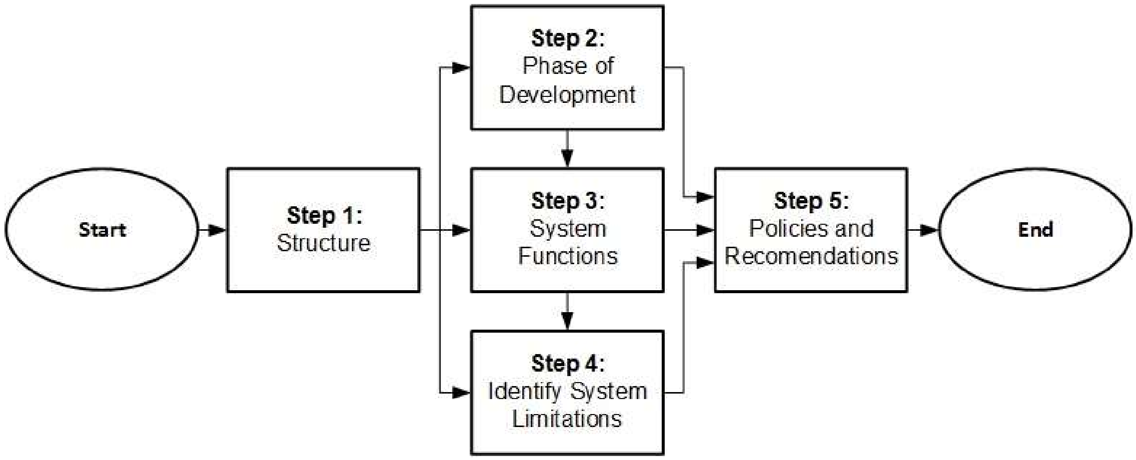


Figure 3.2: Method for analysing a technological innovation system

Source: (Hekkert *et al.*, 2011)

Step 1 requires the structure of the IS and the way in which the components are interrelated to be mapped (Hekkert *et al.*, 2011).

Step 2 indicates that the phase of development and maturity of the system need to be established. This is because the system structure will be different for the different phases of development (Hekkert *et al.*, 2011). The different phases of development include pre-development, development, take-off, acceleration and stabilisation. South Africa can be classified as a technology-receiving country with regard to PV, therefore the pre-development and development phases are not quite applicable in the South African context.

Step 3 requires the evaluation of the IS functions, measuring how the IS is functioning; the evaluative nature of system functions is considered a major breakthrough in IS research (Hekkert *et al.*, 2011). The functional analysis of the system functions forms the most critical part of this study in view of its evaluative nature. Figure 3.3 indicates the interconnection of system functions within a TIS for the take-off and acceleration phase of development (Hekkert *et al.*, 2011).

Step 4 identifies the root cause of functions that are acting as hindrances and obstacles within the system, limiting the growth and proper development and the diffusion of the technology (Hekkert *et al.*, 2011). The system functions can be mapped graphically, as indicated by the example of the Ethiopian PV TIS study in Figure 3.4 (Kebede and Mitsufuji, 2017). Problem areas can easily be identified through the mapping of the system functions.

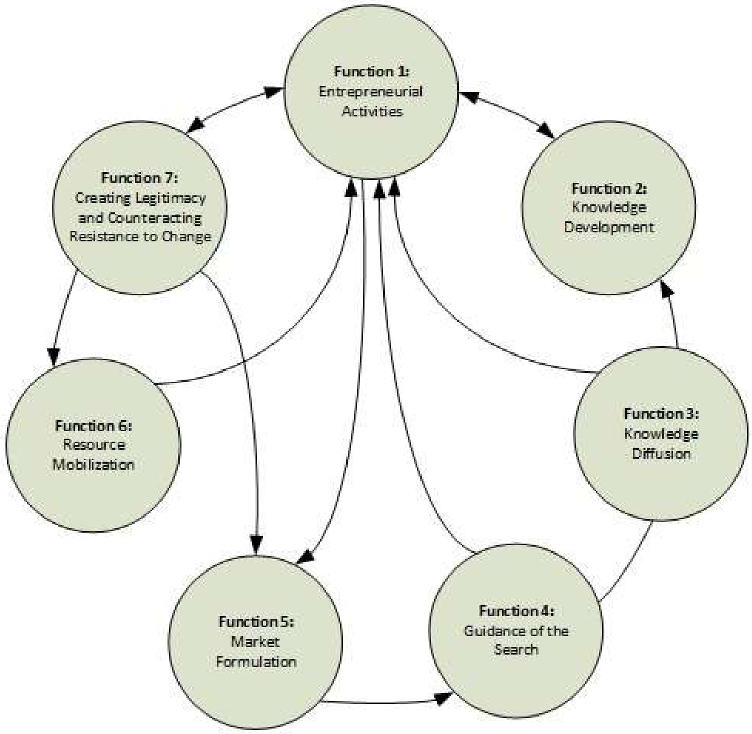


Figure 3.3: Functional pattern of the system functions

Source: (Hekkert *et al.*, 2011)

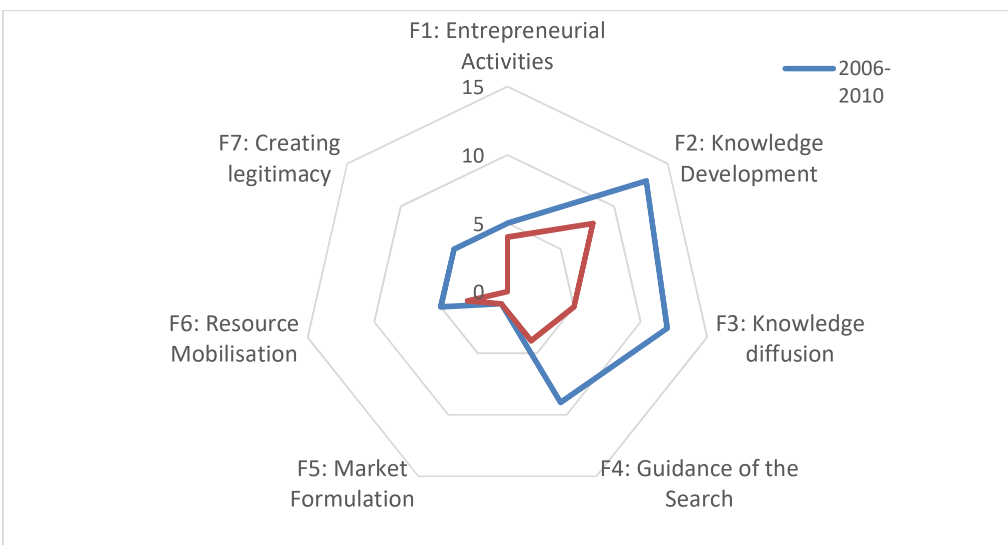


Figure 3.4: Ethiopian study PV TIS function dynamics

Source: (Kebede and Mitsufuji, 2017)

Step 5 After problems in the system have been narrowed down and identified, improvements can be made through policies to remove the barriers, as indicated in Step 4.

4. Research Design and Methodology

4.1. Introduction

The TIS conceptual model proposed by Heckert *et al.,* described in Chapter 3, was used as a framework in evaluating the maturity of the structural components and system functions of the South African PV TIS. The purpose of the study was to identify where barriers, prominent factors and variables that form boundaries to diffusion of the PV TIS was located. This chapter deals with the research method and research design that was used in this study, followed by a discussion on the collection and analysis of data.

4.2. Research Strategy and Design

The study was aimed at the assessment of the PV industry in South Africa to understand the maturity of the system and to find barriers that limit diffusion. The only unit of analysis that could be used for the study was PV, therefore a case study research methodology was chosen to be applied to the context of the TIS framework. The type of case study and the research design selected were exploratory. Exploratory research is best suited to studies with a high level of uncertainty and limited available information. Exploratory case studies are well suited to research methods, especially for investigating 'how', 'what', 'why' and 'who' questions about a present/modern-day set of events over which the researcher has limited to no control (Yin, 2009), such as the research questions presented in Chapter 1 that was investigated by this study. Case studies are often criticised because experiments and research are frequently researcher-biased, therefore special care was taken to present evidence fairly and accurately (Yin, 2009).

The logics of the research was inductive reasoning to combine individual responses to reach general conclusions about the PV industry in South Africa. Secondary data was used to validate findings, therefore the purpose of the enquiry is characterised as exploratory research aimed at discovering barriers to diffusion in South Africa.

There are no formally defined measurements and processes to evaluate the key processes of the innovation systems. An appropriately scaled Likert scale was developed as measurement to measure the performance of the system functions. The purpose of indicators was to serve as a measurement to draw a comparison between the system functions to indicate which functions are lagging behind and caused barriers to diffusion of PV in South Africa.

4.3. Research Methodology and Analysis

The data gathering process was accomplished through a structured online survey to ensure that many of the actors involved in the PV industry from all over South Africa could participate in the study. The survey was structured in a specific manner to evaluate the respondents' view on the components and the system functions of the South African TIS. The objective of the survey was to get as many respondents as possible to fill in the questionnaire to enable the researcher to recognise certain patterns, tendencies and a general perception of the PV industry in South Africa. The data gathering process was conducted by contacting research institutes and PV companies (including suppliers, installers, researchers and experts in the PV field) and asking them to take part in the survey. Participation was voluntarily and was designed to consume as little time as possible. Some of the questions were structured to be open-ended responses, whereas others were multiple choice questions requiring pre-defined Likert scale answers. Respondents could provide their own viewpoints and answers to any of the questions, ensuring that the data were not biased on preconceived perceptions of the preconceived limitations of the researcher.

Data analysis was presented as statistical tables describing the different tendencies in a specific performance. The performance of every function was evaluated by dividing the answers of the questionnaire into quantifiable Likert scale divisions. The overall performance of the system was determined by comparing the rating of the different functions to one another. The questionnaire was structured in a strategic way to evaluate the respondent's views of specific functions within the TIS without them being aware of the targeted function. The results of the different functions was evaluated by:

1. Translating each Likert scale value to a numerical number,
2. Calculating the average result of each survey question as a percentage,
3. Calculating the analysis result of each function by taking the average of all the questions related to the specific functions, and
4. Mapping the seven system functions graphically on a single graph.

The primary data collected from the surveys was validated by supplementing and supporting the primary research results with secondary data if necessary. Gaps in the survey was addressed by open-ended questions and, when necessary, secondary data from articles, statistics and studies found on the internet. Validity was established through correlation of selected answers between different respondents and secondary data. From the results gathered, the extent of development of the TIS functions was evaluated. The outcome of the research results indicated which system functions had to be improved through supportive policies, to remove the barriers of diffusion of the PV TIS.

Table 4.1 indicates the consistency matrix of the research by stating the research question, the relevant literature required for the research, the research design that was followed and the way in which data were collected and analysed.

Table 4.1: Consistency Matrix

Research Question	Research Design	Data Collection	Data Analysis
1) To what extent has the PV TIS been developed in South Africa?	Exploratory case study with research questions focusing primarily on the indicators of each TIS function.	Primary data collection from questionnaires supplemented by secondary data if necessary.	Statistical data analysis based on the Likert scale values translated into averages.
2) What are the present weaknesses of the TIS, particularly regarding knowledge development and diffusion?	Exploratory case study with research questions focusing primarily on each individual indicator.	Primary data collection from questionnaires supplemented by secondary data if necessary.	Statistical data analysis based on correlation, translated into Likert scale categories for comparison.
3) What are the barriers that inhibit further future development of PV in South Africa?	Exploratory case study with primary focus on missing elements pertaining to future development of the South African PV TIS.	Primary data collection from questionnaires supplemented by secondary data if necessary.	Statistical data analysis based on correlation, translated into Likert scale categories for comparison.
4) What policies need to be implemented to strengthen the PV TIS in South Africa?	Based on the evaluation of the PV TIS, inductive reasoning will be used to propose policies that could strengthen the South African PV TIS.	Primary data collection from questionnaires supplemented by secondary data if necessary.	Content analysis based on evidence found in the replies to the preceding questions.

