An Exploratory Study of the South African Concentrated Solar Power Sector using the Technological Innovation Systems Framework

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A research project submitted to the Gordon Institute of Business Science, University of Pretoria, in partial fulfilment of the requirements for the degree of Master of Business Administration.

7 November 2018

Abstract

Wide-scale deployment of renewable energy is required to meet the global challenges of climate change and energy security. Solar photovoltaic (PV) and wind energy occupy the majority of global installed renewable energy technology (RET), but they are intermittent sources of energy and cannot be relied upon to solely meet the energy needs of the future. The problem of energy storage has therefore emerged as a significant barrier to the mass deployment of RET.

Concentrated solar power (CSP), with its inherent storage capacity, offers dispatchable electricity at large scale. However, its deployment to date has been restricted by high capital costs and the limited geographical locations with optimal solar radiation to attain required efficiencies. South Africa, with its abundant solar resources, has the potential to develop an export competitive CSP industry by leveraging existing capabilities in innovation, manufacturing and construction. It has however yet to attain this goal.

This study applies a qualitative, exploratory approach to understand the factors that are currently prohibiting South Africa from being the global leader in CSP by evaluating the functions of the Technological Innovation Systems (TIS) framework through semi-structured interviews with experts within the South African CSP TIS.

The assessment revealed the presence of a largely unfulfilled TIS, with the advancement of the current TIS contingent on further allocation of CSP procurement targets in the Integrated Resource Plan (IRP) and sufficient support to develop entrepreneurial activity. A procurement-driven industrial policy strategy was recommended to address these barriers to further advance the diffusion of CSP towards the end goal of developing an export competitive industry in South Africa.

Keywords

Concentrated solar power, industrialisation policy, renewable energy

Declaration

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University. I further declare that I have obtained the necessary authorisation and consent to carry out this research.

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1. Chapter 1: Introduction to the Research Problem

1.1 Background to the Research Study

Energy consumption and economic growth are inextricably linked and have important implications for policy makers (Shahbaz, Zakaria, Shahzad, & Mahalik, 2018). As such, there is a growing literature on the subject of the ‘energy consumption-growth nexus’ which aims to understand the causal link between economic growth and energy consumption. i.e. does an increase in energy consumption cause an increase in gross domestic product (GDP), or is the reverse true (Belke, Dobnik, & Dreger, 2011; Shahbaz et al., 2018). As alluded to, one of the reasons this topic finds prominence in contemporary literature is that this relationship is highly relevant in policy formation (Chontanawat, Hunt, & Pierse, 2008; Tiba & Omri, 2017). For example, if energy causes GDP, then policies aimed at reducing energy may have detrimental societal implications such as unemployment, which would ultimately affect a countries competitiveness. Although this phenomenon is widely studied, it appears that a consensus has yet to be reached as to whether energy and GDP are causally linked; however, studies have shown the existence of a link between electricity consumption (as a subset of energy consumption) and GDP, running from electricity consumption to GDP (Ozturk, 2010). This renders electricity a limiting factor to economic growth and subsequently any shocks to energy supply will negatively impact economic growth.

The global electricity sector is currently dominated by fossil fuel primary energy resources with coal, natural gas and oil accounting for 38.1%, 23.2% and 3.5% respectively of global electricity production (Figure 1). Hydroelectric energy and nuclear contribute 15.9% and 10.3% respectively, whilst renewable energy only accounts for 8.4% of global energy production (BP, 2018). Fossil fuels still play such a dominant role in the electricity sector due to their efficiency, abundance and convenience, which has resulted in substantial infrastructure development that has entrenched their use in our society. However, this sector is coming under increasing pressure to shift towards cleaner, more sustainable forms of energy, largely in response to global pressures to tackle issues related to climate change and energy security challenges (Gunningham, 2013).

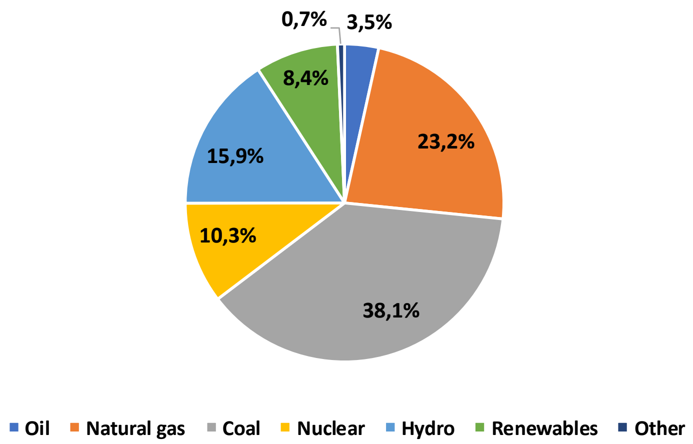


Figure 1: Global electricity generation by fuel source in 2017, 'other' refers to pumped hydro and non-renewable waste (BP, 2018)**.**

Climate change refers to the increase in global temperatures (global warming) caused by the rise in atmospheric greenhouse gas (GHG) concentration, particularly anthropogenic carbon dioxide, released during the combustion of fossil fuels in the production of energy (IPCC, 1995). In 2015, a global accord was reached in which countries agreed to work towards mitigating the effects of climate change. This culminated in the signing of the Paris Agreement at the 21st Conference of the Parties (COP 21). The Paris Agreement or Paris Climate Accord refers an agreement within the United Nations Framework Convention on Climate Change (UNFCCC) signed by 195 nations, with a further 176 being party to it, which aims to counter climate change by keeping a global temperature rise to well below 2 ºC as compared to pre-industrial levels (UN, 2015). Energy security is defined as "the uninterrupted availability of energy sources at an affordable price" (IEA, n.d.-a). Countries typically experience challenges with energy security when they are dependent on a single source of energy from a country who may then be in a position to exploit this relationship for geo-political gain (e.g. EU gas imports from Russia), or they rely on imports from unstable regions (e.g. USA oil imports from the Middle East) (Toke & Vezirgiannidou, 2013). The use of renewable energy (RE) and nuclear energy (Knapp & Pevec, 2018) as a replacement for conventional fossil fuel energy has been touted as a potential mitigation measure to both of these problems; however, the threat of nuclear disasters and difficulties with the safe disposal or radioactive waste has rendered renewable energy as the preferred solution (Jacobsson & Johnson, 2000).

Renewable energy technologies (RETs) convert the energy from naturally occurring, abundant resources (e.g. the sun, wind and waves) into energy that can be used in a productive manner, such as electricity (SANEDI, n.d.). Unlike finite fossil fuel sources, which are concentrated in certain geographical areas, renewable energy sources are naturally replenished and available over wide geographical areas. RETs can therefore be harnessed to reduced dependency on fossil fuels and aid in addressing security of supply challenges. Additionally, RETs do not release GHGs in the production of electricity and as a consequence, the wide scale adoption of renewable energies over fossil fuel derived energy (referred to as 'the decarbonisation of the energy sector') is seen to be key in meeting global commitments to the Paris Agreement (UN, 2015). In addition to these benefits, renewable energy deployment has a number of other socio-economic benefits such as increasing GDP, net employment creation (after accounting for fossil fuel job losses) and improvements in welfare (poverty reduction, improved education and increased food security) (IRENA, 2018a; Schwerhoff & Sy, 2017). However, RETs have yet to reach their full potential in the energy system.

Since the first oil crisis in 1973 (Jacobsson & Johnson, 2000), the interest in RET has increased substantially and, as can be seen in Figure 1, RE is responsible for 8.4% of global power generation in 2017. This electricity is derived mostly from solar photovoltaics (PV) and wind energy (see Section 2.1.1 for additional information). Although, this does signal progress, there is a growing concern that the uptake of RE is not fast enough to curb emissions to realise the envisaged <2 ºC scenario, which requires a 65% share of RE in the global primary energy supply by 2050 (IRENA, 2018b). In fact, the Intergovernmental Panel on Climate Change (IPCC) recently released a special report on the impact of global warming, citing that unprecedented changes are required to limit global warming of 1.5 ºC above pre-industrial levels and that included in the required measures is a need to increase the share of RE to 70 – 85% by 2050 (IPCC, 2018).

One potential reason for the slow uptake of utility-scale renewable energy is that RET such as wind energy and solar PV are intermittent i.e. they generate electricity only when the sun shines or when the wind blows. They are therefore not able to provide a constant supply of electricity to meet demand, and would have to rely on a separate battery storage system in order to become dispatchable (Vieira de Souza & Gilmanova Cavalcante, 2017) . In contrast, concentrated solar power (CSP) is a RET with built-in thermal storage that allows energy collected during the day to be used to generate electricity in the evening (Vieira de Souza & Gilmanova Cavalcante, 2017; Zhang, Baeyens, Degrève, & Cacères, 2013). In CSP, solar radiation is concentrated onto a heat transfer fluid (HTF) that is heated to the point where it can be used to generate steam to drive a conventional turbine to generate electricity (Figure 2). The HTF does not need to be used immediately it can be stored for a period of time (up to 24 hours). Therefore, the primary value that CSP provides to an energy portfolio is its flexibility to dispatch energy as baseload power or for balancing intermittent renewable sources (Lilliestam et al., 2018). CSP is only viable in regions with high direct normal irradiation (DNI) i.e. sunlight that is not obscured by clouds (see Section 2.1.2, Figure 7). A 2016 joint study carried out by the European Solar Thermal Electricity Association (ESTEA), Greenpeace International and *SolarPACES* (part of the International Energy Agency – IEA) indicated that CSP has the potential to provide up to 6% of the world's energy needs by 2030 and 12% by 2050 (Crespo, Bial, Dufour, & Richter, 2016).

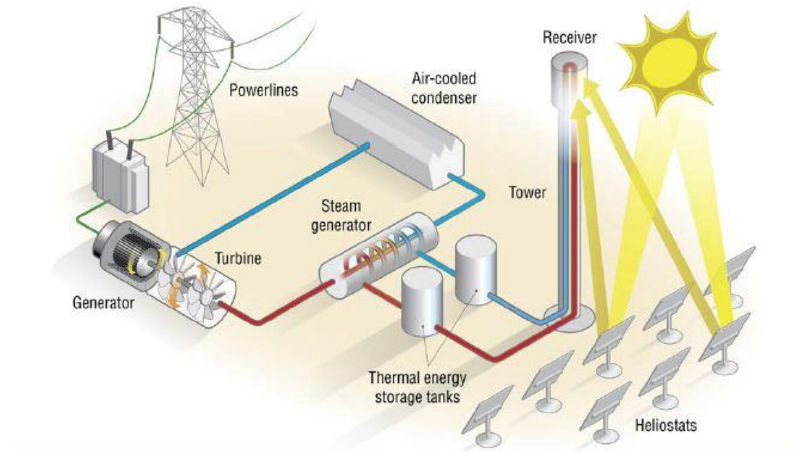


Figure 2: Schematic of a CSP plant – solar radiation is concentrated onto a HTF that is then used to generate steam to drive a turbine to generate electricity (Lombardo, 2015)**.**

South Africa generates more than 90% of its electricity from coal due to the abundance and low cost of this primary energy source (Altieri et al., 2016; Eskom, n.d.). Although in the last decade the dominance of coal in electricity production has come under increasing scrutiny due to a variety of factors such as declining reserves, supply constraints, quality of supplied coal and climate change issues (Xavier, Komendantova, Jarbandhan, & Nel, 2017). Related to the latter point, South Africa ranks amongst the highest in the world for GHG emissions per unit of energy, with the electricity sector alone contributing 45% towards total national GHG emissions (WWF, 2017b). This is therefore an area with substantial GHG emission mitigation potential that needs to be addressed by the country as a signatory to the Paris Agreement. However, emission reduction measures also need to take the equally important developmental needs of the country into account. South Africa currently has unemployment rate of 27.3% and a 10-year average annual GDP growth rate of 1.7%, (Schwab, 2018) against targets of 5.4% year-on-year to 2030 (National Planning Commission, 2012). A country specific study has shown that an increase in energy consumption leads to economic growth and that an increase in energy consumption leads to an increase in carbon dioxide emissions (Menyah & Wolde-Rufael, 2010). These results therefore seem to suggest that in order to reduce emissions South Africa may need to sacrifice economic growth to alleviate environmental pressures if coal remains the dominant source of energy in the country. Decoupling the economic growth from emissions is therefore not a trivial undertaking for South Africa.

Approximately 95% of South Africa's electricity is supplied by the state-owned utility Eskom (Eskom, n.d.), that owns both the electricity supply and transmission infrastructure and who is only allowed to procure electricity from the private sector through specific power procurement programs, which are subject to stringent tender processes. In 2007 Eskom was not able to supply sufficient electricity to meet the countries demand due to a variety of factors such as coal supply issues and poorly maintained infrastructure (Monyei & Adewumi, 2017). This resulted in wide scale power blackouts termed "load shedding" that continued through to 2015 impacting the economy adversely (Bohlmann, Bohlmann, Inglesi-Lotz, & van Heerden, 2016). This situation brought into prominence the need to diversify the South African electricity generation mix to secure energy supply. This fact was first acknowledged many years prior to the instances of loading shedding in the 1998 White Paper on Energy Policy of the Republic of South Africa (Department of Minerals and Energy, 1998), which stated:

Rapid development of renewable energy technologies is taking place in many parts of the world. As costs decrease, more and more applications are becoming cost effective and competitive. In contrast to world trends, however, South Africa has neglected the development and implementation of renewable energy applications, despite the fact that our renewable energy resource base is extensive and many appropriate applications exist (Department of Minerals and Energy, 1998, p79).

As is alluded to in the above quote, South Africa is fortunate to have among the best solar and wind resources in the world (Figure 3) and could generate a substantial portion, if not all, of South Africa's electricity demand from these primary inputs (e.g. it has been estimated that the power generated from wind farm installations on only 0.6% of available South African land would meet the countries entire annual electricity demand) (Knorr et al., 2016). The incorporation of a substantial portion of RE into the South African energy mix would therefore contribute towards addressing both energy security issues and climate change mitigation challenges, whilst still allowing for economic growth.

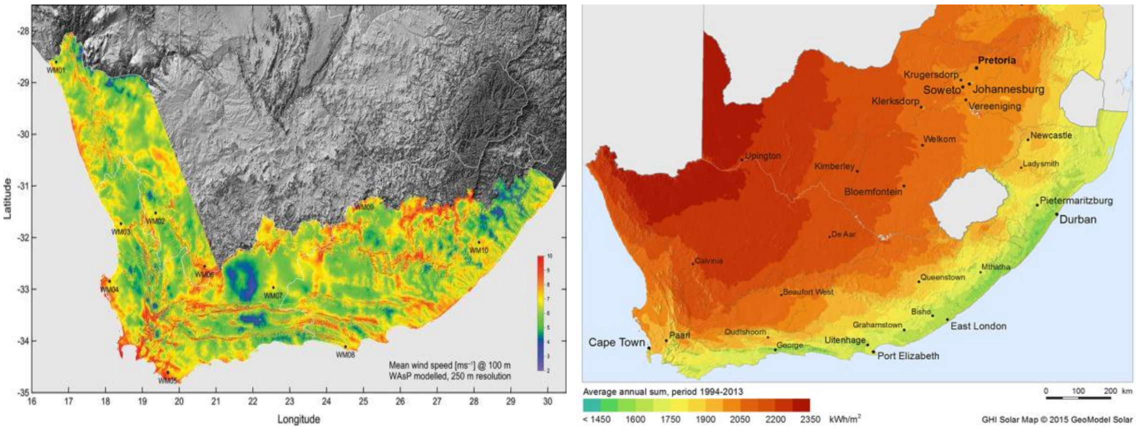


Figure 3: (Left) Wind atlas for South Africa and (right) map of solar radiation intensity (DNI) for South Africa(Knorr et al., 2016)**.**

Since the above mentioned 1998 White Paper on Energy Policy, there have been a number of enabling policy documents and legislation introduced to regulate the renewable energy sector in South Africa and encourage participation of the private sector in electricity generation in the form of Independent Power Producers (IPPs) (see Section 2.2.1). Of these, the key policy document underpinning the future of renewable energy in South Africa is the Integrated Resource Plan (IRP) that details potential scenarios of electricity resources and technologies that South Africa should invest in to meet national demand projections up to 2030 (Department of Energy, 2018).

The vehicle through which the IRP aims to meet the stipulated renewable energy targets is the Renewable Energy Independent Power Producer Procurement Programme (REI4P) (Eberhard & Naude, 2017; IPPPP Office, 2018). This is a large-scale demand-side programme developed to encourage private investment in South Africa's renewable energy sector to enable energy diversification, stimulate a local renewable energy manufacturing sector and aid in addressing South Africa's sustainability transition to meet its climate change commitments (see Section 2.2.2) (Eberhard & Naude, 2016).

Energy procured by the programme has progressively become more cost effective with each bidding round, and is currently at the point of reaching cost parity with new coal-fired power stations (Figure 4). The programme has also realised a host of other benefits including socio-economic impacts (e.g. employment creation), foreign direct investment (FDI) and environmental impacts (water savings and GHG emission reductions) (see Section 2.2.2).

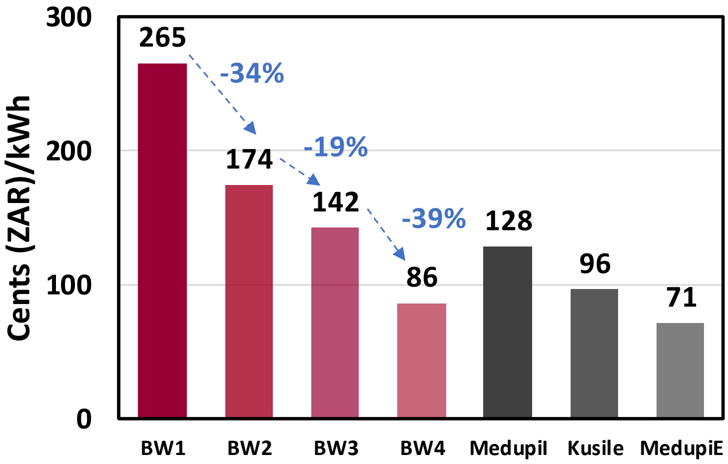


Figure 4: Red bars indicate the contracted price in Cents (ZAR)/kWh at which power is sold to Eskom (represented as a weighted average price over the different technologies) as compared to the levalised cost of electricity for 3 of Eskom's coal-fired power stations under construction. Note: prices are expressed in April 2017 terms and BW refers to 'bid window' (IPPPP Office, 2018)**.**

These results show that the REI4P has taken significant strides towards translating policy into the delivery of renewable energies in South Africa. Yet, despite these efforts and the natural endowment of renewable energy resources, South Africa retains only a small share of the global installed renewable energy capacity (*ca* 0.23%) (IRENA, n.d.-b), and has yet to develop a competitive manufacturing sector in renewable energy technologies. Countries with similar developmental challenges to South Africa such as China and Brazil, are producing competitive renewable energy exports in the form of PV panels and biofuels respectively by leveraging their technological innovation and manufacturing capabilities (De Oliveira & Coelho, 2017; Zou et al., 2017).

CSP technology has been identified as one of the only renewable energy technologies that could provide baseload power owing to the fact that it encompasses thermal energy storage that enables it to produce electricity when there is no solar radiation (Craig, Brent, & Dinter, 2017). Currently, the cost of electricity generated from CSP is substantially higher than PV or wind; however, given its inherent potential to counter the intermittency of these technologies it is poised to become the next subject of extensive effort to reduce cost in the renewable energy sector. It has been suggested that South Africa may well be positioned to become a technology design and manufacturing leader in CSP technology due to its abundant solar resources that provide an ideal testing ground for new technology advancements. Additionally, it is a regional hub and has expertise in automotive manufacture and export that could be leveraged to create manufacturing capabilities in the components required for CSP technology (WWF, 2015).

As part of the REI4P, 1200 MW of CSP has been determined, of this 600 MW has been procured and 300 MW is operational. This places South Africa 3rd in the global ranking of installed CSP capacity, behind the USA (1 758 MW) and Spain (2 300 MW) (IRENA, n.d.-b).

In order to reap the benefits that would come with export competitive technological innovation in CSP, such as increased economic growth through international trade and royalty fees from licencing technologies, South Africa needs to identify the critical factors that are prohibiting this advancement. The Technological Innovation System (TIS) framework has been used successfully in the literature to evaluate the barriers to the innovation and diffusion of emerging technologies by probing which structures and processes hinder innovation in a particular field (Miremadi, Saboohi, & Jacobsson, 2018; Negro, Hekkert, & Smits, 2007). The ultimate outcome of a TIS analysis is suggested policies that will allow the technology to realise it full potential within the environment it is located (Hekkert, Negro, Heimeriks, & Harmsen, 2011).

1.2 Research Problem and Objectives

South Africa has the third largest capacity of CSP globally, enabled by the REI4P that has created a protected space to foster demand and create this market. Leveraging off this, South Africa could become a leading country for the design and manufacture of CSP facilities in the world. However, it is unclear whether the CSP TIS has reached the necessary level of maturity to achieve this ambition.

1.3 Significance of the Research

In the context of a country suffering from a major energy crisis, high unemployment rates as well as increasing pressure from the global community to decarbonise the energy sector, CSP could prove to be a viable renewable energy source that could be used to meet local energy demands whilst establishing a globally competitive industry.

To continue along the path of technological innovation towards the above-mentioned goals, incumbent and future CSP companies need an enabling policy environment. An analysis of the sector using the TIS framework may provide insight into what that policy environment may be. To the best of the author’s knowledge this specific study is a gap in the current TIS literature, as this framework has yet to be applied to CSP as a technology in the context of either a developed or developing country.

1.4 Research Scope

The intention of this study is to analyse the South African CSP sector using the TIS framework. Based on this analysis, the next step is to develop and recommend a policy framework that could enable the South African sector to become a global innovation and manufacturing hub. Finally, the study aims to assess what the future opportunities are for CSP in South Africa taking context specific challenges into account.

To this end, Chapter 2 will focus on the main theoretical concepts relevant to this study, culminating in the research questions that were investigated (Chapter 3). Chapter 4 provides information related to the methodological tools that facilitated the assembly of original data for the analysis of the research problems. This data is presented in a logical sequence, organised by research question in Chapter 5 and these results are discussed in further detail in Chapter 6. A summary of the research findings, final insights and suggestions for further work is provided in Chapter 7.

2. Chapter 2: Literature Review

This chapter aims to build on the previous chapter by providing the reader with further insight into the study's salient topics as well as their connectivity. This information has been collated from the relevant academic literature and has been arranged under specific subheadings. The chapter begins with an introduction to renewable energy to familiarise the reader with the main types of RETs, their role in transitioning the energy sector towards more sustainable energy sources, as well as their current contribution to the global energy mix. This is followed by a more in-depth review of the specific RET subject of this study, namely CSP. This section on renewable energy ends with an account of the state of renewable energy in South Africa, which includes a review of the local renewable energy enabling policies, a summary of the status of the South African renewable energy procurement programme and commentary around the deployment of CSP in South Africa. The topic of sustainability transitions is then introduced in the context of the energy transition towards a decarbonised energy sector, followed by a description of the TIS framework and its relevance to the study of the development and diffusion of RETs. This is followed by a brief review of the literature focused on the application of the framework to the development and diffusion of RETs. The chapter concludes with a short description of the relevance and aims of this study.

2.1 Renewable Energy

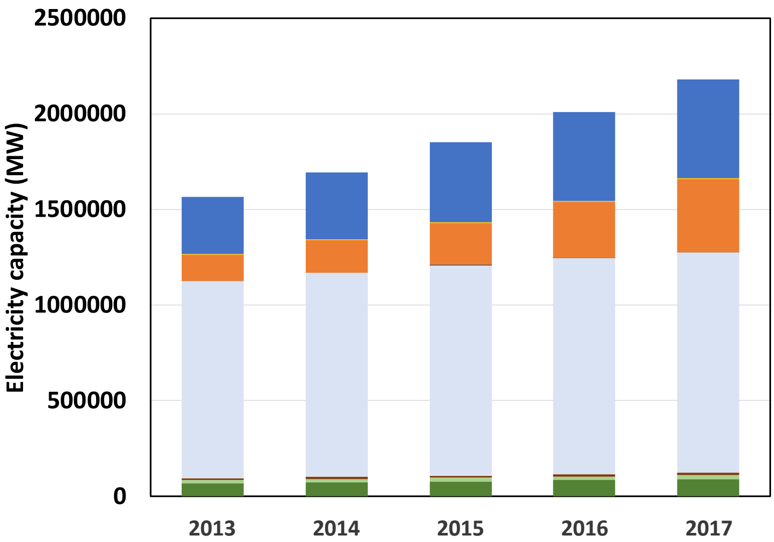
2.1.1 Renewable Energy Technologies

Renewable energy is energy derived from naturally replenished resources (e.g. sunlight, wind, waves, geothermal heat and biological matter) that are available over wide geographical areas. This is in contrast to fossil fuels (e.g. coal) that are derived from finite sources and are concentrated in certain geographical areas only. This form of energy can therefore be harnessed to address security of supply issues faced by using finite fossil fuel resources. Additionally, renewable energy technologies are attractive as the energy produced has a significantly lower environmental impact i.e. unlike fossil fuels they do not release harmful chemical air pollutants and GHGs in the production of energy, this results in improved health benefits for the population (IRENA, n.d.-a). This makes RET an invaluable component in the sustainability transition towards a decarbonised electricity sector (see Section 2.3). A summary of the main forms of renewable energy sources are given in Table 1 – these are bioenergy, geothermal, hydropower, ocean, solar and wind; for a more detailed description see the International Renewable Energy Agency (IRENA) publicly available resources (IRENA, n.d.-b).

Table 1: Summary of the main renewable energy sources and technologies (IRENA, n.d.-b)**.**

Renewable energy technology	Description
Bioenergy Traditional Modern	Energy derived from biological sources. 'Traditional' bioenergy is sourced from the combustion of biomass (e.g. wood, animal waste and charcoal). 'Modern' bioenergy refers to liquid biofuels produced from plant mass (e.g. bagasse, maize) or biogas produced through anaerobic digestion of organic material or biogas harvested from landfills.
Geothermal	Heat from the earth is used to produce steam that can be used to drive a turbine to generate electricity.
Hydropower	Energy derived from flowing water is used to drive a turbine to generate electricity.
Ocean	Energy harnessed from tides, waves and currents can be used to produce electricity. Most of these technologies are still at research and development stage.
Solar PV CSP	Energy harvested from the sun is used to produce electricity. There are two main technologies, solar photovoltaics (PV) and concentrated solar power (CSP). Solar PV technology comprises electronic solar cells that convert sunlight directly into electricity. CSP technology uses mirrors to concentrate solar energy to heat a transfer fluid that is used to produce steam to drive a turbine to generate electricity.
Wind	A wind turbine comprises blades attached to a turbine. The blades are rotated by the wind, which in turn rotate the turbine that is used to produce electricity.

The increase in global installed renewable energy capacity (broken down by technology) from 2013 – 2017 is given in Figure 5. From this data it can be seen that the amount of RE is progressively increasing each year and in 2017 a record breaking 167 GW of installed renewable energy was added, thereby increasing the global RE capacity by 8% relative to 2016 (IRENA, 2018). Hydropower constitutes the largest share of total RE (*ca* 53% in 2017), followed by wind (*ca* 24% in 2017) and solar PV (*ca* 18% in 2017).



	2013	2014	2015	2016	2017
Bioenergy traditional	68346	72373	77679	84927	89635
Bioenergy modern	15951	17258	17965	18754	19323
Geothermal	10735	11191	11838	12266	12913
Hydropower	1032807	1069118	1101616	1130474	1153911
Ocean	509	512	512	518	526
Solar PV	134048	169642	220284	292170	384621
Solar CSP	3841	4498	4749	4849	4951
Wind	299801	349103	416739	467488	513547
Total	1566038	1693695	1851382	2011446	2179427

Figure 5: Global cumulative RE capacity broken down by technology for the period 2013 – 2017 (IRENA, n.d.-b).

The levelized cost of the various RET in years 2010 and 2017 is given in Figure 6 (IRENA, n.d.-b), where the levelized cost of electricity (LCOE) is defined as the revenue required to recover capital and operating expenditure over a specified plant lifetime (Dowling, Zheng, & Zavala, 2017). It can be seen that in most cases the cost has significantly decreased in this time period, reaching cost parity with fossil-fuel based electricity. The exception is CSP that still prices above the upper bound of the fossil-fuel electricity band.

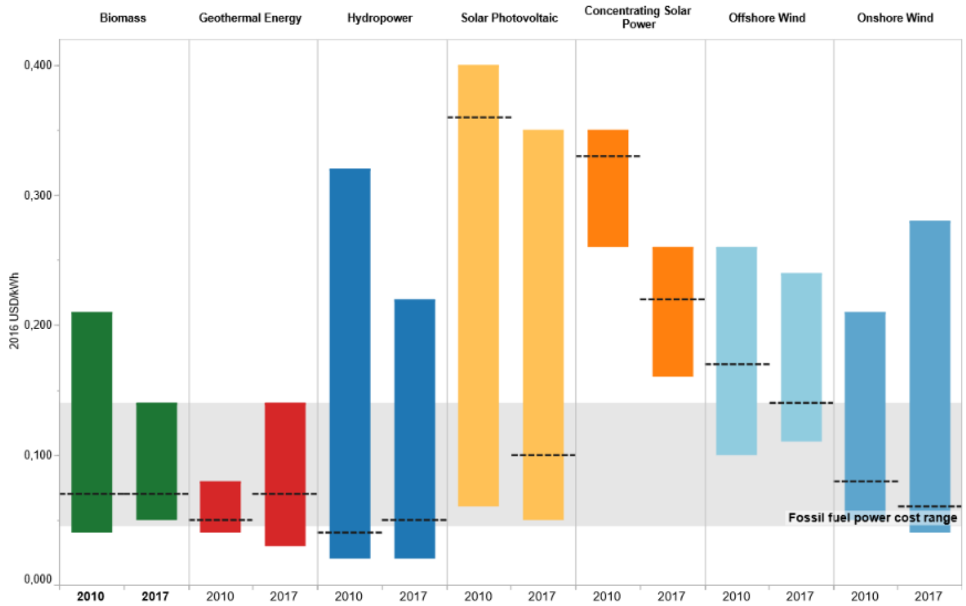


Figure 6: Global levelized cost of electricity from utility-scale renewable energy power generation in 2010 and 2017. Dashed line indicates the global weighted average and the grey band represents the cost range for fossil-fuel power generation (IRENA, n.d.-b)**.**

Renewable energy deployment also has a host of socio-economic benefits associated with it. These have been captured in the 2018 IRENA RE Roadmap document and include: increase in GDP (through investment stimulus and global trade), welfare improvements and job creation. On the latter point, it is acknowledged that there will be approximately 7.4 million fossil fuel job losses in the transition from fossil fuel to renewable energy, but these will be offset by the much greater gain in renewable jobs, which are estimated to be in the order of 19.0 million RE jobs (i.e. a net gain of 11.6 million jobs will be realised) (IRENA, 2018a).

However, despite the significant strides that have been made in increasing global renewable energy capacity there are significant challenges to overcome. These include competition with incumbent fossil fuel energy sources, stranded assets, capital expenditure, research funding to increase competitiveness, public acceptance, overcoming incorrect assumptions (e.g. around the cost of renewable energy), grid reliability and intermittence of supply (Foster et al., 2017; SANEDI, n.d.). This latter point is highly pronounced with solar PV and wind energy i.e. energy is only produced when the sun shines or when the wind blows (Craig, Brent, & Dinter, 2017). This phenomenon can be countered by coupling energy storage technology (e.g. batteries) to the renewable energy technology at significant cost (Feldman, Margolis, Denholm, & Stekli, 2016). CSP, with its inherent storage capacity, offers a potential solution to this issue.

2.1.2 Concentrated Solar Power

The first CSP plant in operation was installed in California, USA in the mid-1980's, and is considered a 'young' technology compared to other energy technologies (Fuqiang et al., 2017). As such the technology is still progressing down it's learning curve and there is still significant potential for large cost reduction in technology development (Lilliestam et al., 2018).

As mention in Table 1, CSP technology uses mirrors or lenses (collectively termed 'solar collectors') to concentrate sunlight onto a small receiver area containing a heat transfer fluid (HTF). The objective is to heat the fluid to produce steam that drives a turbine to generate electricity; the technology on the back end of the plant is essentially the same as a conventional fossil fuel plant (Figure 2). The HTF also functions as thermal storage, whereby the fluid can be stored for a period of time and subsequently mobilised to heat water when electricity is needed.

This ability to store heat and flexibly dispatch electricity even when there is no solar radiation renders CSP a dispatchable form of renewable energy and provides it with a competitive advantage over PV and wind renewable energy. This means that unlike PV and wind, CSP can be used to dispatch electricity according to market needs. Currently CSP can be used as a source of peak power (i.e. power needed when the demand is highest, typically in the early evenings), plants that provide this form of service are called 'peaking plants'. It is envisaged that with further technological advancement it could provide baseload electricity (i.e. the power required to supply continuous demand). As a result, CSP has been described as a renewable energy technology that has significant potential to meet future energy demand (Crespo et al., 2016).

CSP is however, not without its disadvantages. In order to reach the efficiencies that make CSP economical, high levels of solar irradiance are required. Solar radiation is measured using the metric of direct normal irradiation (DNI) and it has been estimated that CSP systems are only economic in regions with a minimum DNI of 1 800 – 2 000 kWh/m^2/year (Behar, Khellaf, & Mohammedi, 2013). This restricts the feasibility of the technology to certain geographical areas – see Figure 7 (Trieb, Schillings, O'Sullivan, Pregger, & Hoyer-Klick, 2009).

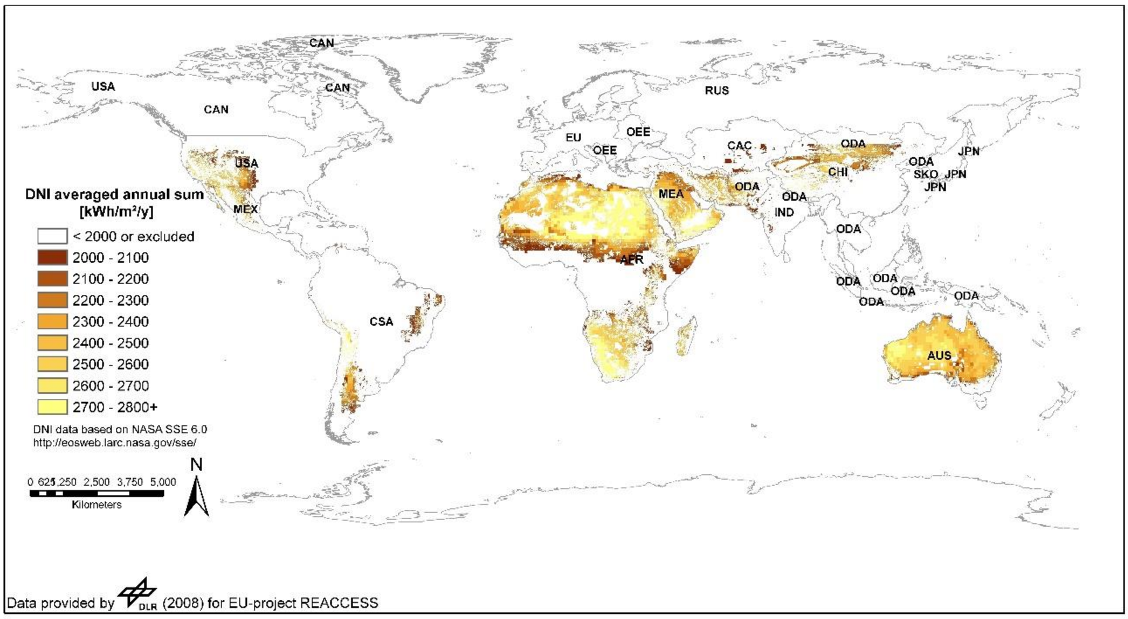


Figure 7: Global view of the annual sum of DNI. CSP viable regions are highlighted in colour (Trieb et al., 2009)**.**

Additionally, CSP requires large quantities of water for cooling of steam, cleaning of mirrors and other process requirements (ca 3 500 litres/MWh, compared to PV or wind energy that uses <5 litres/MWh). This is a severe drawback for CSP plants attempting to operate in water stressed regions and raises environmental impact concerns (Macknick, Newmark, Heath, & Hallett, 2012). Finally, as is shown in Figure 6, the LCOE for CSP is still significantly higher than PV and wind RE and as a consequence the global share of CSP is much lower than these two conventional RE sources. Part of this reason is that CSP suffers from a phenomenon called the 'valley of death', which is an inability to commercialise a viable technology due to an inability to access resources to do so (Craig et al., 2017). The CSP costs depend on, amongst other factors, technology, regional subsidies, solar radiation and local electricity market prices (Dowling et al., 2017). However, it was proposed that the LCOE metric for describing the cost of RET does not sufficiently capture the value of peak electricity dispatch and as a consequence does not reflect the true market value of CSP (Joskow, 2011). This argument was reinforced by recent reports of costs as low as USD 0.07/kWh for two projects in Australia and Dubai respectively (Lilliestam & Pitz-Paal, 2018). In the case of the Australian plant, this low value was obtained as the business model facilitated the sale of power at a premium outside of its power purchasing agreement (PPA) during peak electricity demand when the PV fleet is offline. In the Dubai case this low value was attained through an extended PPA duration and low financing costs (Lilliestam & Pitz-Paal, 2018). If these business models can be replicated in other regions this may signal the commercial breakthrough CSP requires to dominate the RE market.