Relevant Literature: Hekkert et al., (2007); Guo et al. (2009); Hekkert et al. (2011); Kebede and Mitsufuji (2017)

Table 4.2 indicates the survey questions that were developed for the purpose of this study in evaluating the functions and components of the PV TIS in the context of South Africa.

Table 4.2: Research question design for the evaluation of system functions

Function	Question	Indicator
F1: Entrepre-neurial Activities	Who are the most significant actors in the PV industry in SA?	Actors, organisations and institutions making the biggest contribution to the development of the PV TIS in SA.
	Are there enough actors in the PV industry in SA?	Development of the TIS is strongly dependent on the interaction between different actors.
	Where do most PV technologies in SA come from?	Establish whether technology is being imported or developed and manufactured locally.
	To what extent is PV being developed/innovated in SA?	Establish the level of innovation that takes place.
F2: Knowledge Develop-ment	Which knowledge institutions/ organisations produce most knowledge about PV in SA?	Establish which institutions provide PV knowledge.
	Have any PV lessons been learnt from the failures and success of international countries?	Does the South African industry learn from the history of the successes and mistakes of other countries?
	How able is the South African PV industry to learn from external knowledge?	Determine the capability of South Africans to utilise and absorb external knowledge.
	What methods of information feedback from the PV industry are currently in place?	Positive feedback between components contributes to accelerated development of the TIS.
	How would you describe the current absorption capacity of SA in terms of PV technologies?	How well are technologies transferred and implemented in SA?
	How much is your firm investing in R&D in the PV industry?	Indication of how much R&D takes place in firms
	How much knowledge about PV is being created in SA in terms of the number of patents patented?	The number of patents patented gives an indication of the maturity of a TIS.
F3:	How much learning takes place in	Are the education needs met and

Function	Question	Indicator
Knowledge Exchange and Diffusion	the PV work environment?	enough knowledge created and transferred?
	Is collaboration or knowledge exchange taking place between different PV organisations?	Establish if knowledge exchange and diffusion take place.
	How does knowledge transfer take place from knowledge institutes to the market and production (between science and industry)?	Establish how knowledge is transferred.
F4: Guidance of the Search	Is there a clear vision of how actors want the PV industry to develop?	Is there a clear goal of what needs to be established and where the PV TIS should be heading?
	What role does the government play in the PV industry?	What effect does the government have on the PV TIS?
	Have clear and reliable policy goals been established?	Are there policies to guide the TIS in order to reach the goals?
F5: Market Formation	What is the biggest barrier to the development of the PV TIS in SA?	Establish what prohibits the diffusion of PV in SA.
	5.2) Is there enough market opportunity for a PV TIS in SA?	Establish whether there is an actual market.
F6: Resource Mobilisation	How well is PV infrastructure developed?	Are all the systems in place?
	Is there any local or international funding available for the PV industry in SA?	Establish if enough opportunities are available for funding.
	Are there any investment opportunities for the PV industry in SA?	Establish the available funding opportunities.
	Has your company undertaken any projects for which specific grants were issued?	
F7: Creating Legitimacy and Counter-acting Resistance	What is the effect of media and lobbying groups on the PV industry? For example: how did the media influence/form the opinion of the public on PV?	How is the industry influenced by persuasion by the media?
	What is the effect of lobbying by groups with strong economic and	What is the influence of groups with strong economic and political

Function	Question	Indicator
to Change	political weight on advocacy and legitimacy?	weight?
	How much resistance is experienced against new PV technology implementation?	Resistance to change is a naturally occurring aspect of any new technology.
Open-ended questions	What are external barriers that limit the growth of the PV industry in SA?	External barriers.
	What are external drivers that increase the growth of the PV industry in SA?	External drivers.
	What are internal barriers that limit the growth of the PV industry in SA?	Internal barriers.
	What are internal drivers that increase the growth of the PV industry in SA?	Internal drivers.
	How many PV research projects are currently undertaken in your company/institution?	Indicator of active research being done in the PV industry.

5. Results: Data Gathering and Analysis

5.1. Introduction

Out of over 100 individuals, companies and institutions that were approached, 22 participants completed the survey. The participants in the survey had completely different backgrounds and came from diverse locations; they were currently operating within the PV industry and/or had extensive knowledge about the PV industry. The respondents comprised research institutions, organisations, engineers, consultants, manufacturers and distributers. Only the most important data collected in the study are discussed in the sections that follow, followed by a comprehensive analysis and discussion of the results of each system function.

5.2. Results and Analysis

The most prominent results obtained from the survey were translated into tables and figures to indicate tendencies and patterns between system functions and componential structures of the South African PV TIS. Only the most relevant results for the study are depicted, portrayed in figures and tables in this section.

The results from the survey data are analysed and discussed in this section according to the TIS functional analysis discussed in Chapters 3 and 4. The analysis used the Likert scale value of each answer and translated it into a numerical value to calculate the average result of all the survey questions. The average of each of the seven functions was calculated by calculating the average of all the indicators of the survey questions related to the specific function.

5.2.1. F1 - Entrepreneurial Activities

Results

Figure 5.1 indicates the respondents' view of the most significant actors contributing to the PV industry. According to the data gathered, 19 of the 22 participants regarded the private industry as the most significant actor in the PV industry. Knowledge institutes, local government, marketing and the public sector were expected to be the dominant actors in the PV industry, but according to the survey results they are the entities with the least impact. Knowledge institutes should generate new information, since without it innovation cannot occur (as discussed in chapter 2). Local government should promote the technology and its infrastructure with policies and incentives to drive and motivate the adoption of the technology. Marketing should promote the technology and communicate its potential benefits.

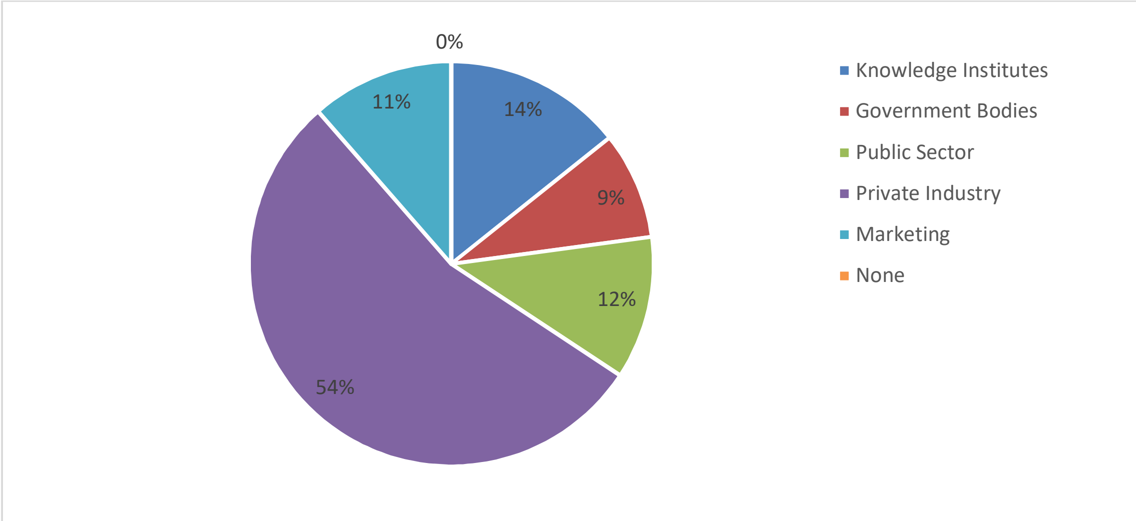


Figure 5.1: The most significant actors in the PV industry

Figure 5.2 indicates a combinational data plot indicating the source of the most dominant PV technologies and the extent to which PV is developed in South Africa. According to Figure 5.2, strong correlation indicates that PV technologies are predominantly imported from the international market. Figure 5.2 indicates the respondents' view on the extent to which PV in South Africa is innovated; strong correlation indicates that very little PV cell manufacturing is occurring in South Africa and that only PV cells are imported, which is then assembled into panels.

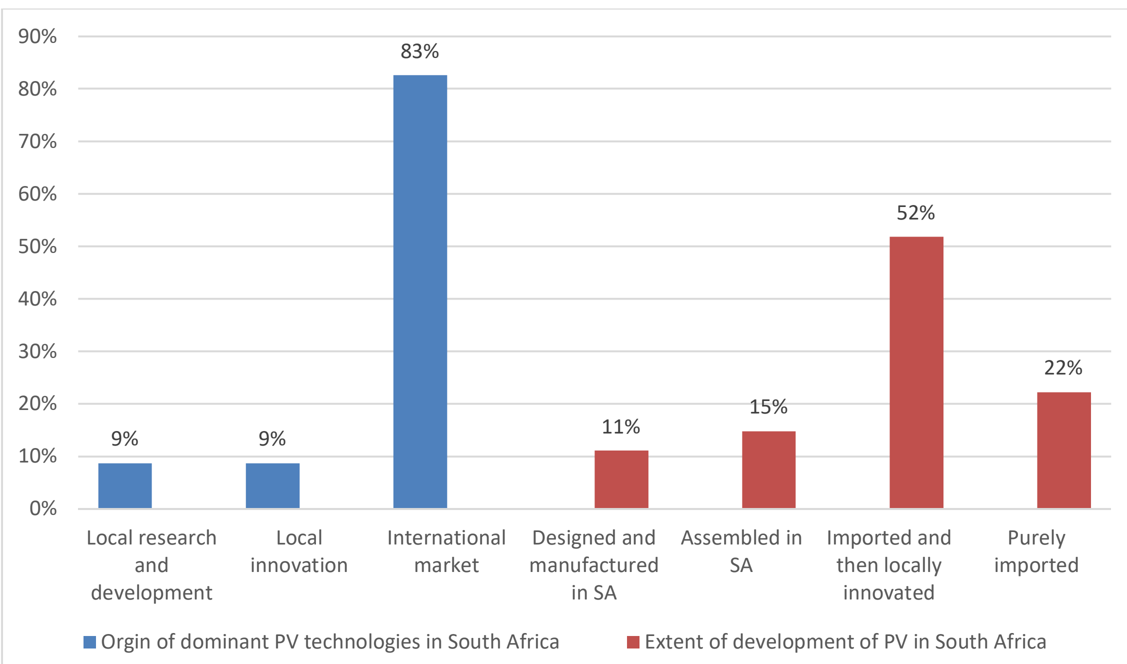


Figure 5.2: Extent of local PV technology development

Analysis

The entrepreneurial activities function contains elements of all the other functions, therefore the analysis also included elements relating to entrepreneurial activities from the other functions. The entrepreneurial activities function was evaluated by calculating the average of the following survey question results:

- The number of actors in the PV industry,
- The extent of PV development in South Africa,
- The percentage of firms' revenue invested in R&D,
- The number of patents patented with regard to PV,
- The number of research projects in organisations, and
- The clarity of the vision the actors had in respect of shaping and steering the PV industry into a specific direction.

Table 5.1 indicates the analysis performed to evaluate the entrepreneurial activities function. The entrepreneurial activities function obtained an overall average result of 42%. The low score of the entrepreneurial activities function analysis result is indicative of a problem(s) occurring in the other functions.

Table 5.1: Entrepreneurial activities analysis

Research Question	Grading [5]	Grading [4]	Grading [3]	Grading [2]	Grading [1]	Grading [0]	Avg.	[%]
	>20%	16%-20%	11%-15%	6%-10%	1%-5%	None		
Percentage of firm's revenue invested in R&D.	2	1	0	1	5	11	**1,1**	**21%**
		Sufficient	Moderate	Neutral	Insufficient	None		
Number of actors in the PV industry in SA.		2	8	2	10	0	**2,1**	**52%**
			Purely local	Assem-bled SA	Imported & innovated	Purely Imported		
Extent of development of PV in SA.			6	14	3	4	**1,8**	**61%**
			Sufficient	Moderate	Insufficient	None		
Number of patents patented with regard to PV.			0	1	16	3	**0,9**	**30%**
			Sufficient	Moderate	Insufficient	None		
Vision of how actors want to develop and shape the PV industry.			1	13	7	1	**1,6**	**55%**
				> 4	1-4	None		
Number of PV research projects in organisations.				3	7	11	**0,6**	**31%**
Entrepreneurial activities analysis result								**42%**

5.2.2. F2 – Knowledge Development

Results

The results in Figure 5.2 in the previous section confirm the theoretical research statement that South Africa is a technology-receiving country with regard to PV, therefore the focus for the evaluation of the knowledge development function was placed predominantly on the mechanisms of learning.

Table 5.2 indicates the survey results of the origin and sources of knowledge contributing most information to the development of the PV industry. According to Table 5.2, 13 of 21 respondents selected knowledge institutions as the most dominant source of information in the PV industry. Representative and regulatory organisations and small, medium and large enterprises are the second biggest contributing source of knowledge in the PV industry.

Table 5.2: Sources of knowledge development in the PV industry

Entity	Respondents [%]
Knowledge institutions	44,8%
Representative and regulatory organisations	24,1%
Small, medium and large enterprises	20,7%
Media	3,4%
International enterprises	3,4%
Private industry	3,4%

Table 5.3 indicates the ability of the South African PV industry to utilise and learn from knowledge developed particular their organisations. The average of Table 5.3 indicates that South Africans have an intermediate to good ability to learn from knowledge and information that can be applied to their organisations. It is expected that the South African PV industry should have a good ability to utilise and learn from external knowledge, because PV technologies are dominantly imported from other countries. Information must be transferred from other countries to enable South Africans to adapt, innovate and integrate the technologies into the electrical infrastructure.

Table 5.3:Ability to utilise and learn from externally developed knowledge

Likert scale	Respondents [%]
Very good	9,10%
Good	31,80%
Intermediate	36,40%
Neutral	9,10%
Weak	13,60%
Very weak	0,00%

Analysis

The analysis of the knowledge development function included all the mechanisms of learning results obtained in the survey. South Africa being a technology-receiving country with regard to PV means that the focus of knowledge development would be on assisting entrepreneurs to innovate existing PV technologies into the electrical infrastructure. The knowledge development function was evaluated on the following:

- The ability to learn from the failures and success of other countries,
- The ability to utilise and learn from knowledge developed outside the organisation,
- The South African absorption capacity in terms of PV technologies,
- The number of patents patented in the PV industry,
- The number of research projects occurring in organisations, and
- The percentage of the firm's revenue invested back into R&D.

Table 5.4 indicates the analysis performed to evaluate the knowledge development function. The knowledge development function obtained an overall average result of 42%. The low score obtained for the analysis of the knowledge development function indicates insufficient knowledge that is available and being generated for the PV industry.

Table 5.4: Knowledge development analysis

Research Question	Grading [6]	Grading [5]	Grading [4]	Grading [3]	Grading [2]	Grading [1]	Grading [0]	Avg.	[%]
	Excellent	Good	Intermediate	Neutral	Weak	Very weak	None		
PV technology absorption capacity	0	5	5	2	10	0	0	**3,2**	**54%**
		>20%	16-20%	11-15%	6%-10%	1%-5%	None		
Amount of firms' revenue invested in R&D		2	1	0	1	5	11	**1,1**	**21%**
		Excellent	Good	Inter-mediate	Neutral	Weak	None		
Utilising and learning from externally developed knowledge		2	7	8	2	3	0	**3,1**	**63%**
				Major	Moderate	Minor	None		
Learning from failure and success of other countries				2	10	8	2	**1,5**	**52%**
				Sufficient	Moderate	Insufficient	None		
Number of patents patented with regard to PV in SA				0	1	16	3	**0,9**	**30%**
					> 4	1 - 4	None		
Number of active PV research projects					3	7	11	**0,6**	**31%**
Knowledge development analysis result									**42%**

5.2.3. F3 – Knowledge Exchange and Diffusion

Results

Figure 5.3 indicates a plot of two series of data indicating the level of learning occurring in the PV industry and the amount of collaboration between firms. According to the results reflected in Figure 5.3, an insufficient to moderate amount of learning occurs through learning by interaction and learning by doing. Figure 5.3 indicates that insufficient to moderate collaboration occurs between organisations in the PV industry.

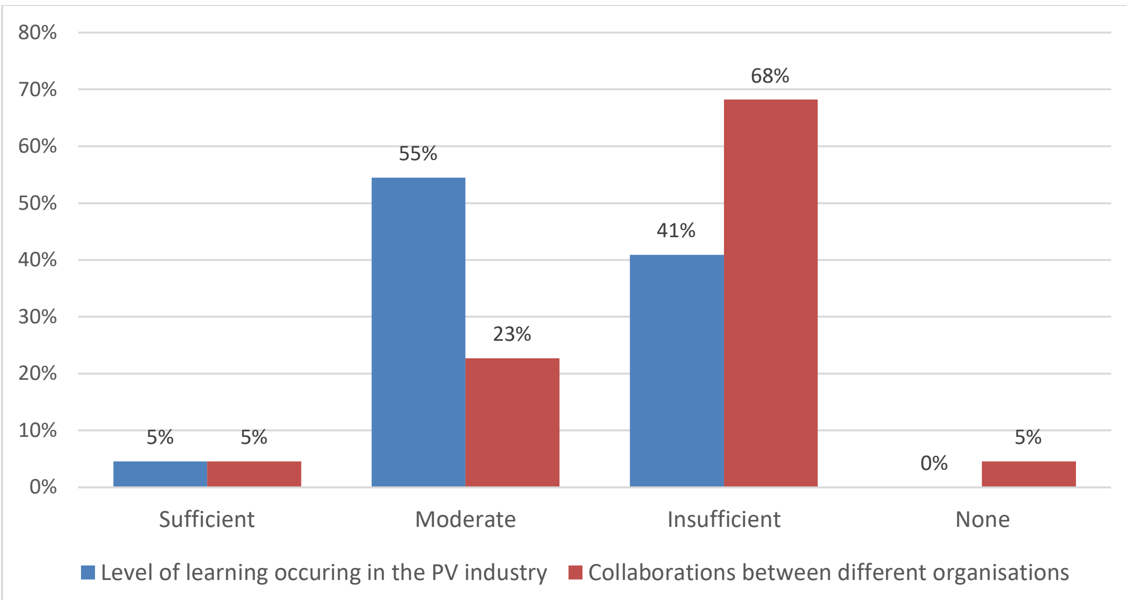


Figure 5.3: Knowledge transfer

Table 5.5 indicates different sources of information from where knowledge is transferred to indicate the type of networks established within the PV industry. According to Table 5.5, all the crucial sources of knowledge necessary for knowledge exchange and knowledge diffusion networks were mentioned by the respondents. Combining the results obtained from Figure 5.3 and Table 5.5, the type of networks available for knowledge transfer could be regarded as sufficient, but the intensity and amount of knowledge being transferred could be regarded as insufficient.

Table 5.5: Sources of information in the PV industry

Institutions	Collaboration
Organisations	Practical applications
Training courses	Research and development
Exhibitions	Patents
Events	New product launches
Organisation memberships	Marketing
Books	Videos
Internet	Networking
Publications	Regulatory organisations
Representative organisations	Intellectual property

Analysis

The analysis of the knowledge exchange and diffusion function included all the survey results indicating the extent of knowledge being shared through networks in the PV industry. The knowledge exchange and diffusion function was evaluated on the following:

- The amount of learning through interaction and learning by doing occurring in the PV industry, and
- The extent to which knowledge is shared between different organisations and institutions in the PV industry.

Table 5.6 indicates the analysis performed to evaluate the knowledge exchange and diffusion function. The knowledge exchange and diffusion function obtained an overall average result of 49%, indicating a neutral amount of knowledge being exchanged between organisations and institutions in the PV industry.

Table 5.6: Knowledge diffusion analysis

Research Question	Grading [3]	Grading [2]	Grading [1]	Grading [0]	Avg.	[%]
	Sufficient	**Moderate**	**Insufficient**	**None**		
Amount of learning occurring in the PV work environment	1	12	9	0	1,6	**55%**
	Sufficient	**Moderate**	**Insufficient**	**None**		
Knowledge exchange between PV organisations	1	5	15	1	1,3	**42%**
Knowledge diffusion analysis result						**49%**

5.2.4. F4 – Guidance of the Search

Results

Figure 5.4 displays three data plots that indicate the rating on the clarity and vision of the direction in which the actors would like to shape the PV industry, the impact local government makes by contributing to the development of the PV industry and the clarity and reliability of the policy goals established for the PV industry. According to the results obtained in Figure 5.4, the average clarity and direction of the development goal of the PV industry is insufficient to moderate. The average result of the role local government plays in the development of the PV industry was calculated as insufficient to moderate. One of the respondents indicated that the role of government was superfluous, indicating too much involvement in the PV industry. The clarity and reliability of policy goals established were clearly indicated as being insufficiently to moderately defined. According to Figure 5.4, the role of local government and the clarity and reliability of PV policy were clearly found to be insufficient.

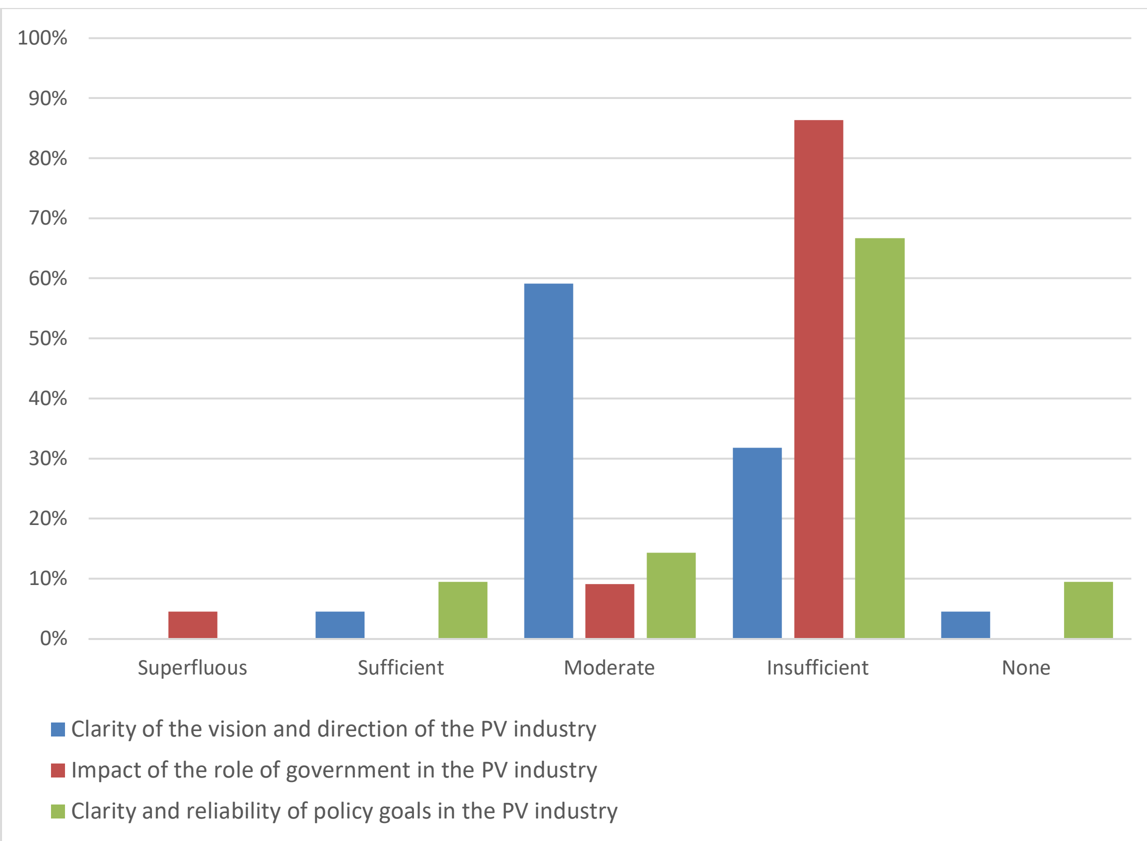


Figure 5.4: Guidance of the search

Analysis

The analysis of the guidance of the search function included all the survey results indicating the external influences that shape and steer the PV industry in a specific direction. The guidance of the search function was evaluated on the following:

- The clarity and vision how the actors want to shape the PV industry,
- The impact local government has on the development of the PV industry, and
- The clarity and reliability of policy goals in the PV industry.