2.1.2.1 Concentrated Solar Power Technologies

A review of the four main forms of CSP technologies is given in the following section. It is noted that in addition to utility-scale electricity applications, solar thermal technology can also be used on a smaller domestic and industrial cooling and heating applications (e.g. generating process heat, desalination etc); however, a review of this application of the technology is beyond the scope of this study.

There are four types of CSP technologies, namely parabolic trough collectors (PTC), linear Fresnel collectors (LFC), Stirling dish technology and solar tower technology (Zhang et al., 2013). These technologies are classified according to the manner in which the solar collectors concentrate the sun's rays. PTC and LFC are classified as line-focusing systems as they concentrate the rays along a focal line, whereas Stirling dish and solar tower technology are considered point-focusing systems as they concentrate the rays towards a single focal point (Siva Reddy, Kaushik, Ranjan, & Tyagi, 2013).

Illustrations of the focusing methods of the four technologies are given in Figure 8 and a brief description of each technology is provided in Sections 2.1.2.1.1 – 2.1.2.1.4 below.

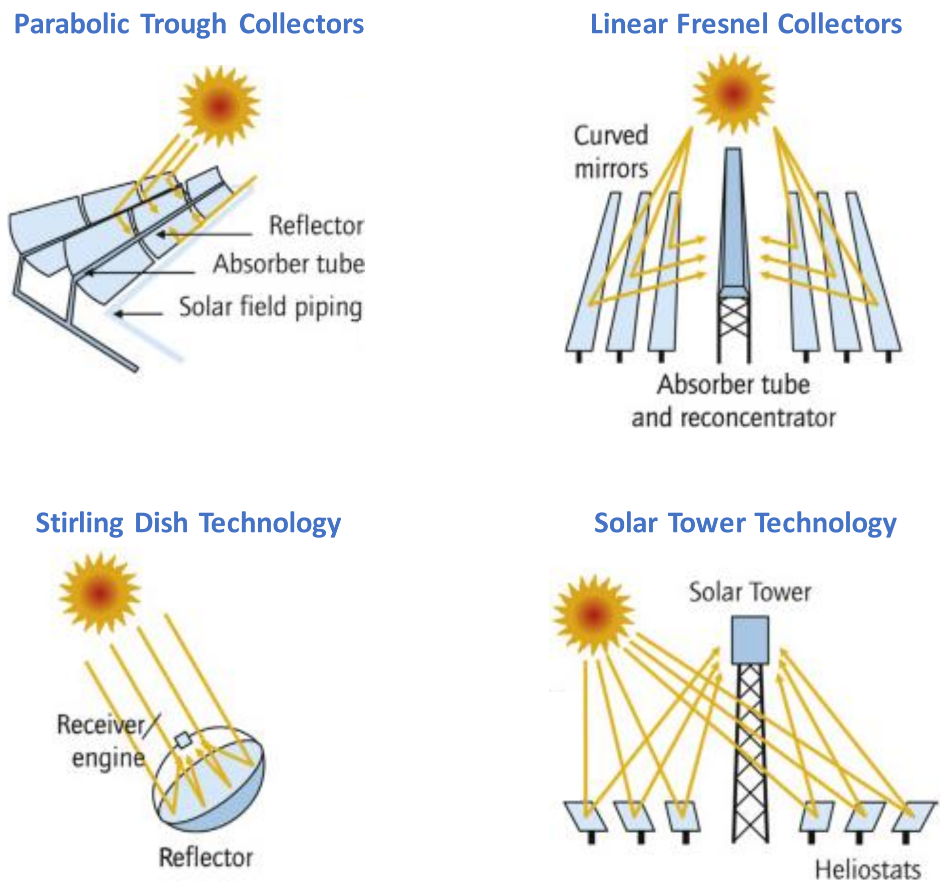


Figure 8: Illustration of the four types of CSP technologies and their respective focusing methods. Rays from the sun are depicted as yellow lines reflecting off the solar collector surfaces and concentrating onto a specific area or point. Figure adapted from reference (Fuqiang et al., 2017)**.**

2.1.2.1.1 Parabolic Trough Collectors

Parabolically curved, trough-shaped mirrors concentrate the sun's rays onto a receiver pipe containing a pre-heated heat transfer fluid (either a synthetic oil or molten salt), running along the focal line of the mirror. The temperature of the transfer fluid increases to *ca* 400 ºC or 540 ºC, depending on the properties of the transfer fluid (the upper bound is associated with molten salt). The heat is then used to generate electricity in a conventional steam generator. The mirrors are arranged in arrays up to 100 metres in length, where a single-axis tracking mechanism continuously orients the mirrors towards the sun as it moves to maximise exposure (Fuqiang et al., 2017).

2.1.2.1.2 Linear Fresnel Collectors

Individual mirrors are arranged at different angles to concentrate the rays on either side of a fixed receiver, which is located along the focal line of the mirrors above the mirror-field. Each line of mirrors has a single-axis tracking system that is individually optimised to ensure that the rays are always focused on the receiver. The receiver comprises an absorber tube filled that is either filled with water for direct steam generation or a heat transfer fluid. There are several cost-related advantages of LFC over PTC i.e. the mirrors are flat (or only slightly curved) and as a result are substantially less expensive to produce, the required support infrastructure is lighter and therefore cheaper, wind-related damage is less as LFCs are more compact, the mirror surface-to-receiver ratio is higher in LFC (receivers are the most expensive component in both technologies). However, the efficiency of this technology is lower than PTC and this needs to be weighed up against the above-mentioned cost savings (Zhu, Wendelin, Wagner, & Kutscher, 2014).

2.1.2.1.3 Stirling Dish Technology

The Stirling dish system comprises a parabolic dish-shaped concentrator that tracks the sun along two axes, and a receiver placed directly at the focal point of the dish. The HTF in the receiver is heated and supplied to the Stirling engine to generate power. It has been noted that this technology has the potential to offer the highest efficiency of all CSP systems, it also has the smallest land footprint and can be placed on uneven terrain; however, despite these advantages the technology is still undergoing development and optimisation, with only a few systems in operation (Zhang et al., 2013).

2.1.2.1.4 Solar Tower Technology

In this technology the receiver is located in a high tower at the centre of a field of mirrors laid out in concentric circles. The mirrors, referred to as 'heliostats' are individually controlled by a computer and track the sun along two axes to constantly focus the maximum amount of direct solar irradiation onto the receiver. A HTF, typically a molten salt, is pumped up to the receiver and heated to temperatures in excess of 600 ºC. The HTF is then pumped down to the storage area where it is used to produce steam immediately or stored for later use (Behar et al., 2013). Tower technology can achieve higher temperatures and therefore higher efficiencies than PTC and LFC, and it is anticipated that for these reasons tower technology will be the dominant technology in the future (Fuqiang et al., 2017).

A breakdown of the capital costs involved in construction of a tower CSP plant is given in Figure 9. From these values it can be seen that the heliostats account for *ca* 38% of the total cost of the plant (Black & Veatch, 2012). This area is therefore subject of much R&D aimed at increasing efficiencies and reducing cost. Additional cost reductions can come from installing larger plants (economies of scale are reached above 130 MW installed capacity) and standardisation of components (components may differ across different tower technology developers; standardising components will realise cost savings) (WWF, 2015).

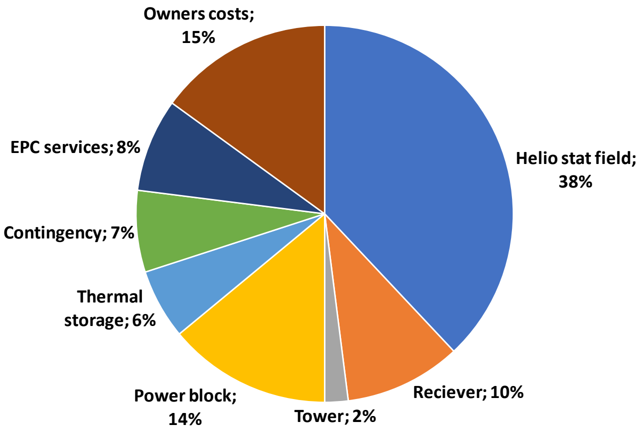


Figure 9: Capital cost breakdown for a tower CSP plant with thermal storage. Note – EPC refers to engineering, procurement and construction costs and cost breakdown is based on a total system cost of $7 040/kW installed capacity (value in 2012 $) (Black & Veatch, 2012)**.**

2.1.2.2 Global CSP Capacity

Planned CSP projects are tracked by the International Energy Agency (IEA) through the *SolarPACES* programme, which is aimed at promoting collaborative development, testing and marketing of CSP plants (IEA, n.d.-b). Project developers supply information that is reviewed by the *SolarPACES* experts, projects are then classified according to a number of parameters including technology used and operational phase of the project, this information is then compiled into a data base. Based on the data obtained through this programme it can be seen that the majority of operational CSP projects utilise the PTC technology Figure 10; however as more projects come on line it is anticipated that the shift will be towards tower technology due to its increased efficiencies (see 2.1.2.1.4) (Behar et al., 2013).

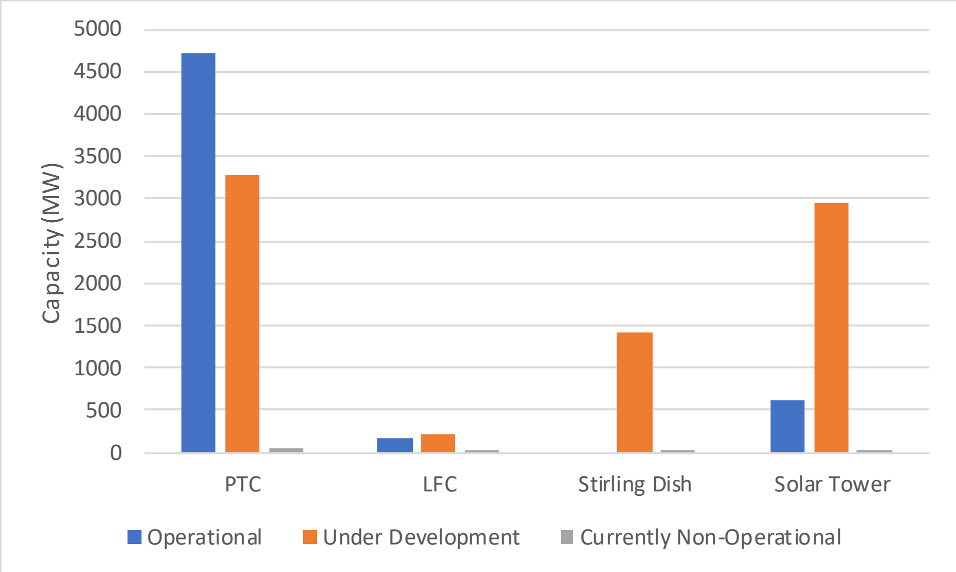


Figure 10: A comparison of reported installed or planned capacity for each of the four CSP technologies broken down by units in operation, under development or non-operational (data: (NREL, n.d.)**.**

As of 2017 the global installed capacity of CSP is 4 951 MW (ca 5 GW), this has increased from a mere 535 MW in 2008 (Figure 11). Spain accounts for more than half of this capacity (2 300 MW), followed by the USA (1 758 MW) and South Africa (300 MW) (Figure 11). However, despite these significant strides in CSP installation over the years, when compared to PV with a global installed capacity of ca 385 GW, CSP is considered a niche market (IRENA, n.d.-b; Lilliestam et al., 2018).

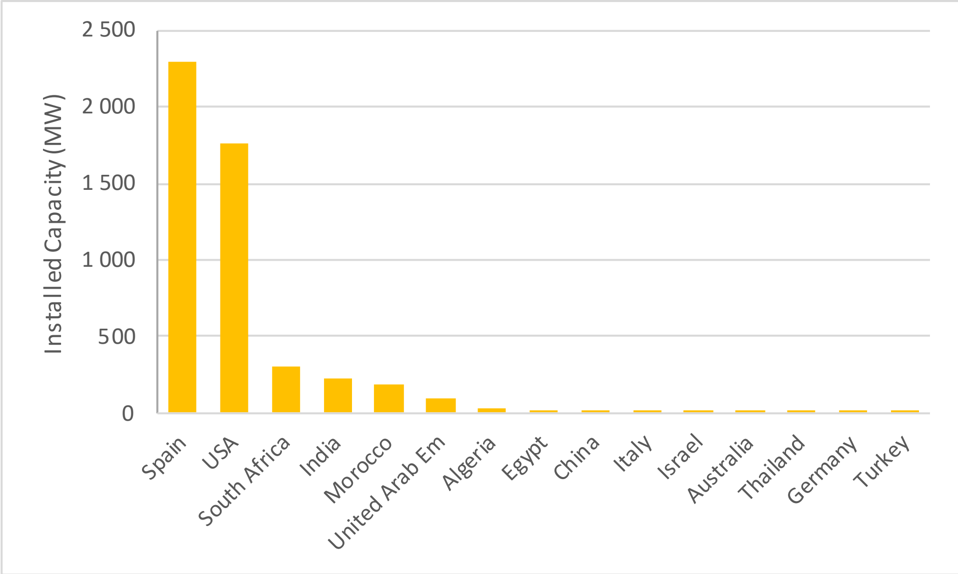


Figure 11: Global installed CSP capacity in 2017 (IRENA, 2018).

The success in Spain has been largely attributed to the use of a RE feed-in tariff (REFIT) policy instrument to stimulate CSP development. A REFIT incentive is one in which governments pay private electricity producers for RE electricity at a predetermined price (NERSA, 2009). In the period between 2004 and 2007 two different renumeration models were implemented that created a favourable economic incentive for CSP investment and further development. Namely, CSP electricity generators that sold electricity to a distributor received 300% of the reference price during the first 25 years and 240% thereafter, whereas those selling to the electricity market received the negotiated market price of electricity, a premium of 250% of the reference price during the first 25 years, 200% afterwards, and an incentive of 10%. These tariffs were adjusted slightly from 2007 to 2012, when they were finally stopped for all new applicants and replaced with a 'Complementary Payment' of 7.5% added to the price of electricity (SolarPACES, 2017). A case study analysis of different incentive models for CSP development is given in the appendix of reference (WWF, 2015).

2.2 The State of Renewable Energy in South Africa

The availability of abundant and cheap coal has rendered South Africa a highly emissions intensive society with significant fossil-fuel based assets (Altieri et al., 2016). This can clearly been seen in Figure 12, which shows that approximately 68% of the country's energy consumption originates from coal (BP, 2018). As a signatory to the Paris Agreement (UN, 2015), South Africa has pledged to reduce GHG emissions to combat climate change. However, as a developing country plagued by high unemployment rates and slow GDP growth (Schwab, 2018), the country cannot afford to prioritise GHG mitigation over economic growth. Significant investment in renewable energy capacity is seen as one of the only ways of achieving both simultaneously.

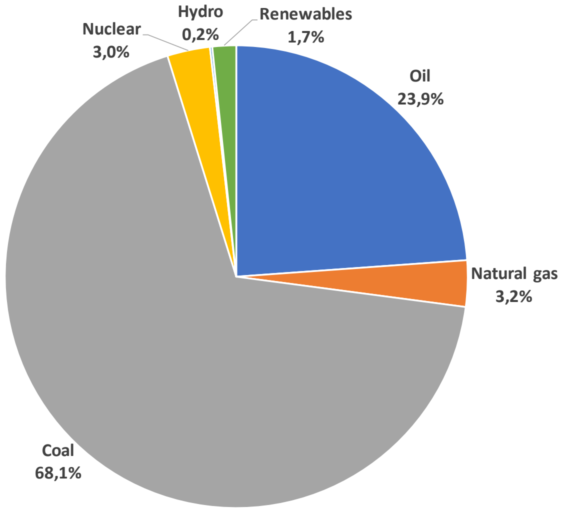


Figure 12: Primary energy consumption by fuel for South Africa in 2017 (BP, 2018)**.**

The installed renewable energy capacity in South Africa over the period from 2008 – 2017 is given in Figure 13 (left). As of 2017, South Africa had approximately 4 959 MW of installed renewable energy sourced mostly from wind energy (2 094 MW), solar PV (1 714 MW) and solar CSP (300 MW) Figure 13 (right). This represents a mere 0.23% of global installed capacity (IRENA, n.d.-b). It can be seen from Figure 13 (left) that the amount of installed capacity was fairly constant at ca 900 MW from 2008 – 2012, then as a result of enabling policy and the REI4P, this value started to rise sharply. A brief description of these enabling policies is given in 2.2.1.

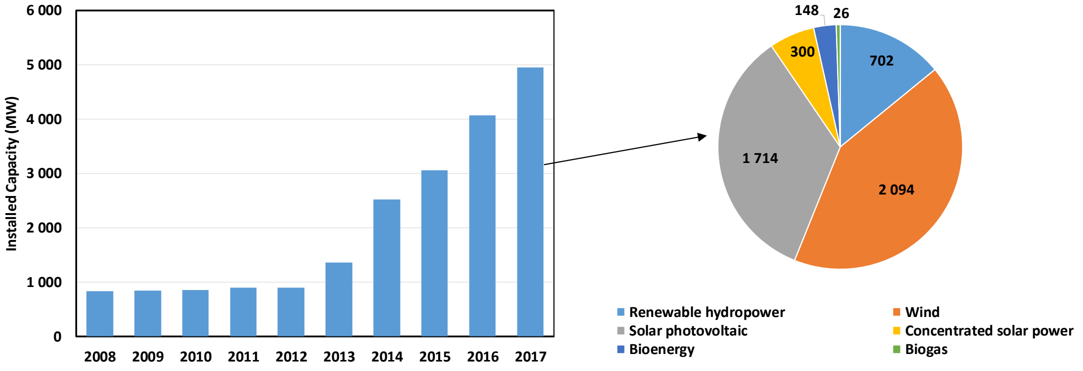


Figure 13: (Left) Installed renewable energy capacity (MW) in South Africa from 2008 – 2017 and (right) installed renewable energy capacity in South Africa in 2017, broken down by RET (IRENA, n.d.-b)**.**

2.2.1 Renewable Energy Enabling Policy and Regulatory Environment in South Africa

Policy support for renewable energy is essential for successful market deployment and South Africa has several key policy documents that have progressively facilitated a growing renewable energy sector in the country. A summary of these policies and their contribution is given in Table 2. As has been alluded to in Section 1, the key policy document underpinning the future of renewable energy in South Africa is the IRP. As such the development of this document and the key features of each revision will be expanded upon in further detail. Additionally, a list of key government departments involved in the energy and electricity sector are given in Table 3.

Table 2: Key policies and legislation that have facilitated the development of a renewable energy sector in South Africa.

Document	Description
The White Paper on Energy Policy (1998)	First document to acknowledge the need to diversify energy sources in order to secure energy supply.
White Paper on Renewable Energy Policy (2003)	Objective of the document was to establish conditions for commercial implementation of renewable energy. Introduced the concept of energy procurement from IPPs. Only published in 2012.
Electricity Regulation Act 4 of 2006	Allows for the Minister of Energy to determine the quantity of generation capacity required and the proportion of which requires participation by IPPs. It also makes provision for the role that Eskom must play as the designated buyer i.e. it must by the electricity generated by IPPs and provide access to the power transmission and distribution systems.
National Energy Act 34 of 2008	Mentions the need for increased generation and consumption of renewable energies in energy planning.
National Development Plan (2011)	A long-term development plan that details goals to be attained by different sectors in society to achieve sustainable economic growth by 2030. Specifically refers to 7 000 MW operational RE by 2020 and 20 000 MW of installed RE and gas capacity by 2030.
White Paper on Climate Change (2011)	Sets out South Africa's climate change response objective.
Green Economy Accord (2011)	Alignment between government, business and labour towards a low-carbon green economy.
IRP 2010 promulgated (2011)	Provide potential scenarios of electricity resources and technologies that South Africa should invest in to meet national demand projections up to 2030.
IRP Revision (2013)	Update of IRP 2010 to align renewable energy scenarios with South Africa's climate change commitment.
Draft IRP (2016)	Includes guides for renewable infrastructure development.
Integrated Energy Plan (2016)	Provides a roadmap for the future energy landscape in South Africa (including liquid fuels, gas and electricity) and includes ambitions of 17 800 MW of RE.
Draft IRP (2018)	Currently out for comment. Updated to include assumptions of declining grid electricity demand. Renewable energy growth is constrained, nuclear sees no additional growth and gas features more prominently.

There are currently four versions of the IRP, each of which is aimed at providing potential scenarios of electricity resources and technologies that South Africa should invest in to meet national demand projections up to 2030. It is intended to be a living plan, subject to continual revision by the DoE. The initial IRP was released for public comment in 2010 and promulgated in 2011. The report was promulgated at a time when the coal-dominated electricity sector was facing severe challenges around the security-of-supply and thus projects that an additional 52.2 GW of new capacity will be required by 2030. During this time is it predicted that the renewable energy share of production steadily increases from 0 – 9%, whilst coal declines from 90% to 65% and nuclear increases from 5% to 23%. An update of the IRP 2010 was release in 2013 in response to the fact that the scenarios provided in the 2010 version were not well aligned with South Africa's climate change commitment. It therefore provides for a scenario in which non-coal based electricity retains a greater share of the energy mix. Notably the scenario in which nuclear becomes prohibitively expense results in new wind and CSP capacity, with CSP accounting for 38 GW of new capacity by 2050. The third draft IRP was released in 2016 for public comment but was never ratified. Unlike the previous version that allocated a large portion of renewable energy to CSP, this version allocates new growth to solar PV, wind and landfill gas technologies (WWF, 2015). This document was the subject of much criticism mostly aimed at the costs used for renewable energy, the unjustified constraints placed on the renewable capacity and prominence of nuclear energy. This then resulted in a re-drafting of the IRP, which was release late in 2018. A key assumption in the document is that grid electricity demand is declining and will continue to decline, coal plants will be decommissioned as they reach end of life. The model also places a restriction on renewables and formulates a least cost plan that only includes further development in PV and wind. The breakdown of the anticipated 2030 installed capacity is: 34 000 MW from coal (46%), 11 930 MW from gas (16%), 11 442 MW from wind (15%), 7 958 MW from solar PV (10%), 4 696 MW hydro (6%), 2 912 MW pumped storage (4%), 1 860 MW from nuclear (2.5%) and 600 MW from CSP (1%) i.e. no additional provision is made growth in either nuclear or CSP generated electricity. This document is currently out for public comment.

Table 3: Key government departments involved in the South African electricity sector (GreenCape, 2017).

Department	Description
National Treasury	Responsible for managing South Africa's national government finances. In the context of the energy sector they ensure affordability of electricity supply and provide sovereign guarantees for the signed PPAs.
Department of Public Enterprises	The governments shareholder representative with oversight responsibility for many state-owned enterprises, including Eskom.
Department of Environmental Affairs (DEA)	This department is the custodian of the environment and ensures that the South African natural resources are protected, conserved and improved. In the context of renewable energy, they are responsible for signing off of environmental impact studies.
Department of Trade and Industry (dti)	This department is responsible for commercial and industrial policy. They ensure industrialisation through the local content requirements of the REI4P, as well as black economic empowerment and small business development.
Department of Science and Technology (DST)	This department is responsible for scientific research development in South Africa.

2.2.2 The Renewable Energy Independent Power Producer Procurement Programme (REI4P)

The REI4P is a competitive bidding process aimed at procuring renewable energy capacity in accordance with the IRP from the private sector. It was initiated in August 2011 and is administered by the Department of Energy (DoE). The technology areas being pursued under the REI4P are wind, solar PV, solar CSP, biogas, biomass, landfill gas and small hydro power. The programme includes both large utility scale projects and small-scale projects, where the latter is defined as projects with installed capacity below 5 MW (IPPPP Office, 2018). The small projects programme was introduced in 2013 to encourage participation from small and medium enterprises (SMEs) (Eberhard & Naude, 2017; IPP, n.d.).

The procurement targets for the REI4P are set out in the form of ministerial determinations, which stipulate both the quantity of procured capacity and the technologies required to achieve the target. The first determination was made in 2011 and it declared that 3 725 MW should be procured from RET. This target has subsequently been revised 3 more times, adding 3 200 MW in 2012, 6 300 MW in 2015 and 1 500 MW in 2016; thus, bringing the cumulative ministerial determination to 14 725 MW. The 14 725 MW must comprise 6 225 MW solar PV, 6 360 MW wind, 1 200 MW CSP, 195 MW small hydro, 25 MW landfill gas, 210 MW biomass, 110 MW biogas and 400 MW from small projects (IPPPP Office, 2018). The DoE, National Treasury (NT) and the Development Bank of Southern Africa (DBSA) established the IPPP Office with the mandate of delivering on these new procurement objectives (IPPPP Office, 2018).

The REI4P process consists of a series of single step, closed-bid auctions whereby Independent Power Producers (IPPs) submit bids for the defined RET categories in response to a Request for Qualification and Proposal (RFP). Bids are then screened and evaluated according to specific criteria. Once selected, successful bidders (referred to as "preferred bidders") are required to sign 20-year power purchasing agreements (PPAs) that allows the particular IPP to sell their electricity to Eskom during that time frame (prices are indexed to inflation) (Eberhard & Naude, 2016). IPPs are responsible for the costs associated with the 'shallow' connection to the nearest substation, whereas Eskom bares the deep connection costs related to strengthening the transmission system. In this process risk is shared between both the IPPs and Eskom (Eberhard & Naude, 2016). An overview of the tender process and key types of companies that are involved in the process is given in Figure 14.

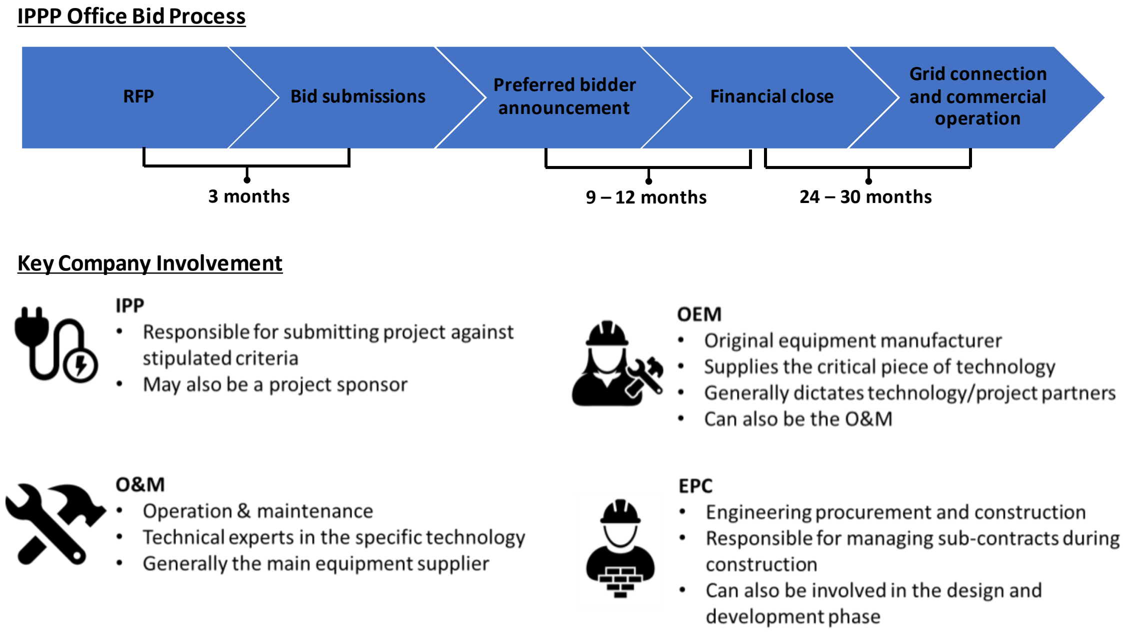
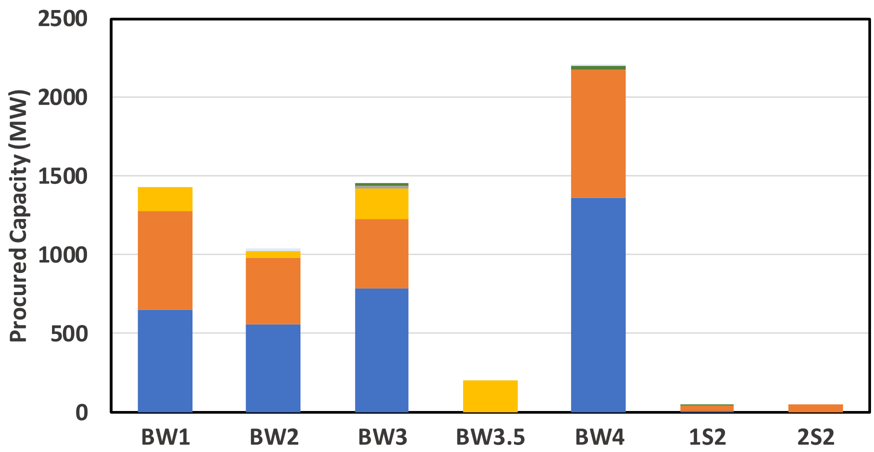


Figure 14: (Top) Overview of the REI4P bidding process as set out by the IPPP office with rough timeline indictors and (bottom) summary of the different company involvement required during the process. Figures adapted from references (Eberhard & Naude, 2017; GreenCape, 2017)**.**

Bids are evaluated using a 70/30 scoring criteria, where 70% of the score is based on price and 30% on economic development criteria (WWF, 2015). These developmental criteria have been included by design through the multi-ministerial collaboration between the NT, the DoE and the department of trade and industry (dti) and are aligned with South Africa's national development agenda detailed in the National Development Plan (NDP) (National Planning Commission, 2012) and the Strategic Infrastructure Projects (SIPs)

(DHET, 2015). They include the following factors: job creation (25%), local content (25%), ownership (15%), management control (5%), preferential procurement (10%), enterprise development (5%) and socio-economic development (15%) – see reference (Eberhard & Naude, 2017) for a more detailed explanation of these factors. Through the procurement of RET using the above-mentioned criteria, the REI4P aims to achieve the energy diversification mandate of the IRP and contribute to combating the global climate change challenge, whilst attracting private investment, stimulating local RET manufacturing capability and driving socio-economic and enterprise development.

To date, 7 bidding rounds or bid windows (BW) have closed; these have been labelled BW1, BW2, BW3, BW3.5, BW4 and 1S2 and 2S2 (where ‘BW’ and ‘S2’ denote utility-scale and small-scale projects respectively). It is noted that BW3.5 refers to a CSP only round and that BW4 was divided into two rounds, BW4 and BW4 expedited – the latter of which was designed to afford a second participation opportunity to projects that were not successful in previous rounds. A total of 6 422 MW has been procured over the 7 BW from 112 projects, representing 44% of the determined capacity of 14 725 MW (IPPPP Office, 2018). Of this procured capacity, 3 776 MW is operational, showing a steady progression towards the NDP interim target of 7 000 MW of operational RE capacity by 2020 and the IRP target of 17 800 MW from RE generation by 2030. A summary of the procured capacity as a function of bid window and technology as of March 2018 is given in Figure 15.



	BW1	BW2	BW3	BW3.5	BW4	1S2	2S2
Hydro	0	14	0	0	5	0	0
Biomass	0	0	17	0	25	10	0
Landfill	0	0	13	0	0	0	0
CSP	150	50	200	200	0	0	0
PV	627	417	435	0	813	30	50
Wind	649	559	787	0	1362	9	0

Figure 15: Procured capacity per BW, broken down by RET. Data obtained from (IPPPP Office,

2018).

The REI4P has garnered a number of achievements both locally and internationally. For example, it has attracted more than R200 billion in investment over the 7 BWs. Of this, 76% has originated from domestic sources whilst the remaining 24% has come from a variety of foreign countries. FDI analysis has shown that the majority of this foreign funding comes from Europe; other significant funders include UK, Japan, China, India, Saudi Arabia, Korea, Africa and the USA (IPPPP Office, 2018). Based on an analysis of IPP investment trends in Sub-Saharan Africa, it can be seen that South Africa is currently attracting the majority of the continents renewable energy FDI (Eberhard, Gratwick, Morella, & Antmann, 2017). A high-level overview of some of the REI4P achievements to date are shown in Figure 16.

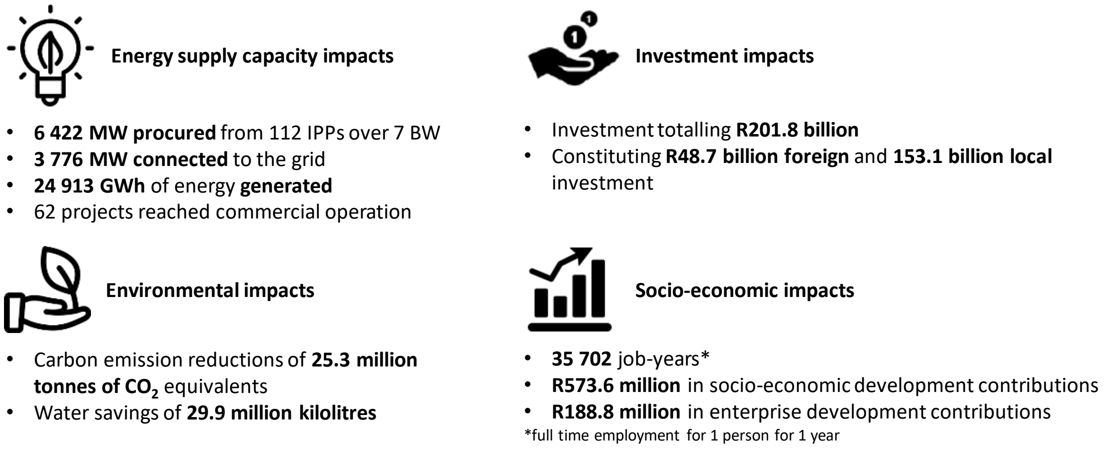
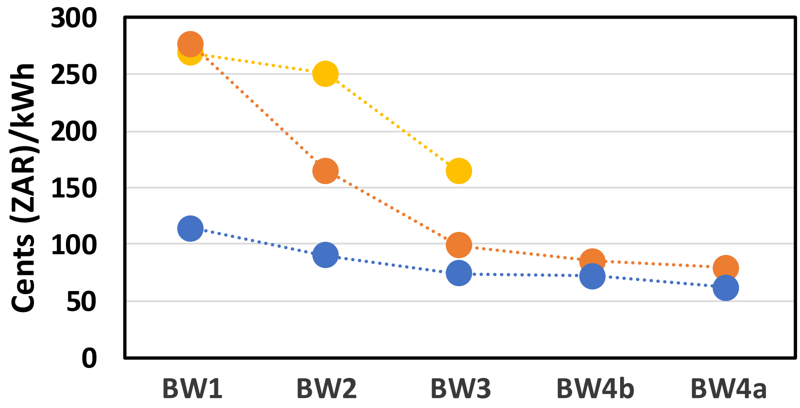


Figure 16: Summary of the REI4P impacts to date. Adapted from reference (IPPPP Office, 2018).