Table 5.7 indicates the analysis performed to evaluate the guidance of the search function. The guidance of the search function obtained an overall average result of 49%, indicating a neutral influence of the actors to shape and steer the PV industry in a direction in order to reach specified goals over a period of time.

Table 5.7: Guidance of the search evaluation

Research Question	Grading [4]	Grading [3]	Grading [2]	Grading [1]	Grading [0]	Avg.	[%]
	Sufficient	**Moderate**	**In-sufficient**	**None**	**Super-fluous**		
The role of local government in the PV industry	1	0	2	19	0	2,1	**52%**
		Sufficient	**Moderate**	**In-sufficient**	**None**		
Clarity on the vision and direction actors have in the industry.		1	13	7	1	1,6	**55%**
		Sufficient	**Moderate**	**In-sufficient**	**None**		
Clarity and reliability of PV policy goals established.		2	3	14	2	1,2	**41%**
Guidance of the search analysis result							**49%**

5.2.5. F5 – Market Formation

Results

Figure 5.5 indicates a two-series data plot of the rating on the market opportunities in the PV industry and the extent of development of PV infrastructure in South Africa. According to Figure 5.5, there are strong indications of a moderate number of opportunities in the PV industry and the extent to which the PV infrastructure is developed. The results in Figure 5.5 indicate that the PV infrastructure is moderately to sufficiently developed, therefore there is moderate to sufficient market opportunities available in the PV industry and there is sufficient interest in PV technologies in South Africa.

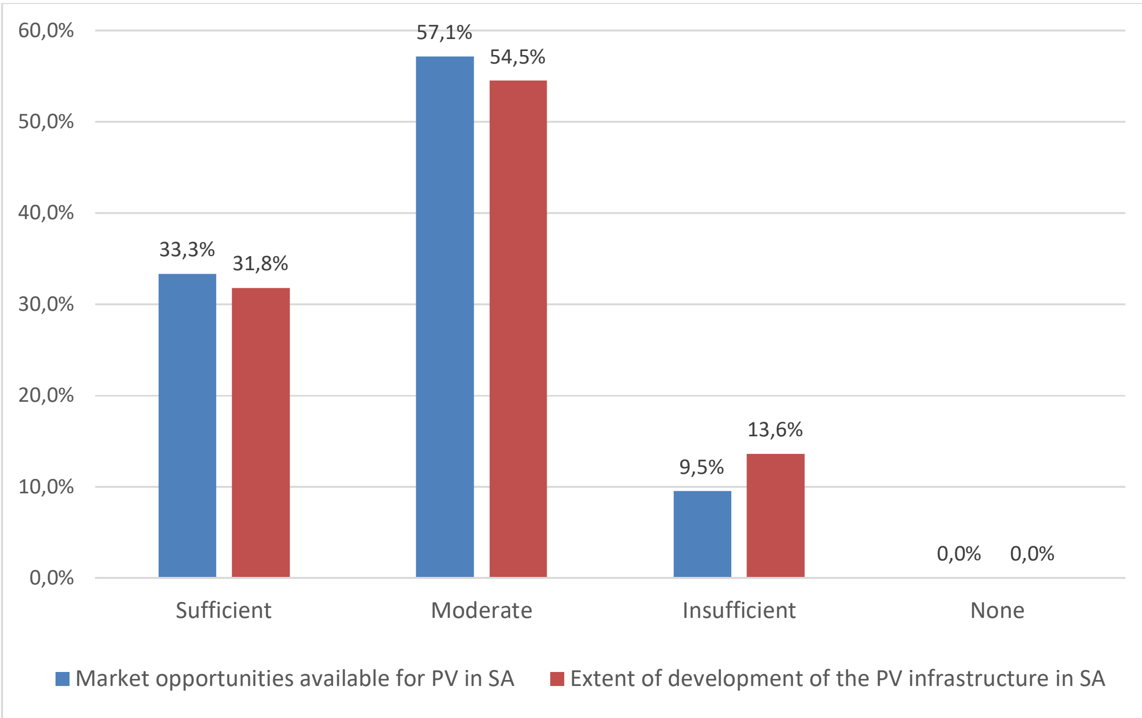


Figure 5.5: Extent of development of PV infrastructure and market opportunities

<u>Analysis</u>

The analysis of the market formation function included all the survey results indicating the available market opportunities in the PV industry. The guidance of the search function was evaluated on the following criteria:

- The number of market opportunities in the PV industry,
- The extent to which the PV infrastructure is developed,
- The availability of local and international funding opportunities,
- The number of PV investment opportunities, and
- An indication of involvement in projects where specific grants were issued.

Table 5.8 indicates the analysis performed to evaluate the market formation function. The market formation function obtained an overall average result of 56%, indicating slightly better than neutral market formation strategies in the PV industry.

Table 5.8: Market formation evaluation

Research Question	Grading [3]	Grading [2]	Grading [1]	Grading [0]	Avg.	[%]
	Sufficient	**Moderate**	**Insufficient**	**None**		
The number of market opportunities in the PV industry.	7	12	2	0	2,2	**75%**
	Sufficient	**Moderate**	**Insufficient**	**None**		
The extent of development of PV infrastructure.	7	12	3	0	2,2	**73%**
	Sufficient	**Moderate**	**Insufficient**	**None**		
Availability of local and international funding for the PV industry in SA.	1	9	11	1	1,5	**49%**
		Yes	**Limited**	**No**		
The number of PV investment opportunities in SA.		13	6	1	1,6	**80%**
			Yes	**No**		
PV projects where specific grants were issued.			1	18	0,1	**5%**
Market formation analysis result						**56%**

5.2.6. F6 – Resource Mobilisation

Results

Figure 5.6 indicates the respondents' view on the biggest barriers that limit the growth of the PV industry in South Africa. According to the results indicated in Figure 5.6, funding was indicated by 18 out of 22 respondents as the most critical issue that limits the development of the PV industry.

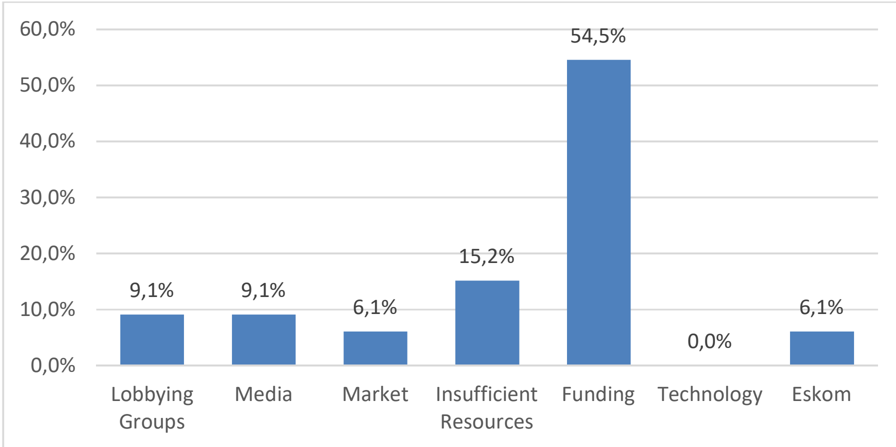


Figure 5.6: Biggest barriers to the development of PV in South Africa

Analysis

The analysis of the resource mobilisation function included all the survey results indicating resources being required for the development of the PV industry. The resource mobilisation function was evaluated on the following criteria:

- The number of actors,
- The availability of local and international funding opportunities,
- The level of collaboration between firms and institutions,
- The extent to which the PV industry is developed,
- The level of learning occurring in the PV work environment, and
- Investment opportunities in the PV industry

Table 5.9 indicates the analysis performed to evaluate the resource mobilisation function. The resource mobilisation function obtained an overall average result of 58%.

Table 5.9: Resource mobilisation evaluation

Research Question	Grading [4]	Grading [3]	Grading [2]	Grading [1]	Grading [0]	Avg.	[%]
	Sufficient	**Moderate**	**Neutral**	**Insufficient**	**None**		
Number of actors in the PV industry.	2	8	2	10	0	2,1	**52%**
		Sufficient	**Moderate**	**Insufficient**	**None**		
Availability of funding in the PV industry.		1	9	11	1	1,5	**49%**
		Sufficient	**Moderate**	**Insufficient**	**None**		
Collaboration and knowledge exchange between organisations.		1	5	15	1	1,3	**42%**
		Sufficient	**Moderate**	**Insufficient**	**None**		
Extent of development of PV infrastructure.		7	12	3	0	2,2	**73%**
		Sufficient	**Moderate**	**Insufficient**	**None**		
Amount of learning occurring in the PV work environment.		1	12	9	0	1,6	**55%**
			Yes	**Limited**	**None**		
Investment opportunities for the PV industry in SA.			13	6	1	1,6	**80%**
Resource mobilisation analysis result							**58%**

5.2.7. F7 – Creating Legitimacy and Counteracting Resistance to Change

Results

Figure 5.7 indicates the processed results on the impact of media and lobbying groups on the PV industry in South Africa. The individual answers were translated into a quantifiable Likert scale. Calculating the average of the Likert scale values in Figure 5.7 indicates that media and lobbying groups have a limited to neutral impact on the PV industry by shaping and influencing public opinion on PV.