It can however be argued that the largest impact the programme has had is in the decline of energy prices. The average bid tariffs in each BW for the 3 largest allocations, namely CSP, PV and wind are given in Figure 17 (see (Eberhard & Naude, 2016) for an analysis of all technology price trends). It can be seen that wind (specifically onshore) has consistently been the cheapest energy source, whilst solar PV has shown the most drastic price drop from ZARc 276/kWh in BW1 to ZARc 79/kWh in BW4. Solar CSP has also shown a price decline from ZARc 276/kWh to ZARc 164/kWh in BW3 and, although this may seem fairly moderate compared to solar PV, this pricing does not accurately reflect the inherent energy storage advantage of CSP (see Section 2.2.2.1 for further discussion). The overall reduction in RET price has been attributed to factors such as lower capacity allocations per round to increase competitiveness, increased investor confidence and a reduction in input costs due to decreased international renewable energy equipment costs in response to excess supply (Eberhard & Naude, 2016).



	BW1	BW2	BW3	BW4b	BW4a
CSP	269	251	164		
PV	276	165	99	85	79
Wind	114	90	74	72	62

Figure 17: Weighted average bid tariff for CSP, PV and wind per bid window – prices in ZAR cents. BW4a awarded the highest rank bid responses, whereas BW4b refers to the expedited round that allowed previously unsuccessful candidates an opportunity to participate. These values are therefore higher and have been included before BW4a to represent the true downward trend in tariffs. Data obtained from (Eberhard & Naude, 2016)**.**

Given the achievements outlined in Figure 16 and Figure 17, it can be seen why the REIPPP programme is being internationally praised for its success (Eberhard et al., 2017). Against expectations it has managed to overcome the obstacles associated with tender processes i.e. claims of high transaction costs, complex processes, extended process times and the risk of inexperienced bidders defaulting on commitments, to deliver some of the lowest priced grid-connected RE capacity in the world (Eberhard et al., 2017). It is also being used to illustrate how a tender process can offer price competitiveness over the alternatives of directly negotiated projects or the use of the popularised REFIT policy incentive. This success however, has not come without challenges.

As the programme gained prominence, the National Union of Mineworkers (NUM), the National Union of Metalworkers of South Africa (NUMSA) and Transform RSA became outspoken opponents of the REI4P. The premise of these organisations' opposition is based on their assumption that the REI4P will lead to widescale coal-sector job losses and is in fact a veiled attempt at privatising Eskom under the guise of 'clean energy' (see for example (Arnoldi, 2018)). This opposition gained sufficient momentum to cause a 2 year delay in the signing of the 27 PPAs awarded to the preferred bidders in BW3.5 and BW4 (Creamer, 2018). Additionally, media reports indicated a reluctance of national power utility Eskom to sign the contracts, citing costs and electricity overcapacity as reasons for their opposition (Njobeni, 2017). Although the signing of the outstanding PPA in April 2018 served to reduce some of the uncertainty associated with the remaining goals of the programme, it has been argued that delay damaged government credibility and increased the risk associated with future investment in South Africa (Ahfeldt, 2017).

2.2.3 CSP Technology in South Africa

South Africa receives an annual average DNI of 2 816 kWh/m^2/year in the Northern Cape region, which makes it an ideal location for CSP (Figure 3). This is higher than both Spain (2 100 kWh/m^2/year) and the USA (2 700 kWh/m^2/year) (Knorr et al., 2016); yet, it lags behind these countries in installed capacity (Figure 11). As of mid-2018, a total of 600 MW CSP has been procured as part of the REI4P, with 300 MW already in operation (see Table 4 for a summary of the CSP projects procured to date). It is noted that from 2014 – mid-2018 Eskom had plans in place to build a 100 MW CSP plant outside of the REI4P. However, in July 2018 Eskom announced that they had cancelled the project and that the funds obtained from several international funders (in the order of USD $75 million or R1.1 billion) would be diverted towards battery storage investments (Njobeni, 2018).

Table 4: Status of current CSP projects in South Africa (Relancio, Cuellar, Walker, & Ettmayr, 2016).

Project Name	Technology	Capacity (MW)	BW	Storage (Hrs)	Status
KaXu Solar 1	PTC	100	1	2.5	Operational
Khi Solar 1	Tower	50	1	2.0	Operational
Bokpoort CSP	PTC	50	2	9.3	Operational
Ilanga CSP1	PTC	100	3	5.0	Construction
Kathu Solar Park	PTC	100	3	4.5	Start-up
Xina CSP	PTC	100	3	6.0	Operational
Redstone CSP	Tower	100	3	12.0	Planning

South Africa is one of the few countries to recognise and reward the dispatchability of CSP by offering a higher tariff peak tariff from BW3. Whilst all other technologies earn their flat bid tariff regardless of the time of day, CSP bidders were incentivised to utilise the storage ability to aid in meeting peak energy demand on the national grid by earning up to 270% of their base price during designated peak energy use times as shown in Figure 18 (Relancio et al., 2016).

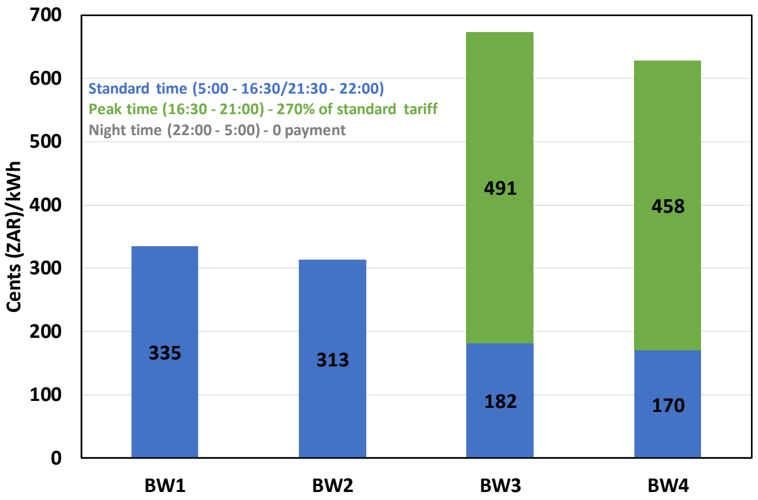


Figure 18: Average bid price for CSP from BW1 – BW4 of the REI4P (Relancio et al., 2016).

CSP is therefore an important technology for providing dispatchable energy, whilst aiding in South Africa's climate change mitigation strategy. However, in addition to this value proposition it also holds the potential to become an industrial development opportunity for the country.

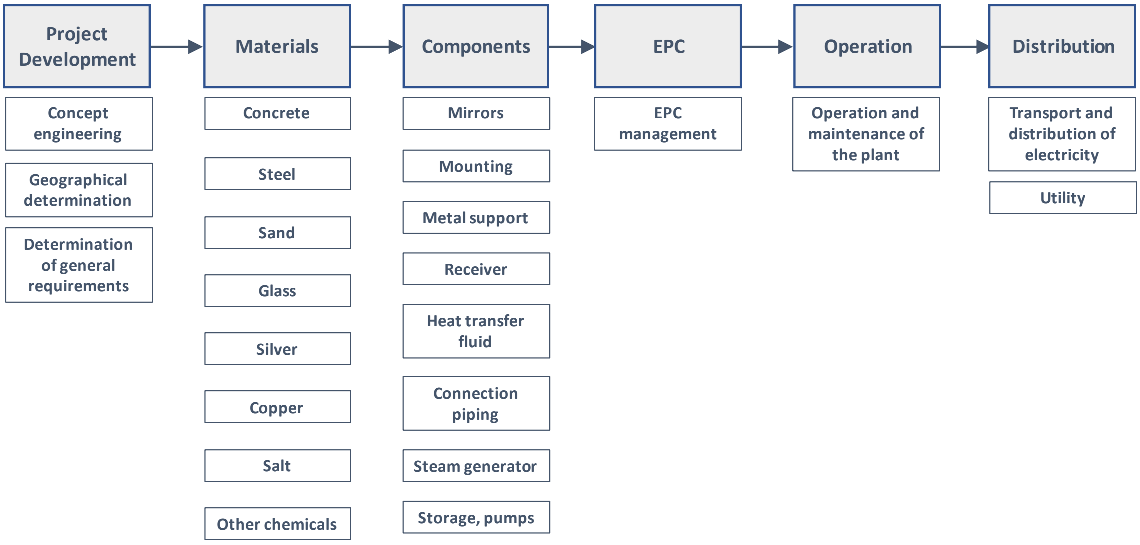


Figure 19: Value chain of a CSP plant (Vieira de Souza & Gilmanova Cavalcante, 2017).

In 2015 the WWF released a report highlighting South Africa's potential to become a global technology design and manufacturing leader in the production of utility-scale CSP plants (WWF, 2015). It was estimated that in the future 70 – 85% of this plant could be produced in South Africa by merely leveraging the countries existing capabilities (see Figure 19 for the value chain of CSP plants). It was argued that South Africa already has advanced capabilities in the design aspect through its strong core of innovative pioneers that have already developed and patented heliostat control systems. The existing domestic automotive manufacturing industry would provide an ideal platform to develop capabilities to manufacture technology components and abundant local suppliers already exist that could supply most of the componentry needed (e.g. electromechanical equipment, steel and glass companies). In addition, the favourable solar resources provide a platform for testing and piloting new technologies which can improve investor confidence in a technology. This inherent geographical advantage puts South Africa at a competitive advantage over other countries that may have similar aspirations and therefore holds the greatest job creation potential above all RETs. The results of the modelling in this study indicated that with the requisite policy in place South Africa could start to export components to the rest of Africa, creating approximately 134 000 jobs (WWF, 2015).

2.3 Sustainability Transitions

The means of promoting and governing the transition towards a decarbonised energy sector is explored in the political and social-science disciplines under the concept of sustainability transitions (Yu & Gibbs, 2018). In broad terms sustainability transitions are socio-technical transitions that occur over long time periods, involve a multitude of different elements with the aim of shifting established socio-technical systems to more sustainable modes of production and consumption (Walwyn, 2016). To attain a greater understanding of this definition requires further elucidation of key terms ‘socio-technical systems’ and ‘transitions’. At a conceptual level, a system is a model of reality that is designed for analytical purposes comprising distinct components that interact with one another and their environment (Markard & Truffer, 2008b). The components of a socio-technical system are actors (individuals, firms, organisations), institutions (regulations, standards of good practice) and material artefacts and knowledge (Markard, Raven, & Truffer, 2012). These components interact with the goal of providing a service to society and are often associated with sectors such as energy supply, water supply or transportation. A transition is a change that is carried out over a significant time span (typically 50 years or more) along multiple dimensions (Markard & Truffer, 2008b). In a socio-technical transition these dimensions include technological, material, organisational, institutional, political, economic and socio-cultural. Therefore, a socio-technical transition encompasses all the elements required to institutionalise a new technology, covering not only the introduction of the technology to society, but also the user practices (including aspects such as buyer commitment to the transition) and the institutional (e.g. regulatory and cultural) changes necessary for adoption (Nelson, Rueda, & Vermeulen, 2018). New products, services, business models and organisations are a typical outcome of a socio-technical transition.

The study of sustainability transitions has high societal relevance due to the scale of the sustainability challenge being faced by society today. This is however a complex field given the number of interacting components that need to be directed towards the goal of the transition. Some active areas of research in sustainability transitions include geographical dimension (Yu & Gibbs, 2018), management studies related to firm level sustainability strategies (Nelson et al., 2018), policy studies and policy advice (Kivimaa & Kern, 2016; Rogge & Reichardt, 2016). There are synergies with the theory of sustainability transitions and the innovation systems (IS) approach to studying technology diffusion. The remained of this thesis will focus on the IS approach.

2.4 Technological Innovation Systems

In the last two decades the socio-technical TIS framework has gained prominence in literature as a valuable conceptual building block of sustainability transitions research (Hekkert et al., 2011; Truffer, 2015). The framework concentrates on identifying the conditions required to develop and diffuse emerging technologies. As such, it is highly relevant for studying RET diffusion, which is known to be an essential component in the sustainability transition towards a decarbonised energy sector (UN, 2015). To manage, facilitate and steer this transformation process requires an in-depth understanding of the factors that contribute to the generation and diffusion of these technological innovations, as well as the dynamics between them i.e. it requires a systems approach (Markard & Truffer, 2008b). As stated by Jacobsson et al., (2000), “It is the character of this system that we need to comprehend if we are to understand how an energy system is transformed” (p.629).

The TIS framework is part of the IS theoretical school. There are a number of IS approaches all defined at different levels i.e. the National Innovation System (NIS) (Freeman, 1995; Godin, 2009), Sectorial Innovation Systems (SIS) (Malerba, 2002), Regional Innovation Systems (RIS) (Saxenian, 1996) and TIS (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007; Markard & Truffer, 2008b). The IS theory purports that innovation and technology change occur through interaction of actors with the system in which the technology is embedded (Hekkert et al., 2007). The performance of an IS depends on the interaction, as well as the flow and utilisation of knowledge, between the components and not their individual successes (Godin, 2009) i.e. it considers the ‘business ecosystem’ (Planko, Cramer, Hekkert, & Chappin, 2017).

The TIS can be conceptualised as a social network, comprising actors (organisations that contribute to a technology e.g. knowledge institutes, industry, government) and institutions (these constitute ‘the rules of the game’ i.e. polices, technology standards, legislation etc that formally regulate, control and shape human interaction) centred around a specific technology (Carlsson & Stankiewicz, 1991; Hekkert et al., 2007; Markard & Truffer, 2008a; Suurs & Hekkert, 2009). It is noted that IS literature collectively refers to actors, institutions, networks and technology as the structural components of the TIS, which provide insight into who is active in the system (Suurs & Hekkert, 2009). It has been more formally defined by Carlsson & Stankiewicz (1991) as "a set of networks of actors and institutions that jointly interact in a specific technology field and contribute to the generation, diffusion and utilisation of variants of a new technology and/or new product" (p.111) and more recently 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, p.3).

From these definitions it is clear that a variety of interlinked actors and activities are required to transform an innovation from an idea to a marketable product or service (Planko et al., 2017). The objective of a TIS analysis is therefore to determine which of these actors and activities are developed to the point where they are advancing the technology and which are underdeveloped and require an intervention. This level of development or maturity mapping is revelled systematically through a TIS 'functions of innovation systems' approach (Hekkert et al., 2007). A high-level overview of the use of the 'functions of innovation systems' approach to identify problem areas and design policy interventions is given in Figure 20 (Hekkert et al., 2011).

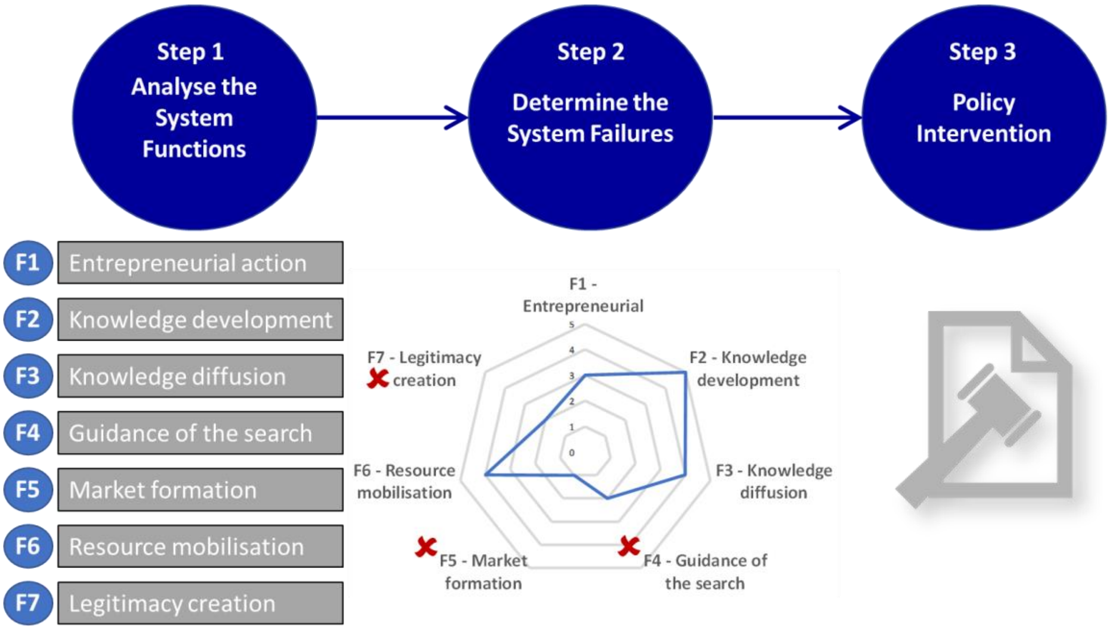


Figure 20: Process for analysis a TIS for policy intervention. Adapted from reference (Hekkert et al., 2011)**.**

This approach has been summarised in Figure 20, which shows that Step 1 involves categorising the activities or processes in the IS according to 7 different functions (see Figure 20 and Section 2.4.1 for further detail). In Step 2, the level of maturity of that function is then determined by posing diagnostic questions to experts or key stakeholders; a function is deemed mature if the level of activity is sufficient to develop that particular technology. A functions level of maturity is then scored on a 5-point Likert scale (where 1 = very weak and 5 = very strong) and the results can be plotted to highlight areas for improvement. Once the level of maturity is established, Step 3 involves devising measures to enhance supporting factors and counteract those that block progress (Hekkert et al., 2007; Kebede & Mitsufuji, 2017; Markard & Truffer, 2008b). Though this approach TIS analysis ultimately finds use as a tool that can be used by policy makers and governing bodies to structure policies and formulate recommendations that will allow a technology to realise its full potential within a specific environment (Bergek et al., 2015). It is noted that different innovation systems may have similar components; however, the interaction between them may be substantially different (Hekkert et al., 2011; Wieczorek et al., 2013). As a consequence, the insights derived from a TIS in one location may not be transferable to the same technology development in another location. It is therefore important that this analysis is carried out for each technology and location pairing.