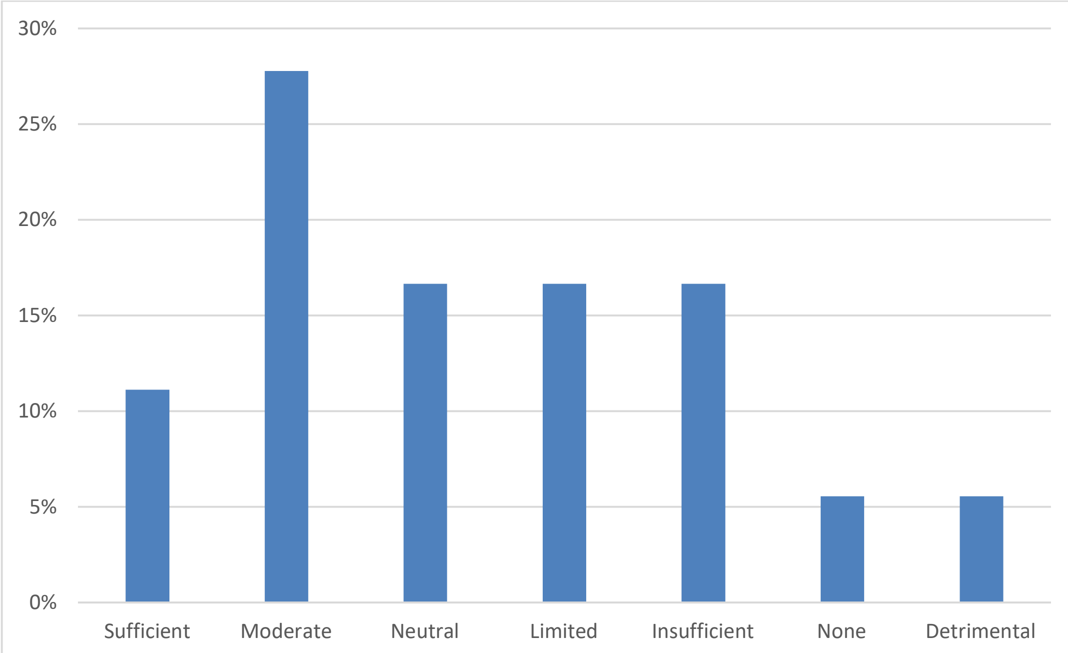


Figure 5.7: Impact of media and lobbying groups on the PV industry in SA

Analysis

The analysis of the function of creating legitimacy and counteracting resistance to change included all the survey results indicating resources promoting PV technology and counteracting opposition to transitioning towards PV. The function of creating legitimacy and counteracting resistance to change was evaluated on the following criteria:

- The effect media and lobbying groups have on the adoption of PV technology,
- Resistance and opposition to PV in South Africa,
- The vision of how the actors want to shape the PV industry,
- Fulfilment of the role of local government in the PV industry, and
- Clarity and reliability of the establishment of PV policy goals.

Table 5.9 indicates the analysis performed to evaluate the resource mobilisation function. The resource mobilisation function obtained an overall average result of 58%.

Table 5.10: Creating legitimacy and counteracting resistance to change

Research Question	Grading [6]	Grading [5]	Grading [4]	Grading [3]	Grading [2]	Grading [1]	Grading [0]	Avg.	[%]
	Sufficient	**Moderate**	**Neutral**	**Limited**	**Insufficient**	**None**	**Detrimental**		
Effect of media and lobbying groups on the PV industry in SA.	2	5	3	3	3	1	1	3,6	**60%**
			None	**slight**	**Neutral**	**Moderate**	**Significant**		
Resistance to PV technology in SA.			0	4	3	5	4	1,4	**36%**
			Superfluous	**Sufficient**	**Moderate**	**Insufficient**	**None**		
Fulfilment of role the local government plays in the PV industry.			1	0	2	19	0	1,2	**31%**
				Sufficient	**Moderate**	**Insufficient**	**None**		
Vision of how actors want to develop and shape the PV industry.				1	13	7	1	1,6	**55%**
				Sufficient	**Moderate**	**Insufficient**	**None**		
Clarity and reliability of the PV policy goals established.				2	3	14	2	1,2	**41%**
Creating legitimacy and counteracting resistance to change analysis result									**45%**

5.3. Functional Analysis Summary of Results

Table 5.11 indicates a summary of the results obtained from functions 1 to 7 in sections 5.2. The overall results of Table 5.11 indicate serious problems in the functionality of the South African PV TIS. The market formation and resource mobilisation functions achieved the highest performance, with all the other functions achieving less than 50%. The overall average of the system functions is calculated to be less than 50%.

Table 5.11: Functional analysis summary of results

Function	Result
F1: Entrepreneurial activities	41,5%
F2: Knowledge development	41,7%
F3: Knowledge diffusion	48,5%
F4: Guidance of the search	49,4%
F5: Market formation	56,2%
F6: Resource mobilisation	58,4%
F7: Creating legitimacy and counteracting resistance to change	44,5%
Functional analysis average result	**48,6%**

5.4. Conclusion

The overall result of the seven PV TIS functions are a clear indication that the PV TIS requires serious attention before it can function properly. From the survey results the functions of the PV TIS are hampered most by the following factors:

- Entrepreneurial Activities
  - Poor investment in R&D,
  - Low number of research projects,
  - Improvement required for number of actors present in the PV industry,
  - Poor performance on number of patents patented for the PV industry,
  - Improvement required for the vision and direction of the PV industry.
- Knowledge development
  - Improvement required for technology absorption capacity,
  - Poor investment in R&D,
  - Improvement required in learning from lessons learned in other countries,
  - Poor performance on number of patents patented for the PV industry,
  - Low number of research projects.

- Knowledge diffusion
    - Improvement required for the level of learning in the PV work environment, and
    - Poor knowledge exchange between actors.
- Guidance of the search
    - Improvement required in role of local government,
    - Poor knowledge exchange between actors,
    - Improvement required for the vision and direction, and
    - Poor establishment of PV policies.
- Market formation
    - Improvement required for funding, and
    - Poor presence of favouring policies such as grants and tax incentives.
- Resource mobilisation
    - Improvement required on number of actors,
    - Improvement required for funding, and
    - Poor collaboration between actors
    - Improvement required for the level of learning and skills being created.
- Creating legitimacy and counteracting resistance to change
    - Poor effect of advocating PV and counteracting resistance,
    - Poor influence of the role of local government,
    - Improvement required for vision of PV industry, and
    - Poor establishment of PV policies and goals.

6. Discussion of Results

This section provides a further discussion of the results obtained in the survey and conclusions reached, as portrayed in Chapter 5.

6.1. System Structural Components

The structural component analysis was briefly discussed according to the guideline provided in Table 3.1. The system structural components overlap with the results provided in section 6.2.

6.1.1. Actors

The actors in the PV industry involve all the entities directly or indirectly contributing to the development, growth and utilisation of the technology.

Actors

The rating on the number of actors present in the PV industry is illustrated in Table 5.1, indicating that the rating on the number of actors is neutral to moderate and more actors need to be present in the industry.

Market Demand

According to the survey results in Table 5.8, a moderate to sufficient number of market opportunities are available in the PV industry. The increase in market demand was caused by the realisation of the effect of carbon dioxide emissions on global warming, the push to generate power from greener sources and the recent interruptions in the supply of electrical power. South Africa experiences some degree of resistance against PV, as indicated by one of the respondents who said that there is “too much drive for coal, benefits of solar not communicated” effectively in South Africa.

Educational needs

According to Table 5.5, numerous sources of information are available in the PV industry. According to Table 5.6, an insufficient to moderate amount of learning occurs in the PV industry, especially when knowledge developed by institutions is retained for their own advantage. One of the respondents indicated that there is “lack of knowledge, research and development in SA” and that more free information has to be broadcast. Another respondent indicated that there is “lack of skilled employees” in the PV industry.

6.1.2. Institutions

The institutions in the PV industry involve the policies and regulations that are established to influenced and that is enforced by regulatory bodies and authorities.

Policies and Regulations

The comments made by various respondents indicate “lack of technology standardisation”, “regulations” being a barrier to the development of PV and the need to “shorten the time span on concept moving to legislation.” The results in Table 5.8 indicate that very few grants and tax incentives are available to the PV industry in South Africa.

Collaboration

The amount of knowledge transfer occurring in the PV industry was calculated to be insufficient to moderate, according to Figure 5.3. The respondent made some comments on the intermediary organisation. One of the respondents indicated that knowledge transfer from knowledge institutes to the PV industry occured “through associations, memberships and mainly regulations carried out by municipalities.”

6.1.3. Networks

The networks and relationships in the PV industry that allow knowledge to be shared between different actors within the system fulfil a necessary condition for innovation. Table 5.5 indicates different sources of information available to the PV industry. These sources have to be accessed through certain networks. Table 5.6 indicates that knowledge exchange between different entities in the PV industry is insufficient to moderate, indicating that the establishment of networks between actors needs to be improved significantly.

6.1.4. Technological Factors

Technological factors in the PV industry refer to a specific technology in which the direction and trajectory are important for what it wishes to accomplish.

Direction and Trajectory

Clarity on the vision of the direction into which the actors in the PV industry would like to steer the technology was found to be insufficient to moderate, according to Figure 5.4. The results indicate that clear policy goals and targets need to be established to guide the direction of the PV industry.

Technological factors

The only technological factor posing a threat to the development of the PV industry is low “energy output efficiency”, especially pertaining to PV systems where energy storage is required.

6.2. System Functions

6.2.1. F1 - Entrepreneurial Activities

China and India have clearly demonstrated the need for entrepreneurial activities and incremental knowledge development by gradually moving away from importing PV technologies to driving entrepreneurial activities and becoming the largest manufacturers of PV in the world (Edsand, 2016). Figure 5.2 indicates the source of dominant PV technologies in South Africa and the local innovating capability. According to Figure 5.2, most PV technologies are imported from the international market. This statement is verified by examining only two organisations capable of manufacturing PV cells in the South African territory (PTiP Innovations, 2014; ARTsolar, 2017). The South African PV industry currently lacks local capability and capacity to mass-produce PV cells in order to obtain technology advancement and become a competitor in the international market, while creating jobs and economic activity in a struggling economy. This is a current weakness in the system and could be a barrier inhibiting the future growth of the PV industry in South Africa.

Figure 5.1 indicates that the private industry was designated as the most significant actor contributing to the development of the PV TIS by the majority of respondents. One might expect the local government to be one of the most important actors in the system in order to steer the development of the technology in a particular direction, enhance the technology through favourable policies and allocate resources to support the intended infrastructure. The public sector, marketing and research institutes are also expected to make a significant contribution to the PV industry, by promoting the technology and driving its adoption and diffusion (Lundvall, 2007). Figure 5.1 provides proof that the presence and influence of actors in terms of marketing, knowledge institutes, government and the public sector are almost universally unsatisfactory. This is causing a barrier to the current and future development of the PV industry because it is more difficult for individuals and small companies to exert a significant influence on the PV industry, in view of the limited availability of resources.

According to the survey analysis results in Table 5.1, the entrepreneurial activities function obtained a result of 42%, indicating a drastic need for improvement. According to the discussion in Chapter 2, the poor performance of entrepreneurial activities is indicative of problems occurring in the other functions. This was confirmed by an analysis of the six other functions. The poor results of the entrepreneurial activities function are due to the low re-investment of firms' revenue in R&D, an insufficient number of patents patented in the PV industry and the low number of research projects in organisations. All these factors are related to taking advantage of new and existing information and translating it into business activities and innovation that form a critical part of entrepreneurial activities (Hekkert *et al.*, 2007).

6.2.2. F2 – Knowledge Development

Knowledge in a modern economy can be regarded as the most fundamental resource, whereas learning can be regarded as the most important process (Lundvall, 2007). The competencies of organisations and actors can be enhanced through learning; one way in which knowledge can be increased is through collaboration and interaction with other actors and organisations in the PV industry, resulting in new competencies and skills being developed, ultimately leading to new innovations (Lundvall, 2007). The different sources of knowledge are important for the analysis of a TIS to rate the quality of the resources and the entities/institutions forming part thereof. The different sources of knowledge in the PV industry are indicated in Table 5.5 and the list seems to be satisfactory, without any key contributors being left out. Unfortunately, Table 5.5 does not indicate the level of contribution of each source of knowledge.

Table 5.2 indicates that knowledge institutes are the most dominant source of information in the PV industry, followed by representative and regulatory organisations and small, medium and large enterprises. The contribution of knowledge through media, international resources and the private industry is unexpectedly low, indicating limitations existing in the mechanisms of learning and the way learning occurs in the PV industry. The media are an important source of knowledge because of the influence they have on the public and the way new market entrants learn about technology and the benefits it can provide. This statement is supported by respondents' remarks about PV education, indicating that a section of the public in South Africa "still view it is an economically inefficient technology that requires more development before being viable as a suitable energy supply system" and that it is "probably cheaper to rely on coal based energy generation." These statements are true to a certain extent, but do not consider that improvement in adoption of PV would drive local business activity, knowledge development, innovation, improved technology efficiency and lower prices. One respondent indicated that "not enough information [was] given to the public" and another that the PV industry suffered to a certain degree owing to "bad quality work by under-qualified/inexperienced businesses". An even greater attempt will have to be made to develop knowledge specifically focusing on training small businesses and information communicating the benefits of PV to the public.

International sources of information are important because PV technologies are dominantly sourced from the international market, thus emphasising the importance of learning from the failures, success and lessons learned from other countries to ensure similar mistakes are not made. The survey results indicated that South Africa learnt minor to moderate lessons from other countries, confirming that insufficient information had been learned from other countries. This is both a present and future barrier that inhibits the development of the PV industry.

The absorption capacity of developing countries is extremely relevant because technology transfer would be common practice for a country to be able to adopt technology (Edsand, 2016). Knowledge development could also be measured by measuring the absorption capacity through evaluating the level of education and training related to the technology, and measuring the ability of institutions and organisations to receive, learn and implement the technology (Edsand, 2016). According to Table 5.3, South Africans have an intermediate to good ability to learn from knowledge produced outside their organisations. The survey results indicate that South Africans have a neutral to intermediate ability and capability to adopt PV technologies. Innovation is related to the ability to develop, absorb and utilise knowledge. These results indicate that the PV industry requires some degree of improvement in the ability to absorb and utilise technologies, which is related to the level of education. This means that the level of education and training is currently a barrier in the PV industry.

Much of the knowledge about PV resides within leading countries around the world. If South Africa would like to implement PV on a large scale, the knowledge structure will have to change and learning will have to become critical. Knowledge development is important to enable a country to move away from purchasing technologies from other countries and rather build local capability and innovative capacity (Edsand, 2016). Some of the survey respondents commented on the availability of knowledge in the PV industry. Some of these comments were that “there isn't enough freely available information on PV with regards to the layman - this information needs to be broadcast more” and that there is currently a “lack of knowledge and research and development in SA.” The comments made by the respondents confirm the results provided in Table 5.4. Depending on the vision of the key stakeholders in the PV industry, organisations need to be able to access quality information to advance the development of the PV industry.

R&D expenditure could indicate that local knowledge and capabilities are being developed (Edsand, 2016). Investment in the PV industry is critical to ensure that new knowledge is developed. According to the respondents, 50% of their companies were not investing in R&D, whereas 23% of the companies were investing 1% - 5% of their turnover in R&D; only 18% of companies were investing more than 5% in new R&D. This statement was supported by one of the survey respondents who remarked that currently knowledge is created through “practical applications, not so much in R&D”. The low investment in R&D leads to results indicating an insufficient number of patents patented in the PV industry in Table 5.1. The low investment in R&D will be a major barrier inhibiting the future development of the PV industry.

According to the survey, knowledge and information about the PV industry market are obtained predominantly through PV installers, followed by customer and manufacturer feedback and the media. Feedback mechanisms are important to the PV industry to ensure user requirements and market demand are satisfied. The knowledge development function also evaluates the market readiness of the PV industry. Feedback from the public is also required to ensure that the PV industry is able to satisfy the needs of adopters, which could result in an increased adoption rate of PV.

According to the survey analysis results in Table 5.4, the knowledge development function obtained a result of 42%, indicating drastic need for improvement. The poor analysis result is mainly due to the weak investment by firms in R&D, insufficient number of patents patented and insufficient number of research projects currently undertaken in organisations.

6.2.3. F3 – Knowledge Diffusion

The interrelationships and interaction between firms, production, institutions and knowledge are extremely important; a fundamental characteristic of innovation is that it requires interaction (Lundvall, 2007). The important elements of knowledge, especially those related to the performance of the economy, are usually difficult to transfer because they are located in human capital and in core competencies of organisations (Lundvall, 2007). Relationships between people and organisations can be seen as a link or carrier that is a key element in knowledge transfer, from where new knowledge is created and diffused (Lundvall, 2007). Figure 5.3 indicates the level of learning in the PV work environment as insufficient to moderate, occurring through interaction and working on projects. Insufficient knowledge transfer between individuals acts as a hindrance obstructing learning in the PV industry, indicating a current and future barrier that limits the development of the PV industry.

The way in which formal institutions operate and interact with participants in the system is extremely important to ensure a clear understanding of the functionality of the system (Lundvall, 2007). Information developed in organisations that is not shared inside and/or outside the organisation makes a limited contribution to innovation and ultimately economic development (Lundvall, 2007). According to Figure 5.3, insufficient to moderate collaboration and knowledge exchange are occurring between actors in the PV industry. Some of the survey respondents made the following comments on knowledge transfer and diffusion between science and industry, indicating that some degree of knowledge transfer between organisations is occurring in the PV industry:

- “Institutions are trying hard to transfer knowledge through exhibitions and short course trainings offered by small companies and technology institutions.”
- Knowledge transfer occurs “through associations, memberships and mainly regulations carried out by municipalities, re-installations, accepted levels of installer quality and electrical wiring etc.”
- “Through collaboration in feasibility studies of large-scale projects or innovative solutions.”
- “Very little. Patents and NDAs imposed on private industry by knowledge organisations like CSIR on co-developed IP, generally falls short in instilling trust toward the latter.”
- “Very slow transfer with most institutions retaining knowledge for their own advantage.”

Remarkably, 23% of the respondents indicated that very little to limited knowledge is being transferred from research organisations to the PV industry. According to the respondents, knowledge is predominantly transferred through organisations and media. According to Figure 5.2 and Table 5.2, PV technologies are sourced predominantly from the international market with limited knowledge transfer occurring from the international market. According to the results of this study and the remarks made about knowledge transfer, inter-organisational networking and knowledge transfer act as a hindrance to both the current and future development of the PV industry.

The analysis on the extent of development of the knowledge diffusion function in Table 5.6 achieved a result of 49%, indicating that the level of knowledge sharing between actors is a hindrance to the development of PV TIS.

6.2.4. F4 – Guidance of the Search

Technology change is not a naturally occurring phenomenon; it has to be steered in a direction by the guidance of the search function. Guidance of the search function refers to goals, policies, promises, needs and expectations of the actors that the emerging technology should accomplish and clarify the goals and objectives indicating what needs to be accomplished by the emerging technology. The guidance of the search function must adhere to technology users’ specific needs and is therefore responsible for defining the visibility and clarification of the direction and goals to be reached by the TIS. Resources need to be allocated in order to be able to reach the specified goals set out for the system and enforced by the local government, the industry and market demand.

Feedback mechanisms from users to manufacturers and suppliers are critical to gain a competitive advantage and to accelerate the development of the system (Lundvall, 2007; Edsand, 2016). Interactive learning with users is critical for product development, production and innovation to establish a connection between production and sales (Lundvall, 2007).

According to Figure 5.4 and Table 5.7, the clarity of the vision of the PV industry, the impact of the local government and the clarity and reliability of the PV policy goals are rated insufficient to moderate. This statement is confirmed by some of the respondents indicating "lack of technology standardisation" and that authorities are "slow to implement PV legislation", which will have to be improved significantly. According to Table 5.7, the results of the enquiry into the clarity and reliability of policy goals for the PV industry are that these are rated insufficient to moderate. This statement is supported by one of the respondents who mentioned the "need to create and adopt engineering standardisation" for the PV industry. One of the barriers in the current PV industry is the lack of direction serving as guidance on what needs to be accomplished. Lack of clarity and direction would inhibit future development of the PV industry.

One of the respondents, commenting on the role of the local government, indicated that it was guilty of "too much involvement" and that "the market needs to be liberated", referring to the requirement to diversify energy producers. The statement is supported by various comments made in the survey results indicating that Eskom is currently a major obstacle to the PV industry. The future development of the PV industry depends on the influence of government, its expectations and its support for the technology.

The overall extent of development of the guidance of the search function was calculated to be 49%, indicating the need for major stakeholders and government in the PV industry to take leadership by setting targets to be achieved by the PV industry and to steer the industry into a specific direction. The low value result obtained by the knowledge development and diffusion function is due to insufficient fulfilment of the role of government, lack of clarity and direction.

6.2.5. F5 – Market Formation

An emerging technology can only be successful if there is sufficient market demand for the technology. Market demand could be initiated through favourable policies and incentives to generate positive outcomes for the adoption of the technology, such as tax exemptions or deductions through rebates and constructive policies and niche markets being created.

Barriers limiting the performance of the market formation function can easily be identified from Table 5.8. The market formation function is negatively influenced by the result indicating that only one out of 19 respondents was part of a project in the past for which a specific grant had been awarded (Table 5.8). The respondent taking part in the project indicated that the grant was awarded based on a “tax incentive via Section 12J”, indicating some level of favourable policies and incentives available to the PV industry. The market formation function is limited by the absence of favourable policies promoting the adoption of the technology.

According to Table 5.8 and Figure 5.6, funding remains one of the biggest challenges in the PV industry, especially pertaining to the “high initial cost of solar PV”, indicated by one of the respondents. Other respondents indicated that funding was “adequate but expensive” and that they “can't really think of any international companies that want to invest in the PV industry in SA.” The cost of PV in South Africa creates a major barrier to the adoption of PV.

One of the respondents indicated that local PV firms have to compete with “international corporations having the resources to win bigger projects and cutting out local stakeholders.” One of the barriers in the PV industry is that local organisations have to compete with international organisations, which eliminates small companies from receiving tenders. Another respondent mentioned constraints, including high rates of PV “import tax, little to no local manufacturers, long lead time of product, not a lot of product variation available.” The market formation function needs to be supported by key stakeholders and the local government to support local businesses while enhancing local economic activity. Government could improve the adoption rate of PV by relaxing PV importation tax or providing tax incentives until local manufacturing is fully implemented and functional.

Some of the respondents indicated that recent interest in the adoption of PV can be attributed to the fact that “most people react on other in the everlasting goal not to fall behind”, “ESKOM shortcoming shaped public opinion more than any media” and that “people are currently aware of the crisis that Eskom presents. Alternative energy is then expressed, and people seem pro-PV systems and other forms of sustainable energy.” These statements are supported by Figure 5.5, indicating that there are moderate to sufficient market opportunities available in the PV industry. The market opportunities result is further supported by a comment made by one of the respondents, indicating that “South Africa is still viewed as the gateway to Africa and has the potential to create large growth opportunities for global players in the energy market to move into Africa.”

The market formation function indicated in Table 5.8, achieved a rating of 56%. The market formation function was influenced negatively by the poor availability of grants and favourable policies promoting the adoption of PV and the availability of funding in the PV industry.

6.2.6. F6 – Resource Mobilisation

Resource mobilisation is responsible for the allocation of human capital, investors, material management and financial aid. It involves three types of resources: financial resources, human resources and physical resources. The resource mobilisation function is responsible for ensuring that the actors in the PV industry have access to sufficient resources that can help with the creation, development and implementation of the technology.

Technologies in most developing countries are usually funded and supported through grants, loans, financing, international investments and mitigation. Figure 5.6 indicates that funding is one of the biggest barriers to the development of the PV industry. This statement is supported by the result calculated in Table 5.4, indicating limited investment in R&D. One of the respondents commented that the "media can have a bigger effect, pushing government and the public sector to do more PV research and development." Another respondent indicated that there is "not sufficient support and subsidies compared to foreign governments."

One of the respondents mentioned "Financial constraints/investment, availability of resources, lack of skilled employees." This statement emphasises that all three indicators of the resource mobilisation function are barriers to the development of the PV industry. These statements are confirmend by the results calculated in Table 5.9, indicating the limited amount of collaboration and learning occurring in the PV industry.

The resource mobilisation function was evaluated by mapping the number of financial grants and loans companies and institutions used for R&D of the specific technology, funding available for the improvement of the technology, the number of educational programmes presented and launched in the specific technology field and adequate knowledge transferred to the required phase of development. The extent of development of the resource mobilisation function in Table 5.9 was calculated as 58%. The result of the resource mobilisation function was affected by the weak funding and limited collaboration occurring between organisations and institutions in the PV industry.