As has been established, the TIS approach has become widely acclaimed as a method to study socio-technical systems; however, it is still undergoing conceptual development and as such has garnered some criticism. Much of this criticism is addressed directly through the literature as specific systems are investigated. For example, (Suurs & Hekkert, 2009) introduced the concept of ‘event history analysis’ to address the perceived static nature of the TIS approach in analysing the biofuels TIS in the Netherlands; whereas (Edsand, 2017) expressed that the influence of the wider context in emerging markets is not dealt with sufficiently and proposed an expanded framework that includes ‘Landscape factors’ to investigate the barriers to wind energy diffusion in Colombia. However, there are also some general criticisms of TIS in the academic discourse on this topic (Truffer, 2015). These general criticisms are summarised in Table 5, along with the responses given by TIS subject-matter experts (Markard, Hekkert, & Jacobsson, 2015).

Table 5: Response to general criticisms of the TIS approach. Responses summarised from (Markard et al., 2015)**.**

Criticism	Response
How does TIS deal with context? TIS is inward-oriented and downplays the importance of external context structures (Musiolik & Markard, 2011).	The functions approach does account for both endogenous (internal to the IS) and exogenous (external to the IS) factors; it may however miss some nuances such as context dynamics that unfold as a consequence of the TIS. Therefore, there is an acknowledgement that a more systemic context analysis can improve TIS analysis.
How to delineate a TIS? Setting the boundaries of the TIS on a case-by-case basis may result in the analyst missing important relationships or interactions. It leads to lack of uniformity, which makes comparison difficult (Coenen, 2015).	It is agreed that many authors fail to explicitly state where they have drawn their boundaries and suggestions were provided how to improve this (e.g. it should be an iterative process, re-evaluate each time insights are obtained). The experts do however stand by the statement that TIS boundaries should be identified empirically and case-by-case.
How to deal with spatial aspects? Refers to insufficient consideration of geographical issues. A country specific TIS misses out on the global aspects of the TIS. It can also not be assumed that TIS development will be the same in developing, emerging and industrialised countries (Coenen, 2015; Coenen & Truffer, 2012).	It is agreed that there is a lack of guidance in how to account for the global linkages that influence a local TIS. Cross-country studies that examine how TIS structures in different countries complement one another are encouraged. It is also agreed that the degree of development of the country plays a significant role in the TIS formation. Although the TIS analyses does capture these dynamics, it is agreed that further theory development is needed.
Is the TIS framework useful for studying transitions? TIS analysis fails to account for the inertia of incumbent socio-technical regimes. It also fails in its ability to address the interactions of other socio-technical systems (complementary or competing technology to the focal TIS) (Geels, 2011).	It is agreed that the TIS framework does not explicitly consider incumbent socio-technical regimes, although this information will likely surface indirectly in the analysis of certain functions. It is also agreed that it does not consider multiple technologies and that further conceptual development is needed.
How can politics be better incorporated into TIS research? The role of politics is relegated to the periphery of the analysis (Kern, 2015).	It is agreed that whilst politics often require more focus than it is afforded, it is considered in the multiple functions (e.g. function related to legitimisation of the technology). Detailed political analysis may be better undertaken within the NIS framework.
What are the limits for policy recommendation? TIS analysis is aimed at providing policy recommendations in support of a technology. It does not ask the question, should the technology be recommended given the alternatives (Bening, Blum, & Schmidt, 2015).	The TIS framework cannot justify technology choices, it can only provide support for the decision that must be made at the political level.

The remainder of this section will focus on a more detailed explanation of the functions of a TIS (Section 2.4.1) as well as provide a review of the salient RET TIS literature (Section 2.4.2).

2.4.1 Functions of a TIS

The functions used in this study are based on the original set of functions published by (Hekkert et al., 2007). An investigation of the TIS literature revealed that whilst there have been suggested additions and amendments made in the TIS literature since the introduction of Hekkert's functions, these 7 functions still form the core of all studies and therefore provide a set of functions that are commonly defined and understood.

2.4.1.1 F1 – Entrepreneurial Experimentation and Production

Entrepreneurs serve to convert inputs (new knowledge, networks and markets) into outputs of new business opportunities through innovative activities and business strategies (Miremadi et al., 2018). There are typically two types of entrepreneurs in the TIS, incumbent firms that diversify their business interests in order to take advantage of new developments, and new entrants seeking opportunities in new markets (Hekkert et al., 2007).

Entrepreneurs are essential components of a TIS because without their willingness to take on risk and test a new technology though innovative commercial experiments it would not be possible to gain important learnings that are essential to resolving the large amount of uncertainty associated with the development and diffusion of that technology (Suurs & Hekkert, 2009). Knowledge gained through entrepreneurial experimentation includes understanding how the technology functions under different situations, as well as insights into how consumers, government, competitors and suppliers react to the technology (Hekkert et al., 2007).

The presence of active entrepreneurs in the system is generally an indication of the positive performance of the whole innovation system. This is because the success or failure of an entrepreneurial firm is generally linked to the development of the remaining six functions. Thus, a lack of active entrepreneurs typically indicates that one or several of the remaining functions require an intervention (Reichardt, Negro, Rogge, & Hekkert, 2016).

2.4.1.2 F2 – Knowledge Development

This function refers to how knowledge is developed and combined in the innovation system (Bergek, Jacobsson, & Sandén, 2008). 'Knowledge' largely refers to technical knowledge, but it can also be related to markets, networks or user preferences. In the realm of technical knowledge, it is concerned with the methods of learning i.e. 'learning by searching' (R&D activities) and 'learning by doing' (laboratory experiments, piloting studies).

Increase in knowledge development effort is signalled by an increase in R&D activity (e.g. increasing number of academic publications, PhD studies on the topic, emergence of research centres investigating the technology, university and business collaborations), number of patents filed and investments in R&D. Collectively these lead to increases in technological performance, which can be demonstrated through learning-curves (Hekkert et al., 2007). Thus, intensification of these above-mentioned factors signals an increasingly stronger 'knowledge development' function.

2.4.1.3 F3 – Knowledge Diffusion

This function involves the exchange and diffusion of information between actors within the network through knowledge-sharing interactions (e.g. workshops or conferences) or through the formation of partnerships (e.g. between technology developers). The transfer of information can therefore be between actors involved in R&D activities as well as between R&D actors and other structures such as government, competitors and market (Miremadi et al., 2018).

These types of interactions are particularly important in the policy environment where information regarding the latest technological insights should be used to inform policy decisions (e.g. long and short-term target setting) (Hekkert et al., 2007). Other valuable learning opportunities gained through networking activities include user producer interactions that facilitate 'learning-by-using' (Lundvall, Johnson, Andersen, & Dalum, 2002). This can aid in stimulating innovation to produce a product more in-line with user's needs. This function, like F2, can therefore be considered a mechanism of learning.

2.4.1.4 F4 – Guidance of the Search

In a resource constrained environment with multiple options available, choices must be made as to which technologies to pursue and where to focus activities. Focus is important, because without it, resources could become diluted to the point where no options will flourish. In line with this, the guidance of the search function refers to activities, incentives and mechanisms that create visibility of needs and goals of technology users to aid in clearly directing the allocation of resources along a specific path (Hekkert et al., 2007; Miremadi et al., 2018).

These activities can be at the individual level (e.g. through the expression of consumer choice), at a group level (e.g. through interaction between technology users and producers examining the merits of a specific technology over alternatives) or at an institutional level (e.g. through governments setting policy targets that will accelerate or impede the development and uptake of a technology). This function therefore acknowledges that technological change is not autonomous and that creating visibility of societies preferences can influence R&D activity and facilitate convergence in development (Suurs & Hekkert, 2009).

Guidance of the search works synergistically with (F1) and (F3) to effect change. This is aptly illustrated by Hekkert et al., 2007, p.423:

Often actors (whether R&D focused or policy minded) are initially driven by little more than a hunch. Vague ideas are often tried out in experiments (function 1), their success (and failure) can be communicated to other actors (function 3), thereby reducing the (perceived) degree of uncertainty. This in turn triggers expectations, which are communicated throughout the system (function 4). Occasionally, under the influence of 'success stories', expectations on a specific topic converge and generate momentum for change in a specific direction.

2.4.1.5 F5 – Market Formation

New technologies are often unrefined and not immediately suited to their ultimate intended use, this makes it difficult to compete with existing mature technologies. This function refers to interventions that can be put in place to create protected space to foster sufficient markets and demand for the new technology. This is often done by creating an artificial or niche market through mechanisms such as creating financial incentives for adopting the emerging technology. In doing so, actors are able to acquire knowledge about the technology (F2 and F3) and create expectation (F4) (Hekkert et al., 2007) thereby facilitating the growth of that technology (Suurs & Hekkert, 2009).

2.4.1.6 F6 – Resource Mobilisation

This function refers to the allocation of financial and human capital as an input towards knowledge development (F2). This includes activities such as raising funding for long term R&D projects, piloting of technologies in niche markets (link to F1), for hiring personnel as well as for developing them (Hekkert et al., 2007). This funding can come from governments support programmes, industry sponsors or venture capitalists. This function is important because without financial means and the presence of actors with the requisite skills an emerging technology will not be supported.

2.4.1.7 F7 – Counteract Resistance to Change/Legitimacy Creation

Legitimacy is a form of social acceptance and is required for resources to be mobilised (Jacobsson, 2008). This function therefore refers to activities related to the active advocacy of a new technology that are required to counter resistance by members of an incumbent regime who may be opposed to the advancement of the new technology (Suurs & Hekkert, 2009). Examples of advocacy activities include political lobbying for resources and favourable tax regimes by advocacy coalitions (collections of actors with a shared goal of shaping the institutions towards favourable adoption of the technology) (Jacobsson, 2008).

Unlike governments, advocacy coalitions do not have the direct authority to change institutions, they have to effect change through persuasion; typically, successful coalitions are those that gain sufficient political power. There is therefore a strong link between F7 and F4, as these lobbying activities promote the advancement of the technology (Hekkert et al., 2007).

2.4.2 TIS and Renewable Energy Technologies

The TIS framework approach has been widely used to investigate the growth of renewable energy technologies (RET) in certain regions. These papers have focused on specific technologies such as photovoltaics (Dewald & Truffer, 2011; Kebede & Mitsufuji, 2017; Walwyn, 2016), biopower (Jacobsson, 2008; Negro et al., 2007; Suurs & Hekkert, 2009; Wirth & Markard, 2011), wind energy (Bento & Fontes, 2015; Edsand, 2017; Jacobsson & Karltorp, 2013; Karltorp, Guo, & Sandén, 2017; Konrad, Markard, Ruef, & Truffer, 2012; Reichardt et al., 2016; Reichardt, Rogge, & Negro, 2017; Wieczorek et al., 2013), fuel cells (Markard & Truffer, 2008a; Musiolik & Markard, 2011) and tidal kite energy (Andersson, Hellsmark, & Sandén, 2018), as well as provided research on the general deployment of RET (Jacobsson & Johnson, 2000; Miremadi et al., 2018; Negro, Alkemade, & Hekkert, 2012). To the best of the authors knowledge, there are currently no published studies utilising the TIS framework to examine CSP in any country.

The following section will provide an overview of selected studies in order to illustrate the contribution they have made to the emergent literature on the application of the innovation’s systems approach to RET. This section is not intended to provide an exhaustive review of renewable energy TIS literature, but rather to merely highlight some unique aspects that may be applicable to this study. For this reason, PV and wind energy RET were selected for this review as they account for the largest proportion of installed RET in South Africa. This section will then conclude with a summary of the general RET studies.

The TIS framework has been used to examine the diffusion of PV in Germany with a specific focus on the market development processes (Dewald & Truffer, 2011). The study aimed to provide a more explicit analysis of market dynamics by analysing the structure, stage of development, mutual dependencies and contribution of the different market segments to the overall PV TIS in Germany. The authors concluded that the dynamics vary by market segment and that it's important to understand these dynamics and their interdependencies as they can either create synergies or barriers that impact the overall trajectory of the technology. It was put forth that adopting this differentiated view improves the design of technology-oriented policies. Walwyn (2016) used a TIS analysis to investigate the potential of rooftop solar systems to generate an 'electrification grant' to replace the conventional social grant system in in low-income communities in South Africa. The function analysis revealed that whilst much of the required structure is in place, the lack of an established regulatory framework and sufficient levels of skilled human resources to support the installation and maintenance present significant barriers to the fulfilment of the TIS. The TIS analysis of solar PV systems in Ethiopia focused on understanding the diffusion of a RET in a developing country (Kebede & Mitsufuji, 2017). The authors argue that a modified set of indicators are required for a developing country due to different focuses; a developed country TIS focuses on *generating*, *diffusing* and *using* a new technology (labelled a 'R&D-based TIS'), whereas in developing countries the focus is *introducing* the RET generated in an advanced country, then *diffusing* and *using*, whilst simultaneously attempting to build local innovative capacity (labelled a 'diffusion-driven TIS'). The indicators were thus modified to reflect this e.g. F2: Knowledge Development measured learning by doing, using and interacting activities such as number of feasibility studies, testing new business models, as opposed to the conventional indicators such as number of patents and scientific publications. The study showed that as the full TIS emerged the key policies promoted by the Ethiopian Government were sufficient to improve the adoption of PV, but failed to guarantee a market, resulting in poor entrepreneurial activity.

Wind energy is by far the most widely analysed RET using the TIS framework approach. Both (Wieczorek et al., 2013) and (Jacobsson & Karltorp, 2013) published studies in 2013 on the European offshore wind innovation system. The Wieczorek et al. (2013) study was aimed at providing policy recommendations to improve the deployment of offshore wind energy in Europe against the European 2050 vision of moving to a competitive low carbon economy. This was achieved through a detailed investigation of the offshore wind TIS in Denmark, UK, the Netherlands and Germany. The collated results indicated the emergence of a European TIS, which was largely attributed to strong entrepreneurial and knowledge creation functions in all four countries. However, functions F6 – Resource Mobilisation, F5 – Market Formation and F7 – Legitimacy Creation were found to be weak to varying degrees in the different countries. It was suggested that a coordinated policy effort be applied across all European countries to address these challenges and reach the European low carbon goals. Similarly, Jacobsson et al., (2013) positioned their investigation of offshore wind in Europe as a RET with the potential to significantly contribute to Europe's 2050 low carbon economy goals. Contrary to Wieczorek et al., (2013), Jacobsson et al., (2013) did not analyse separate country offshore wind TIS, but rather pulled elements from 5 countries (Denmark, Germany, UK, Netherlands and Sweden) into an aggregated TIS for Northern Europe. The novelty claimed in this study is that of using a TIS approach to capture a wide range of policy challenges. Interestingly, despite this slightly different approach, Jacobsson et al., (2013) findings with respect to strong and weak functions, were identical to Wieczorek et al. (2013). Proceeding the identification of the 3 weak functions, Jacobsson et al., (2013) identified of 7 policy challenges associated with these weak functions which could be addressed through the development of new financing solutions, recruitment and training strategies and promoting alignment of institutions located across the various countries. Finally, aligned with Wieczorek et al. (2013), it was concluded that co-ordinated policy development process is required across the European countries to achieve these changes required to improve the development and diffusion of offshore wind for Europe.

Bento et al. (2015) took a novel approach at studying the process of wind renewable technology diffusion. This study was predicated on the assumption that transnational interactions between mature markets and developing ones can aid in accelerating the formation of the local TIS in the latter. This study thereby adds an additional *spatial* element to the RET TIS framework, which essentially considers a country level TIS as a component of a 'global' TIS that can influence and be influenced by other countries within the global TIS. By comparing the growth of the wind TIS in the highly mature market in Demark to that of the follower market in Portugal it was found that indeed wind technologies were adopted much faster in Portugal than Denmark. This was in part attributed to the fact that Portugal was able to benefit from the knowledge and technology spill overs created during the early innovation stage in Denmark through mechanisms such as international R&D projects and the formation of strategic alliances with foreign companies. These factors lead to an improved local absorptive capacity leading to accelerated implementation of the RET in Portugal.

A historic analysis of the co-evolution of the German offshore wind TIS and its corresponding policy mix was used by Reichardt et al., (2016) to illustrate two policy related concepts. Firstly, the concept that a comprehensive policy mix (comprising several interacting policy instruments, policy strategy and policy processes) is a more effective output of a TIS analysis than a single policy instrument. Secondly, it was argued that there are interdependencies between the TIS development and policy mix that lead to a cycle of continuous improvement (i.e. an iterative process exists whereby policy mixes supported by credible actors create a platform for TIS development, system problems are then encountered and through a feedback loop lead to adjustments of the policy mix). The study culminated in four key implications for policy makers: (1) policy strategy with an ambitious and stable long-term target stimulates TIS developments through creating expectation, (2) demand-pull instruments (e.g. payments to consumers producing their own electricity in the form of feed-in tariffs) are essential for TIS development, (3) political commitment is necessary as it can be the main driver propelling the development of the TIS when systemic problems are encountered and (4) flexible adjustments of policy mix elements are needed to maintain continuity in the TIS development, these need to be weighed-up against the need for providing policy stability. This study was later expanded upon by the same group with a specific focus on the policy-making processes (e.g. time taken to react, setting up policy working groups etc) and their effect on TIS performance (Reichardt et al., 2017). The authors note that policy-making processes are important to study within the TIS framework as they are linked to the design of the IS policy instruments and thus the development of the TIS. Additionally, a close study of policy processes show how intimately policy makers are embedded within the developing TIS, which is typically an indicator of their priorities and their potential reactiveness in dealing with systemic issues that may arise. Broadly it was found that process involving stakeholder participation had a positive impact on the TIS performance, whereas slow response to system problems (referred to as 'tardy reactiveness') has a negative influence. It was suggested that a temporary technology-specific expert task force may accelerate the policy process and increase policy acceptance.

The aspect of financial resource mobilisation was presented by Karltorp et al., (2016) using the case of Chinese wind power. This study was initiated to understand how the industry that was able to deployed wind energy in the formative phase of the TIS so rapidly and at scale though the use of ample financial capital, later began to face increasing financial constraints. Through the investigation it was found that in fact the rapid deployment during the initial stages may have been to the detriment of developing a balanced innovation system, with the financial constraints experienced later linked to under developed functions: F1 – Entrepreneurial Experimentation and F2 – Knowledge Development. Relating to the concept proposed by (Hekkert et al., 2011), which states the relative importance of the different function changes with the phase of development of the TIS, it seemed that there was too much focus on financial resource mobilisation and too little on (F1) and (F2) in the early stages of the Chinese wind TIS. The work therefore demonstrated the importance of balanced growth, which may require focus on different functions at different stages of TIS development.

The Columbian wind energy TIS was analysed by Edsand et al. (2017) with the view to isolating weaknesses in the TIS that prevent the RET from reaching its potential of providing the entire countries energy needs. This study introduced the concept of Landscape Factors (i.e. exogenous factors stemming from the wider context) to supplement the conventional TIS indicators. It was argued that Landscaping Factors, (e.g. climate change, environmental awareness, corruption, armed conflict, economic growth and unequal access to education) are more prominent in developing countries and should therefore be incorporated into the TIS analysis; this was dubbed an 'extended' TIS function approach. This study was novel as the inclusion of landscape factors in the analysis extends the list of interventions, which could aid in developing and diffusing RET, beyond just institutional and organisational reforms.

The general RET TIS studies are focused on the development and diffusion of renewable energy in response to climate change pressures. In 2000, Jacobsson et al., (2000) introduced the concept of using a TIS approach to investigate the diffusion of renewable energy technology. This pioneering study had 3 main objectives, (1) dispel the perception that nuclear energy is the only viable alternative to fossil fuels by illustrating the global uptake of RET, (2) present a rough analytical framework, to study the transformation process towards a global energy mix with a significant portion of RE and (3) identify a set of issues that need to be researched to understand the issues and influence the outcome positively. This paper was important as it provided a logical and formalised method to analyse an integrated process informed by so many stakeholders.

The study by Nego et al., (2012) aimed to answer which system failures impede the development and diffusion of RET. RET studies in which the system was analysed using a socio-technical framework (including TIS), were chosen as the unit of analysis. The authors then identified the challenges mentioned in these studies and mapped these to 5 categories of systems failures classified in the literature (market structure problems, infrastructure problems (physical and knowledge), institutional problems, interaction problems and capability problems). It was found that the most reoccurring barrier was a lack of stable institutions to stimulate RET development and a lack of alignment of these institutions with other sectors and regional institutions. These barriers tend to block RET development or strengthen the current fossil fuel lock-in. It was suggested that this could be due to lack of capabilities of several actors (e.g. lack of technical knowledge by policy makers, deficiencies of entrepreneurs to articulate their support needs to government etc). These observations are highly relevant as governments and policy makers are seen as dominant actors in stimulating and steering RET socio-technical systems as part of the broader sustainability transition objectives. Policy recommendations from the study include the need to tailor policy measures to specific technological systems considering the development phase of the IS, specific problems related to the technology etc. and avoid a 'one model fits all' approach. Additionally, the need for long term, consistent policy was highlighted as a means to decrease uncertainties for entrepreneurs, engineers and investors. Finally, the study brought to the fore the requirement for policy makers to consider the needs of new entrants and smaller innovation firms, which are often masked by larger incumbent firms, but are essential in stimulating future innovation. This paper therefore contributes to the TIS literature by providing a novel systematic overview of problems encountered in RET development and diffusion and generalising these into lessons learnt. These lessons can be used by policy makers and actors with influence on policy makers to improve the speed and direction of RET diffusion.

Finally, Miremadi et al., (2018) developed a comprehensive set of innovation indicators at both a TIS and an energy innovation system (EIS)[1] level with the aim of designing improved policies. This work was predicated on the notion that the indicators developed to date neglect consideration of the 5 stages of the innovation process and therefore do not capture valuable feedback loops (e.g. emergence of new firms can lead to an increase in R&D funding). The concept was then applied to compare the strengths of the respective EIS of Nordic countries with a view to understand how the countries can learn from each other to advance their climate change commitments.

2.5 Conclusion

CSP is a RET with significant potential to contribute towards the decarbonisation of the South African energy sector, addressing issues associated with both climate change and energy security. It also has the potential to create an export competitive industry that would contribute to increasing economic growth in South Africa by leveraging existing capabilities in innovation, manufacturing and construction and through exploitation of its abundant solar resources to provide a platform to pilot and commercialise this technology

[1] An EIS is defined at the sectoral level and comprises individual RET TIS. The study of EIS's is relevant in the context of meeting climate change goals.

(WWF, 2015). This study therefore seeks to first understand why, given this potential, South Africa has only the third largest installed capacity of CSP in the world at 300 MW, lagging far behind the USA (1 758 MW) and Spain (2 300 MW) (IRENA, n.d.-b). The TIS framework will therefore be used to identify which system functions are prohibiting the fulfilment of the TIS. Based on this analysis it then aims to understand what measures can be put in place to realise an export competitive CSP industry in South Africa.

3. Chapter 3: Research Questions

The conceptual model of (Hekkert et al., 2007) will be used in the study to evaluate the status of CSP TIS in the context of SA critically. This model has successfully been used to analyse emerging renewable energy technologies, however to the author's best knowledge it has not been applied to CSP technology innovation anywhere in the world. The ultimate aim of the study is to recommend policy that could enable an export competitive CSP industry in South Africa. To this end the following research questions will be investigated:

RESEARCH QUESTION 1: What is the level of maturity of the CSP sector, as determined through the application of the TIS framework?

This question aims to identify the barriers prohibiting the fulfilment of the South African CSP TIS through an analysis of the 7 system functions.

RESEARCH QUESTION 2: Based on the results of the TIS analysis, what are the key interventions that need to take place to realise the potential of South Africa becoming a global competitor in this arena?

The aim of this research question is to propose policy measures to address the deficiencies identified in the current South African CSP TIS.

RESEARCH QUESTION 3: What are the future opportunities for CSP in South Africa?

This question seeks to understand what the participants view of the future of CSP in South Africa is within the global and local challenges facing CSP.

4. Chapter 4: Research Methodology

The previous chapter outlined the 3 research questions underpinning this study. This chapter will describe the research design, sampling technique, measurement instrument, as well as the approach to gathering appropriate data required to answer these research questions. It will also provide commentary on the strengths and weaknesses of the chosen research method.

4.1 Research Design

The objective of this study is to first determine the level of maturity of the South African CSP TIS through an analysis of the 7 functions of the TIS framework. Once the maturity is established, the aim is to understand the prospects for CSP in SA and key interventions required to develop a globally competitive industry.

As noted by Hekkert et al., 2007, it is currently not possible to evaluate an IS on quantitiative measures alone as technologies and regions are different from each other, which makes it difficult to define an optimum TIS as a refence point. Since the context in which the technology is embedded plays such an important role in developing the TIS, benchmarking different systems is challenging i.e. what is deemed an effective system in one country may not be transferable to another. The functioning of an innovation system therefore needs to be assessed by experts and key stakeholders that are active within the specific innovation system under investigation though a semi-structured interview process guided by diagnostic questions.

4.1.1 Research Philosophy

The philosophical position taken by the researcher in this case was one of interpretivism. Interpretivism highlights that the researcher should understand differences between humans in their role as ‘social actors’ (i.e. as people who interpret their roles according to a definition that is appropriate to them). Interpretivism requires the researcher to adopt an empathetic stance towards the social actors, understanding their environment from their point of view. The interpretivism approach was deemed appropriate as the researcher interprets the nature of the research objectives to be informed by the research subject’s personal interpretation of the TIS functions (Saunders & Lewis, 2012).

4.1.2 Approach and Purpose

The objective of the study is to suggest policy based on the analysed data that would enable the South African CSP sector to become a global leader. This is therefore typical of an inductive approach, which involves the ‘bottom up’ development of a theory as a result of data analysis. This study is classed as an exploratory as it aims to discover new information that is not known by the research (Saunders & Lewis, 2012).

4.1.3 Research Method

The study used a mixed methods approach, namely quantitative, inferential statistical analysis and the qualitative approach of semi-structured interviews. Question 1 required respondents to assess the performance of each one of the TIS functions relative to its ability to contribute to a highly developed globally competitive CSP industry in South Africa by ranking these functions on a Likert scale from 1 – 5, where 1 = very poor, 2 = poor, 3 = acceptable, 4 = good and 5 = excellent. These responses were then collated and an average value determined for each function – this average value represented the overall level of performance of that function as perceived by the sample. The respondents were then required to qualify these rankings through an interview process guided by a set of diagnostic questions to corroborate the rankings as well as impart further insight into the quantitative data. In doing so, the semi-structured interview process served to triangulate the quantitative data, where triangulation is defined as *"…the use of two or more independent sources of data or data collection methods within one study in order to help ensure that the data are telling you why you think they are telling you."* (Saunders & Lewis, 2012, p122). Questions 2 and 3 were answered purely using the above-mentioned qualitative approach of semi-structured one-on-one interviews.

4.2 Population

A population is defined as a complete set of group members that share some common characteristic (Zikmund, Babin, Carr, & Griffin, 2013). The respondents in this study were experts and key stakeholders in the South African CSP industry.

4.3 Time Horizon

A cross-sectional research approach provides a 'snap shot' of data collected at one particular time, whereas a longitudinal study is carried out over time and is intended to track changes (Saunders & Lewis, 2012). The qualitative approach of collecting data from interviews over a short time period was deemed sufficient to answer the research question, therefore a cross-sectional time horizon was appropriate. Additionally, given the research time frame it was impractical to attempt a longitudinal study, which may or may not have yielded additional insights in this specific case.

4.4 Sampling Method and Size

A sample is a subgroup of the entire population from which researchers collect data because it is generally impractical or impossible to collect data from the whole population (due to time, accessibility or financial constraints) (Saunders & Lewis, 2012). This study used the technique of non-probability sampling, as it was not possible to select a sample from the population at random because the complete list of the population was not known. By implication, this further means that the chance or probably of selecting any member of the population was not known. This is in contrast to probability sampling where the entire population is known and each member of the population has a known, non-zero chance of being selected (Zikmund, Babin, Carr, & Griffin, 2013). For this study the population comprises all people that have been, or are currently, involved in the South African CSP sector. This includes, but is not limited to, researchers, members of the IPPP office, Eskom employees, private companies, CSP plant operators, project developers, EPC contractors, members of non-governmental organisations, RE consultants and journalists in the field of renewable energy.

A non-probability sampling technique was used, which included both purposive sampling and snowball sampling (Saunders & Lewis, 2012). Purposive sampling was initially used to select a small sample for collecting qualitative data. The researcher used their own judgement to select members of the population that they felt could aid in answering the research question and meeting the study objectives. During the course of these initial interviews the snowballing sampling technique was employed, whereby interviewees made referrals to other potential interview candidates, which facilitated access to further key experts.

As the study was qualitative in nature, a small sample size was used. This consisted of 13 individuals with CSP expertise in a range of areas including research and development, journalism, private sector renewable energy development, development and deployment of renewable energy at Eskom, industrial incentive creation and IPPP office officials (further information is provided in Table 7 in Section 5.1).

In qualitative research, the size of the required sample is determined when saturation is reached. Saturation is defined as the point where additional data no longer provides any (or very limited) new insights (Zikmund et al., 2013) and is affected by aspects such as how heterogeneous the population is and how narrow or wide the focus of the research question is i.e. saturation will likely be reach if the sample is taken from a homogenous population and/or the research question is narrow and focused (Saunders, Lewis, & Thornhill, 2011). To improve the likelihood of reaching saturation a pilot study was conducted. Two respondents were interviewed prior to scheduling the remaining interviews. This allowed the researcher to test the questions and ensure that they were focused enough (this also aided in assuring validity – see Section 4.6.2). The pilot interviews did not reveal any major flaws in the designed interview process and these responses have been included 'as is' as part of the sample. A saturation graph showing the number of new codes created per respondent was constructed to test whether saturation was reached (Figure 21). As can be seen from the graph limited-to-no new responses were added for respondents 12 and 13. It can therefore be concluded that saturation was reached.

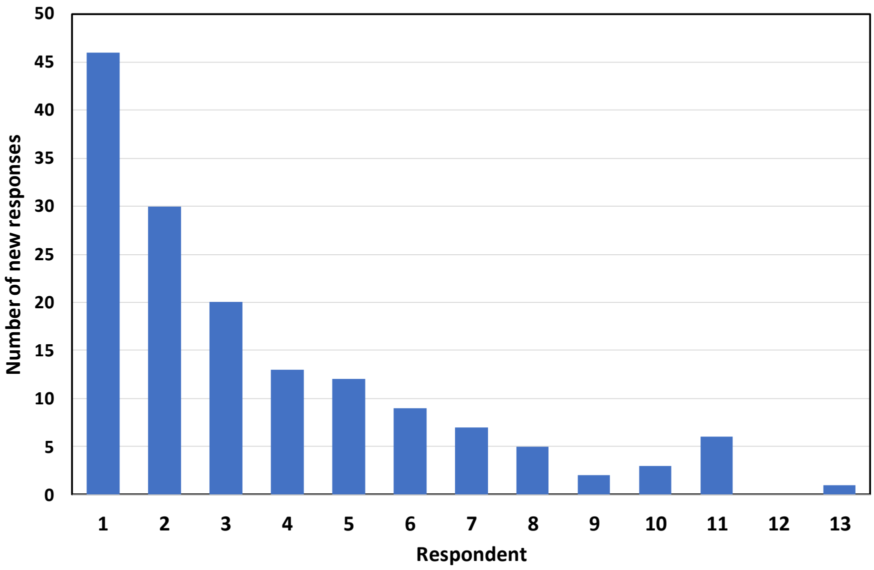


Figure 21: Saturation graph showing the number of new responses per respondent.

4.5 Unit of Analysis

The aim of the study is to assess whether the CSP sector in South Africa is poised to become a leading global competitor in CSP technology through expert interviews. The unit of analysis, defined as the main entity that will be analysed in the research (Hair, Wolfinbarger, Bush, & Ortinau, 2008), is therefore the CSP expert. Given that this study is about their opinions formed from their emersion within the context of the South African CSP sector, the individual as the unit of analysis is appropriate.

4.6 Measurement

4.6.1 Measurement Instrument

As the objective was to gain an understanding on whether barriers exist within the CSP sector in South Africa that will hinder the country's ability to become a leading competitor of this technology, an inductive, exploratory study facilitated by semi-structured interviews was appropriate.

Several themes of question were prepared, but the order varied depending on the direction of the conversation. This permitted the respondents to lead the conversation and explore their personal opinion, allowing for deeper insights to emerge. However, care had to be taken to avoid the conversation steering too far from the main objective (Saunders & Lewis, 2012).

4.6.2 Validity and Reliability

Validity and reliability aspects were also considered. Validity implies that accurate data has been collected and reliability implies consistency in the data collection (Saunders & Lewis, 2012). These measures are put in place to ultimately ensure that the questions being posed are understood by the respondents in the manner intended by the researcher and that they solicit a response by the interviewee that is commonly understood by both parties. According to Saunders & Lewis (2012), validity and reliability of the measurement instrument (and therefore the data) depends on the design of the questions, the structure of how the questions are posed and the extent of the pilot testing.

In the context of interviews, validity is demonstrated when the interviewer derives the meaning that the interviewee intended from the language used. To improve the validity of the data collected the interviewer selectively reaffirmed what was understood from the answer, allowing the interviewee an opportunity to correct any misunderstandings.

For the measurement instrument to be reliable it must produce consistent results under different conditions e.g. with different interviewers. The main issue when it comes to reliability and semi-structured interviews is bias. This bias takes the form of (Saunders et al., 2011):

- interviewer bias, where the interviewer inadvertently forces the interviewee to respond a certain way due to their tone or non-verbal behaviour that is informed by the interviewers own personal beliefs
- response bias, where the interviewee is not prepared to divulge information that may lead to probing questions that they are not comfortable with so they only present information that places them in good light.

Given the flexible, adaptive nature of a semi-structured interview it can be difficult to eliminate bias (Zikmund et al., 2013); however if the interviewer is aware of them they can attempt to limit their influence. In the case of this study the researcher attempted to mitigate the influence of potential biases by remaining cognisant of the words used, the tone of voice employed and remining focused on the responses of the interviewees.

4.6.3 Data Collection

Data was collected through semi-structured interviews with 13 key experts in the field of CSP in South Africa. As highlighted by Saunders & Lewis (2012), questions should be centred on a set of predetermined themes to guide the conversation towards the attainment of relevant information. Following this, the interview questions were derived from the research questions given in Chapter 3. Additionally, (Hekkert et al., 2011) was consulted to formulate the questions used to probe the degree of development of the TIS functions. As mentioned, in Section 2.4, TIS analysis is specific to a region and technology pairing, therefore the questions in (Hekkert et al., 2011) could only be used as a guide and were adapted accordingly to this specific study. The interview guideline can be found in Appendix A.

Interviews were held at safe and quiet locations with the identified members of the sample. Preference was given to face-to-face interviews, however, where this was not possible (due to diary incompatibility, or the respondent was not located in the same geographic area as the interviewer) telephonic interviews were used. Questions and main themes were sent to the interviewees prior to the discussion to allow them an opportunity to think about their responses so that not too much time was wasted explaining the core concepts. At the start of the interview the researcher clarified whether the respondent was happy that the interview was recorded and expressed a clear time commitment (ca 40 – 60 mins). The researcher then introduced themselves, gave a brief synopsis of the project, described where the data will appear and informed them that they can have access to the document once it’s complete. All questions and responses were recorded (audio) and transcribed after the interview for data analysis (Saunders & Lewis, 2012), the researcher also noted any interesting observations (e.g. when a respondent seemed to be hesitant to answer a question) on paper during the conversation. In accordance with the exploratory nature of the study, respondents were encouraged to answer questions openly and freely, drawing from their personal experiences throughout the interview process.