6.2.7. F7 – Creating Legitimacy and Counteracting Resistance to Change

The function related to creating legitimacy and counteracting resistance to change indicates the level of advocacy and support from local stakeholders in the PV industry. The creating legitimacy and counteracting resistance to change function was evaluated by identifying and evaluating the various stimulants responsible for lobbying and counteracting resistance to change

Some survey results were positive comments on the effect of the media and lobbying groups, indicating that the “media has positive outlook” on PV and that the “media has helped to create a positive image of PV projects in fixing some of the problems facing Eskom”, reflecting the view that “internationally it seems like a good opportunity” and that the “media suggests we need to move to green energy production.” Some of the respondents made negative comments, indicating that the influence of the media and lobbying groups is “very limited” and that they “are not doing enough” to advocate and promote PV, while providing “little overall coverage” of the technology. One of the respondents indicated that the effect of lobbying groups “can be detrimental as they are not inclusive but personal” and that in some cases the “socio-economic impact [is] not a major consideration or motivation.” While the responses in the survey results indicate mixed emotions about media and lobbying groups, comments point to the significant impact of the media on shaping the public’s view of PV. The remarks made by the respondents support the results obtained in Table 5.10. The mixed responses from the respondents indicate that the creating legitimacy and counteracting resistance to change function can only operate fluently if it is supported by the guidance of the search function. This is necessary to ensure that the two functions work in unity in steering the technology in the intended direction while accomplishing the goals the key stakeholders and government have defined.

Interest in the PV industry in South Africa has been greatly enhanced over the past few years. According to the remarks made by various survey respondents, some of the drivers were “increased power prices” and “interruptions in power supply” due to “load shedding” caused by underinvestment in power infrastructure and “poor management”. Another driver for the adoption of PV was the realisation of the effect of “climate change”, “depletion of natural resources” and “environmental consciousness”, which in return triggered the “global push to minimise carbon emissions” and the “drive to go green” energy-generating methods.

Some of the respondents indicated that the energy sector in South Africa still has “too much drive for coal” and “nuclear”, the “push for dependency on fossil fuels to invigorate local mines” is too great and the “benefits of solar [are] not communicated.” This statement is extremely important, indicating that the job creation potential of PV is under-realised in South Africa. According to Table 2.6, the mining sector and the utilities sector currently employ 434 000 and 148 000 people in South Africa respectively. According to section 2.2.3, solar PV can provide on average 30 jobs per MW of PV installed. The analysis of the respondents' data indicated that advocacy and lobbying by those having strong economic weight and influence have “not taken into account the seriousness of the energy crisis” in South Africa. The research results indicate that key stakeholders and people with strong economic weigh have not realised the urgency to influence the energy sector by moving to renewable energy modes of electricity production. Advocacy promoting the PV industry is a major barrier to the current and future development of the PV industry.

The extent of development of the creating legitimacy and counteracting resistance to change function is indicated in Table 5.10. It achieved an overall rating of 45%. According to Figure 5.7, the effect of the media and lobbying groups on promoting PV is an uncorrelated response with an almost uniformly spread distribution. The average of the results in Figure 5.7 indicates that media and lobbying groups have a limited to neutral effect in promoting the PV industry in South Africa. The results of Figure 5.7 indicate that media and lobbying groups perform well in some areas, but poorly in other areas in promoting PV adoption.

6.3. Extent of development of the South African PV TIS

The data presented in Table 5.11 can be mapped graphically to indicate the extent of development of the South African PV TIS. Figure 6.1 is a spider diagram mapping the PV TIS functions, representing one of the deliverables for the research project. The spider diagram briefly indicates that the market formation and resource mobilisation functions are the outliers with the best performance in the system, and that entrepreneurial activities and knowledge development functions were rated worst. The overall performance of the TIS is indicative of barriers limiting the growth of both the present and future development of the PV industry. The barriers in the system can be removed through the formulation and implementation of policies guiding the development and growth of the South African PV TIS.

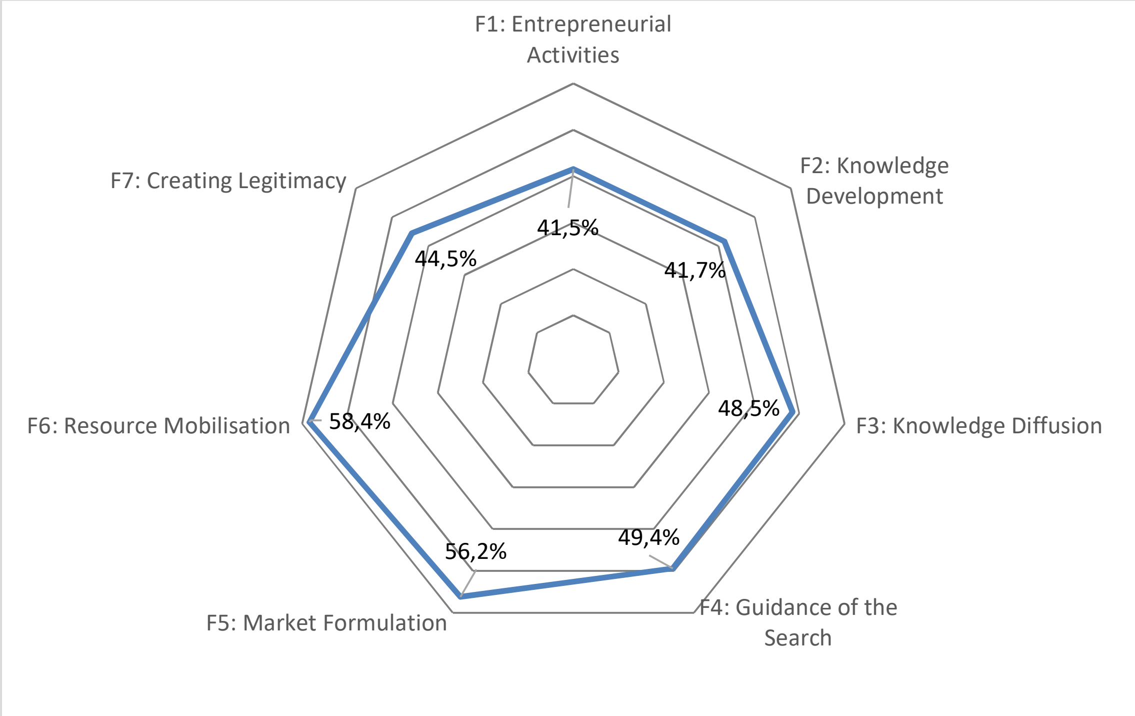


Figure 6.1: Extent of development of the South African PV TIS

6.4. Policy Recommendations

Policies need to be established to enhance economic growth and development (Lundvall, 2007). Innovation involves enormous amount of uncertainty; the objectives the innovation system is required to achieve are difficult to specify fully in advance, but can be guided by policies to steer the TIS in a direction that would accomplish the goals (Lundvall, 2007). RET activities need to be monitored on a continuous basis to ensure that the policies being implemented are evaluated to support the technologies, which is especially important for developing countries (Edsand, 2016). The TIS should be monitored on a continuous basis to drive improvements as the system progresses through the different stages of development towards system advancement and maturity (Edsand, 2016).

Because of the intricacy of the indicators related to the system function, the policies intended to remove the barriers inhibiting the development of the PV industry were not discussed according to a specific structure. The policy recommendations required for the PV industry are indicated in Table 6.1.

Table 6.1: Policy Recommendations

Regulation/Policy	Description
Environmental conservation	Protecting the environment by granting incentives for the implementation of products and processes conserving the environment.
Knowledge development	Providing incentives for firms investing their revenue in R&D and innovation, encouraging organisations to develop knowledge by implementing research projects.
Product and consumer	Introducing and promoting new products and market entries more frequently to promote innovation by enhancing the adoption and diffusion of new technologies.
Providing education	Providing incentives to organisations promoting knowledge development by disclosing technical information and technical expertise to start-ups and small businesses.
Research partnerships and collaboration	Providing incentives for companies forming partnerships and attempting to collaborate in R&D activities, ensuring increased performance and efficiency by combining organisational resources to form a synergy.
Public and start-up funding opportunity	Providing opportunities for new market entrants and increasing the probability of new patents being patented, resulting in more competitive markets being established.
Periodical policy revision strategy	Policies need to be re-evaluated to ensure that the policy has the impact on the goal policy makers intended it to accomplish, improving the reliability of implemented policies.
Technology roadmap	Establishing policies and goals that clearly communicate to the actors a clear vision and mission statement that the regulatory body and government wish to accomplish with the technology, providing direction for the actors and guiding them on the allocation of resources.
Institutional supporting measures.	Providing support from government in providing research institutions and knowledge centres with the necessary resources to produce and exploit knowledge.
Establishing technology transfer offices	Driving commercialisation of PV through the implementation of technology transfer offices that assist firms in bridging the gap in knowledge transfer between actors (knowledge institutes, entrepreneurs, organisations, etc.) in the PV industry.
Encourage communication network expansion	The implementation of innovations can be increased if the tacit knowledge of individuals and organisations is shared between science and industry, and between businesses across different sectors and industries.

Regulation/Policy	Description
Developing network relationships	Organising events where local and international organisations are given the opportunity to interact and establish networks in which knowledge can be shared and transferred.
Communicating with regulatory organisations and government.	Establishing communication channels that enable the industry to raise issues and concerns regarding regulations and technology with regulatory organisations and government.
Local competency and capacity	Promoting local product development by favouring companies tendering with locally produced products, creating economic activity and forcing local and international firms to establish local manufacturing plants.
Decentralising energy production	Establishing regulations giving organisations the ability to compete in the utilities sector by supplying electricity to the public, creating more competitive markets and causing the cost of electricity to decrease.
Investments	Providing investors with an opportunity to invest in projects in the industry with an attractive return on investment. This would provide funding opportunities for the PV industry.
Education	Providing education to the public regarding the technology and the potential benefits it can provide in an attempt to counteract resistance to change.
Technology standardisation	Establishing clear policies regulating the technology.

Source: Adapted from (Blind, 2012; Cunningham and Ramlogan, 2012; Kohler *et al.*, 2012; Rigby and Ramlogan, 2012)

7. Conclusions and Recommendations

The TIS framework approach, proposed by Heckert et al. (2007), as discussed in Chapter 3, distinguishes between seven system functions was used to evaluate the extent of development of the South African PV infrastructure. The system functions were evaluated based on a series of components that must be present for a specific function.

7.1. Conclusions

From the results obtained in the analysis of Chapter 5, the extent of development of the PV infrastructure was calculated based on the indicators of each function. The evaluation results of the different indicators provide guidance on the barriers that limits the development and growth of the system.

7.1.1. Extent to which the PV TIS has been Developed in South Africa

The extent of development of the PV infrastructure was determined by evaluating the system functions and mapping then graphically, as indicated in Figure 6.1. According to the results obtained, all the system functions are actively present in the South African PV TIS. The best performing functions were calculated to be the resource mobilisation function and the market formulating function, whereas the worst performing functions were calculated to be the entrepreneurial activities function and the knowledge development function.

7.1.2. Present Weaknesses of the TIS, particularly regarding Knowledge Development and Knowledge Diffusion within the PV TIS

The present weaknesses in the system, particularly related to knowledge development and diffusion were indicated to be:

- Investment in R&D,
- Number of patents patented,
- Research projects in organisations,
- Technology absorption capacity,
- Learning from experiences of other countries,
- Inter-organisational collaboration and networks, and
- Level of learning and skills transferred.

7.1.3. Barriers that Inhibit the Future Development of PV TIS in South Africa

The barriers that inhibit the future development of the PV TIS are indicated to be:

- Amount invested in R&D,
- Clarity and direction of what the PV industry needs to accomplish,
- Fulfilment of the role of the local government and regulatory organisations,
- Advocating PV technology,
- Education provided to the public and start-up businesses,
- Number of actors present in the PV industry,
- Knowledge development and innovation,
- Research projects in organisations,
- Technology absorption capacity,
- Learning from experiences of other countries,
- Level of learning and skills transferred.
- Dependency on international market in producing PV technology, and
- Inter-organisational collaboration, linkage and networking.

7.1.4. Recommended policies to strengthen the PV TIS in South Africa

The policies recommended for the South African PV TIS originated from the indicators of the barriers that limit the development and growth of the PV industry. The recommended policies are focused on stimulating and encouraging local demand, developing skills and absorption capacity to discourage reliance on the importation of technologies by encouraging local research, development and manufacturing:

- Environmental conservation,
- Knowledge development,
- Providing education,
- Research partnerships and collaboration,
- Public and start-up funding opportunities,
- Periodical policy revision strategy,
- Technology roadmap,
- Institutional supporting measures.,
- Establishing technology transfer offices,

- Encouraging communication network expansion,
- Developing network relationships,
- Communicating with regulatory organisations and government,
- Local competency and capacity,
- Decentralising energy production,
- Investments,
- Education, and
- Technology standardisation.

7.2. Contributions of this Study

This study contributed to literature by applying the TIS framework analysis approach to the context of South Africa, to analyse the extent of development of the PV industry. This study provided positive indicators that help with the development and growth of the PV industry, and conversely provided indicators of barriers that inhibit the development and growth of the PV industry. This study also made suggestions on policies to remove the barriers existing in the PV TIS.

7.3. Recommendations for Future Research

Recommended future studies would entail repeating the same study over the course of a few years with the addition of the same analysis for other countries in the world. The results can then be used to draw comparisons between the development of the countries and the effect different policies have on the development and growth of the PV industry.

References

ARTsolar. 2017. *South Africa's Only Locally Owned Solar Panel Manufacturer* [Online]. Available: https://artsolar.net/ [Accessed 28 October 2017].

Baker, L. 2016. Technology Development in South Africa: The Case of Wind and Solar PV. *SPRU: Science Policy Research Unit,* Working Paper Series, pp 2-21.

Batawy, S. A. E. & Morsi, W. G. 2016. Optimal Secondary Distribution System Design Considering Rooftop Solar Photovoltaics. *IEEE Transactions on Sustainable Energy,* 7(4), pp 1662-1671.

Blind, K. 2012. The Impact of Regulaton on Innovation. Compendium of Evidence on the Effectiveness of Innovation Policy Intervention, Nesta

BP. 2017. BP Statistical Review of World Energy. June 2017, BP Statistical Review of World Energy (Centre for Energy Economics Research and Policy).

Cape Town Government. 2016. *Utility Services - Electricity Services (Consumptive)* [Online]. Available: https://resource.capetown.gov.za [Accessed 22 July 2017].

Chudy, M., Mwaura, J., Walwyn, D. & Lalk, J. The Effect of Increased Photovoltaic Energy Generation on Electricity Price and Capacity in South Africa. AFRICON 2015, 14-17 Sept. 2015 2015. 1-6.

Cunningham, P. & Ramlogan, R. 2012. The Effects of Innovation Networks. Compendium of Evidence on the Effectiveness of Innovation Policy Intervention, Nesta

Edsand, H.-E. 2016. Technological Innovation Systems and the Wider Context: A Framework for Developing Countries.

Enerdata. 2017. *World Consumption Statistics* [Online]. Available: https://yearbook.enerdata.net/ [Accessed 23 August 2017].

Eskom. 2016. *Historical Average Prices and Increase* [Online]. Available: http://www.eskom.co.za [Accessed 25 September 2017].

Fluri, T. 2009. *Solar Resource Mapping in South Africa* [Online]. Centre for Renewable and Sustainable Energy Studies: Stellenbosch University. Available: http://www.crses.sun.ac.za [Accessed 9 July 2017].

Fritz, W. L. O. Challenges of Tying Small Scale Renewable Energy Systems to the Grid in South Africa. 2013 Proceedings of the 21st Domestic Use of Energy Conference, 3-4 April 2013 Cape Town, South Africa. IEEE, 1-5.

Godin, B. 2009. National Innovation System. *Science, Technology, & Human Values,* 34(4), pp 476-501.

Guo, Y., Zhu, D. & Wang, X. Profiling Innovation System for Solar Photovoltaics in China. 2009 IEEE International Conference on Industrial Engineering and Engineering Management, 8-11 December 2009. 100-104.

Hekkert, M., Negro, S., Heimeriks, G. & Harmsen, R. 2011. Technological Innovation System Analysis. A manual for analysts, Universiteit Utrecht

Hekkert, M. P. & Negro, S. O. 2009. Functions of Innovation Systems as a Framework to Understand Sustainable Technological Change: Empirical Evidence for Earlier Claims. *Technological Forecasting and Social Change,* 76(4), pp 584-594.

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S. & Smits, R. E. H. M. 2007. Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change,* 74(4), pp 413-432.

Herbst, L. & Lalk, J. 2015. A Review of the Policy Documents Behind South Africa's Renewable Energy Independent Power Producer Procurement Programme. *IEEE International Symposium on Technology in Society (ISTAS) Proceedings.* Dublin, Ireland: IEEE.

IEA. 2014. *Technology Roadmap* [Online]. International Energy Agency,. Available: https://www.iea.org/roadmaps/ [Accessed 1 September 2017].

IRENA. 2017a. Accelerating the Energy Transition Through Innovation. a working paper based on global REmap analysis, The International Renewable Energy Agency (Abu Dhabi).

IRENA. 2017b. Renewable Capacity Statistics 2017. The International Renewable Energy Agency (Abu Dhabi).

IRENA. 2017c. Renewable Energy and Jobs - Annual Review 2017. The International Renewable Energy Agency (Abu Dhabi).

Kebede, K. Y. & Mitsufuji, T. 2017. Technological Innovation System Building for Diffusion of Renewable Energy Technology: A Case of Solar PV Systems in Ethiopia. *Technological Forecasting and Social Change,* 114, pp 242-253.

Kohler, C., Laredo, P. & Rammer, C. 2012. The Impact and Effectiveness of Fiscal Incentives for R&D. Compendium of Evidence on the Effectiveness of Innovation Policy Intervention, Nesta

Krupa, J. & Burch, S. 2011. A New Energy Future for South Africa: The Political Ecology of South African Renewable Energy. *Energy Policy,* 39(10), pp 6254-6261.

Lundvall, B.-A. 2007. National Innovation System: Analytical Focusing Device and Policy Learning Tool. *ITPS, Swedish Institute for Growth Policy Studies,* Working paper R2007:004, pp 7-30.

Maeda, M. & Mori, K. An Inverse Innovation for Photovoltaic (PV) Industry. 1st International Technology Management Conference, ITMC 2011, 27 June 2011 2011 San Jose, CA. 1st International Technology Management Conference, ITMC 2011, 1034-1041.

Markard, J., Hekkert, M. & Jacobsson, S. 2015. The Technological Innovation Systems Framework: Response to Six Criticisms. *Environmental Innovation and Societal Transitions,* 16**,** pp 76-86.

Mathews, G. E. & Mathews, E. H. 2016. Household Photovoltaics; A Worthwhile investment? *2016 International Conference on the Domestic Use of Energy (DUE).* Cape Town, South Africa: IEEE.

Münzberg, J., Baum, S. & Stadler, I. 2016. Economic Evaluation, Optimization and Comparison of Photovoltaic-Battery-Grid Power Supply System in Single- and Multi-Family Buildings with Increasing Share of Renewable Energy. *Cologne Institute for Renewable Energy.* Cologne, Germany: IEEE.

Musau, M. P., Odero, N. A. & Wekesa, C. W. 207. Implementation of Environmental Decision Making Tool for Renewable Energy Utilization: A Case of Wind and Solar. IEEE EUROCON 2017 -17th International Conference on Smart Technologies, 6-8 July 2017 2017 Ohrid, Macedonia. IEEE, 816-821.

Peter, G. 2011. Solar Power System Technologies. *Large-Scale Solar Power System Design: An Engineering Guide for Grid-Connected Solar Power Generation.* McGraw Hill Professional, Access Engineering.

Pollet, B. G., Staffell, I. & Adamson, K.-A. 2015. Current Energy Landscape in the Republic of South Africa. *International Journal of Hydrogen Energy,* 40**,** pp 16685-16701.

PQRS. 2016. August 2016 PQRS Industry Report.

PTiP Innovations. 2014. *Demonstration and Manufacturing Plant* [Online]. Available: http://www.ptip.co.za/.

Rigby, J. & Ramlogan, R. 2012. The Impact and Effectiveness of Support Measures for Exploiting Intellectual Property. Compendium of Evidence on the Effectiveness of Innovation Policy Intervention, NESTA

Roesch, A., Ronteix, P., Thobela, M. & Daniel Goldstuck 2015. Technology Innovations: Solar Grid-based (PV). *SAIREC - South African Renewable Energy Conference,* (1)**,** pp.

Saari, S. & Haapasalo, H. 2012. Knowledge Transfer Processes in Product Development - Theoretical Analysis in Small Technology Parks. *Technology and Investment,* 3(1)**,** pp 12.

Saez-de-Ibarra, A., Herrera, V. I., Milo, A., Gaztanaga, H., Etxeberria-Otadui, I., Bacha, S. & Padros, A. 2016. Management Strategy for Market Participation of Photovoltaic Power Plants Including Storage Systems. *IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS,* 52(5)**,** pp.

SASSA. 2017. A Statistical Summary of Social Grants in South Africa, South Africa Social Security Agency (online).

Solargis. 2016. *Solar Resource Maps* [Online]. Available: http://solargis.com [Accessed 29 June 2017].

Stats SA. 2017a. *Capital Expenditure by the Public Sector, 2016* [Online]. Available: http://www.statssa.gov.za [Accessed 25 September 2017].

Stats SA. 2017b. Quarterly Labour Force Survey. *Statistical release.* Quarter 2: 2017 ed.: Statistics SA.

Tsao, J., Lewis, N. & Crabtree, G. 2006. Solar FAQs.

Varda, V. & Kuzle, I. The Influence of Renewable Energy Systems, Energy Storage and Electrical Vehicles on Croatian Power System Operation. IEEE EUROCON 2017 -17th International Conference on Smart Technologies, 6-8 July 2017 2017 Ohrid, Macedonia. IEEE, 448-455.

Walwyn, D. R. 2016. The Use of the Technological Innovation Systems Framework to Identify the Critical Factors for a Successful Sustainability Transition to Rooftop Solar in Low-Income Communities within South Africa. *In:* Zobaa, A. F., Afifi, S. N. & Pisica, I. (eds.) *Sustainable Energy - Technological Issues, Applications and Case Studies.* Rijeka: InTech, Ch, pp Ch. 03.

Walwyn, D. R. & Brent, A. C. 2014. Renewable Energy Gathers Steam in South Africa. *Renewable and Sustainable Energy Reviews,* 41(2015)**,** pp 390-401.

World Energy Council. 2016. World Energy Resources 2016.

Wright, J. G., Calitz, J., Heerden, R. v., Bischof-Niemz, D. T., Mushwana, C. & Senatla, M. 2017. Formal Comments on the Integrated Resource Plan (IRP) Update Assumptions, Base Case and Observations 2016. CSIR Energy Centre.

Yin, R. K. 2009. *Case Study Research*, SAGE Publications, Inc.

Zawilska, E. & Brooks, M. J. 2011. Solar Energy Measurement on the South African East Coast. *World Renewable Energy Congress 2011.* Linköping Sweden: Solar Thermal Applications (STH).