4.7 Data Analysis

Data analysis is defined as the breaking down of interview text into common themes to gain new insights into the topic under investigation (Saunders & Lewis, 2012). To facilitated data analysis, interviews were recorded and transcribed to produce text that could be analysed. The recordings and transcriptions were listened to several times to ensure the most accurate representation of the interviews.

The text was then coded using the Atlas.ti software package thematically. This involved interrogating the text line-by-line and assigning a short phrase to represent the salient features of that portion of text (Zikmund et al., 2013). This code was then assigned to text with similar meaning, but not necessarily the same wording, across the interviews – see Table 6 for an example of the varying responses received to the question "Do you think that the policy environment is supportive to entrepreneurs?", all coded under "supportive environment_no".

Table 6: Example of how similar responses were grouped into codes.

Code	Reference	Response
supportive environment_ no	1:8	Absolutely and unambiguously no.
	2:15	The simple answer is no. Lots of clarity is needed
	4:5	I don't think it is.
	5:4	No, it's not
	6:7	No, I don't think so.
	8:66	I do not think REIPPP supports entrepreneurial activity at all.
	10:4	No, not for CSP – too much uncertainty
	12:8	The short answer is that I don't think the environment is sufficiently supportive of entrepreneurs.
	13:3	In general, definitely not. Can see that in the amount of these small micro enterprises, and if you look at the stats as well South African has a disproportionately low amount of employment in these small companies compared to worldwide.

Where possible, codes were then grouped together by similarity into themes to analyse their connections to derive further insight from the data (Zikmund et al., 2013). The process of coding and grouping codes into themes was carried out iteratively and a summary of the final themes, their respective codes as well as the number of times the codes were repeated (i.e. their frequency) generated in the course of data analysis is given in the supporting information provided separately.

4.8 Limitations

Major limitations of this qualitative study include:

- The fact that the results cannot be generalised to the population as this is non-probability sampling
- Bias – both interviewer bias and response bias during the interview (see Section 5.4 for further explanation) (Zikmund et al., 2013)
- Lack of formal training for the interviewer could have affected the quality of the results generated
- People may have had problems expressing their opinions in a cogent manner

- Exploratory research is largely subjective e.g. the interviewer may misinterpret an interviewee’s response which will affect the reliability of the data. It was found that this was more prominent in the telephonic interviews, where facial and other bodily queues could not assist in resolving uncertainty. In these instances the researcher had to make a point of verbally clarifying to ensure the intended meaning was captured (Saunders et al., 2011).

5. Chapter 5: Results

This chapter will present the findings of the one-to-one expert interviews. This will take the following format, first the sample will be described, then the coding themes will be outlined and finally the results will be presented under sub-headings of each research question. Results will be supported by direct quotes from the interviews where appropriate; all quotes will be prefaced by the arbitrary number designated to the respondent. The interview questions have also been mapped against the research questions described in Chapter 3 and are presented in this format in the consistency matrix given in Appendix B. Note that during the course of this study the IRP 2018 was released for public comment. Therefore, some interviews allude to the fact that the IRP still needs to be issued.

5.1 Sample Description

Thirteen people were interviewed for the purpose of this study. Judgemental sampling and snowballing techniques were used to select the individuals, who were all considered an expert in a particular aspect related to the CSP industry in South Africa. A description of these individuals, highlighting their affiliation to the South African CSP industry, is provided in Table 7. All 13 respondents are male; although, this was not by design. Several females were approached in the course of the study and none were able to participate and either declined (due to lack of availability) or delegated the interview to a colleague (that happened to be male). Additionally, it is noted that the researcher would have ideally liked representatives from civil society and operations to be included in the sample. As such, several non-governmental organisations and plant operators were approached, however no responses were received.

Table 7: Description of the interviewees from the sample.

Respondent	Description
R1	Internationally accredited researcher in the field of CSP.
R2	Internationally accredited researcher in the field of CSP.
R3	Journalist in the field of renewable energy, with several publications on the South African CSP industry.
R4	Industry expert with significant experience in R&D related to CSP projects for industrial application.
R5	Employee at a private Development Company, involved in renewable energy projects with significant research experience in CSP.
R6	High ranked member of the IPPP office.
R7	Renewable energy consultant that has worked closely with the private and public sector developing CSP projects in South Africa.
R8	Employee at the dti involved in developing incentives for industrialisation of the renewable energy sector in South Africa.
R9	Eskom employee (industrial engineer) with previous experience in developing CSP projects for the state-owned utility provider.
R10	Eskom employee (industrial engineer) with current experience in developing CSP projects for the state-owned utility provider.
R11	PhD student with a specific research focus on business models to encourage private sector participation in the South African energy sector.
R12	Industrial engineer working in R&D at a large energy company in South Africa, with a specific focus on renewable energy integration into current energy supplies.
R13	Industrial engineer working in R&D at a large energy company in South Africa, with previous experience in the development of alternative energy projects (including CSP).

5.2 Coding Themes

Code themes, derived from the codes shown in Chapter 4, have been grouped by research question and are shown in Table 8 – Table 9. This data will be analysed further in Sections 5.3 – 5.4.

Table 8: Code themes emerging from analysis of data related to question 1.

Research Question	Theme
QUESTION 1	
F1 – Entrepreneurial Activity	Presence and types of South African firms
	Lost opportunity to develop entrepreneurial activity
	Sentiments related to a supportive entrepreneurial environment
	Challenges and barriers to entrepreneurial activity
F2 – Knowledge Development	CSP research activities in South Africa
	Challenges and barriers to knowledge development
	Level of knowledge development as it pertains to developing a competitive CSP industry in South Africa
F3 – Knowledge Diffusion	Knowledge transfer between academic institutions
	Knowledge transfer between academia and industry
	Knowledge transfer between Eskom and industry
	Knowledge transfer from international companies to South African academic institutes
	Knowledge transfer from international companies to South African companies
	Level of knowledge diffusion as it pertains to developing a competitive CSP industry in South Africa
F4 – Guidance of the Search	Presence or absence of goals towards the development of CSP in South Africa
	Presence or absence of supporting policy
	DST and dti current role
	Future role of the DST and dti
F5 – Market Formation	Description and definition of the CSP market in South Africa
	Role and impact of the REI4P on market formation

F6 – Resource Mobilisation	Role of the REI4P in creating sufficient financial incentive to develop the South African CSP market
	Funding availability
	Skilled HR resources
F7 – Counteract resistance to change/legitimacy creation	Advocacy groups and their actions
	Counter lobby actions
	Negative perception that has been created about CSP
	Barrier formation through bureaucracy

Table 9: Code themes emerging from analysis of data related to question 2.

Research Question	Theme
QUESTION 2	Solutions to improving entrepreneurial experimentation
	Solutions to increasing knowledge development
	Solutions to improving knowledge diffusion
	Solutions to improving guidance of the search
	Solutions to increase resource mobilisation
	Solutions to improving legitimacy creation

Table 10: Code themes emerging from analysis of data related to question 3.

Research Question	Theme
QUESTION 3	General disadvantages of CSP over other RETs
	Challenges for CSP in the South African context
	Potential for CSP in the South African context

5.3 Results for Research Question 1

RESEARCH QUESTION 1: What is the level of maturity of the CSP sector, as determined through the application of the TIS framework?

As was described in Section 4.1.3, participants were requested to rate the performance each function on a Likert scale from 1 – 5, where 1 = very poor, 2 = poor, 3 = acceptable, 4 = good and 5 = excellent, relative to that functions ability to contribute to a highly developed globally competitive CSP industry in South Africa. The average value per function was computed from the responses received and this is shown in Figure 22. Functions F1, F4 and F7 have the lowest values, scoring an average of 2.0, F6 and F5 are slightly higher at 2.3 and 2.4 respectively, with F2 and F3 scoring the highest average values of 2.6 and 2.7 respectively. From these results it can be seen that overall the South African TIS is at a low level of maturity. Further insight into these rankings is provided in the proceeding analysis of the one-to-one semi-structured interviews.

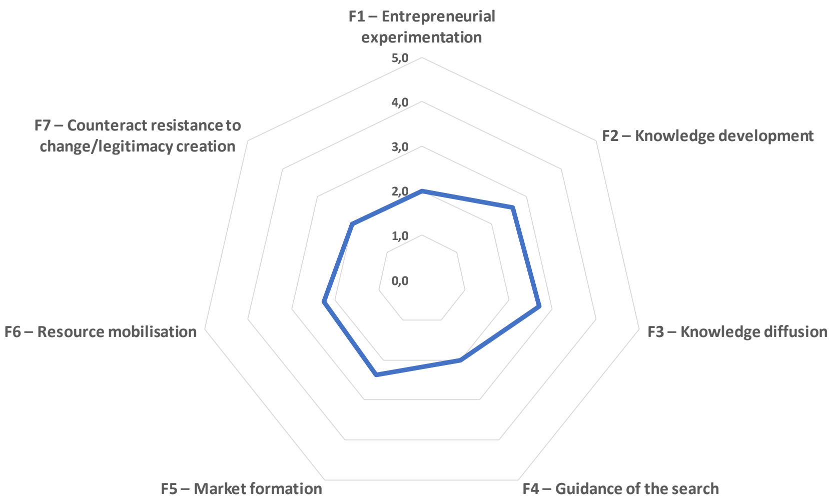


Figure 22: Extent of the development of the South African CSP TIS as perceived by the sample under investigation.

5.3.1 F1 – Entrepreneurial Activity

Entrepreneurs are integral components of the TIS as their willingness to assume risk and pursue business opportunities in the face of uncertainty, both in the technology and the environment in which the technology will operate, is essential for the development of the TIS (Reichardt et al., 2016). In this regard, respondents were asked a series of questions with a view to understand whether there are active local entrepreneurs in the South African CSP industry and, if so, which aspect of CSP are their activities directed towards. Additionally, the questions sought to establish whether the participants viewed the current policy environment supportive and what the main barriers to entry are for new entrepreneurs.

The majority of the respondents were of the opinion that there are limited-to-no local firms involved in the utility-scale South African CSP industry. They expressed that active firms are mostly engaged in non-specialised services, such as construction and site utilities, or non-proprietary services such as those associated with the back-end of the plant (i.e. services that can be found in established coal fired power stations, see Section 2.1.2).

> *(R1) "Many local companies involved in infrastructure have been interested in CSP. These companies are typically not high tech or innovators in this space, but would like to perform activities pertaining to construction… The other sector is the local prospectors and land owner-based development partners. None of these offer new innovations but would be part of the ecosystem."*

(R3) "…there is a whole lot of entrepreneurship that's going on about how to support the CSP industry and the renewable energy industry and general specifically locally, but this is related to things like site toilets and catering etc".

(R12) "If you look at the more conventional things around CSP like the steam drums and those things, they are actually just sourced in country, it doesn't even matter who makes it – it's any large mechanical manufacturers. No proprietary equipment in that, it could be made anywhere."

Several participants went on to elaborate that most firms in the South African CSP industry are foreign. Although, this wasn't necessarily seen in a negative light by all, where one academic expert implied that this could in fact facilitate knowledge development (F2) and diffusion (F3).

(R2) "I think everyone that has pitched a plant so far as trucked in engineers from overseas and I think that is a good thing. They needed to bring the people in that had the expertise that had been developed over the year. Development was in Spain and the US who had the know-how on how to build such a plant."

Although, it was noted by a member of the IPPP office that this transfer does not seem to be happening, as the foreign owners of the technologies are hesitant to allow local resources to work on their technology for fear of losing their bank warranties.

(R6) "most of these people who come with technologies, they have given so many warranties into that technology, and they will say … we don't want anyone to touch this thing, if somebody else touches it, you lose your warranties…this constrains the participation by small businesses."

Some respondents referred to the fact that the lack of local entrepreneurial participation wasn't always as prominent, citing examples of companies such as BBE and Sasol previous involvement.

(R12) "I know Sasol did some development early on, on the Heliostats and we [Sasol] sold that IP"

Following this, one academic expert expressed that this specific sale of local IP and exiting of local companies from the industry represented a significant lost opportunity for South Africa to retain valuable IP.

(R1) "Sasol invested in the early development of the Stellio heliostat now considered the world's best heliostat. It is being built in a project in China and have been the selected heliostat for the large Redstone project previously and

likely again now. The value of this heliostat cannot be overstated and given that Sasol completely relinquished the rights to their investment at the time without any form of protecting the rights for SA is unfortunate."

It was noted by several participants that whilst the representation of local companies in utility-scale entrepreneurial activity was limited, there does appear to be some activity in non-utility scale applications.

The question on whether the policy and economic environment was supportive of emerging entrepreneurs, was met with an almost unanimous negative response:

(R1) "Absolutely and unambiguously no."

(R2) "The simple answer is no. Lots of clarity is needed."

(R7) "I do not think REIPPP supports entrepreneurial activity at all."

with only two participants willing to concede that the policy efforts to date have created some support for entrepreneurs, but not enough to develop a competitive industry.

(R10) "I think they [politicians] like to say that they are, I think the drive around industrialisation is quite strong now as part of the Africa strategy. But a lot of it has been driven from policy in terms of what is the next step and what is the next stage of electrification and energy needs…"

(R11) "We see some stuff like the SEZ [Special Economic Zone] being created. There are some spaces being created where I guess concessional arrangements in place to try and help some of these companies…"

Respondents identified a range of challenges to entrepreneurial development, with policy challenges being the most common. More explicitly, lack of policy, policy certainty and the restrictive nature of the IRP.

(*R3) "I think that it's simply because the policy isn't in place,"*

(R4) "I almost funded a company out in Springs that could have put up a production line to produce mirrors locally for CSP, but currently they're not…. they were going to put up the bulk of the money, but they needed to know that policy is certain, that to support the demand for CSP. Otherwise you can't set up a line and remove it after one use – but that didn't happen.

(R7) "The biggest problem is the government's insistence that your new build must be according to IRP and if you want to deviate from the IRP, then you need a ministerial determination if you are bigger than 1 MW… and we don't get it so

it is not possible in the current South African context to build a power generation plant that is bigger that 1 MW...”

The next most common challenge mentioned was availability of funding, which was mainly attributed to investors only being willing to fund established CSP technologies:

(R6) “...even from a lending point of view, the lenders, they feel much more comfortable seeing a technology that has been operational for at least two years. If you bring in a technology that you do it locally, and they haven’t seen it in operation, you have got a problem. They are not going to fund that.”

as well as their general hesitance to fund CSP due to its high cost.

(R12) “It's definitely going to be capital, these are not cheap technologies to develop and to build. The CAPEX [capital expenditure] of this technology is prohibitive, even on a small scale for testing. So, it is not something that really lends itself to entrepreneurial activity without a large amount of investment. So, it's acquiring funding for both commercial and pilot installations.”

Although one industry expert noted that, whilst the costs are high, the technoeconomic evaluation needs to consider the storage component to reflect the true value of the technology.

(R5) “…from an investment point of view CSP is still generally one of the most expensive renewable energy technologies, but it is to be put in context because the majority of the CSP power plants built in South Africa have a storage component, which means they can actually be despatched which actually means that the power is not only generated when the sun is out for example…”

The requirement that only prove technology can be tendered for the REI4P also featured as a main barrier to entrepreneurial experimentation.

(R4) “…so you will find that IPP’s will want to use technology that they are comfortable with because that’s what the banks want and that’s what they went with. There was no drive or no local inventions to take on board.”

(R7) “The REIPPP does not stimulate small companies and therefore and it is very difficult to build a mega project on the back of an entrepreneurial company.”

The lack of a local value chain resulting from a lack of IP ownership was also cited as a barrier.

(R8) "Because we don't have a significant value chain established in South Africa, so I would assume one would have to go across the waters to access that value chain… it means that you need a deep pocket to carry it through, because you sort of essential pay everything now because a local value chain does not exist."

It was also mentioned that the delay in signing the PPA for project Redstone caused major harm to the CSP sector, and consequently to the attraction of future entrepreneurial activity. Additionally, related to this topic, the closure of manufacturing facilities for the wind sector were mentioned by the renewable energy journalist as a cautionary comment for the CSP sector.

(R3) "The tragedy, certainly with the wind sector…we had had enough certainty to entice two wind-tower manufacturers to set up…and their pipelines just dried up due to the Eskom refusal to sign for 2 years. Some one of the factories was mothballed and sold back to the IDC for R1. You had one of the biggest inverter manufacturers, SMA, that was setting up a state-of-the-art facility Cape Town and they fled. So, it's quite tragic that we could have had the first mover advantage in all of these technologies and we could be exporting wind turbine towers to East Africa now and we could be the regional supplier of this stuff and we've thrown it all away. And again, this is not sufficiently articulated but it borders on a crime against humanity and is therefore quite tragic."

Other challenges mentioned included lack of experience of local resources to support entrepreneurial activities, cancellation of the Eskom CSP project, the large size of CSP projects required to justify the economics and politics within the South African government.

5.3.2 F2 – Knowledge Development

Technology is at the heart of a TIS, therefore by implication the technology must first exist and then be continuously improved if the TIS is to reach its full potential. This occurs through knowledge development activities such as R&D, so-called 'learning by searching' and experiments and piloting studies, so-called 'learning by doing' (Bergek et al., 2008). To ascertain the level of knowledge development in the South African CSP TIS, respondents were asked to comment on their knowledge of CSP activities in South Africa, what they viewed the main challenges to knowledge development in the TIS and whether they considered this function as a barrier to developing a competitive CSP industry in South Africa.

All respondents, bar 3, were aware of some form of CSP research that was being carried out at South African universities. By far the most respondents mentioned STERG, based at the University of Stellenbosch in the Western Cape, as the leading CSP research centre in South Africa.

> *(R1) "Stellenbosch University [SU] is the lead CSP institution and about 2 or 3 years ago, CSIR recommended that SU become the lead institution for CSP R&D... SU's STERG is one of the world's largest CSP R&D groups."*

One respondent was also aware of socio-economic and economic development research work that was also being conducted at SU.

Several respondents were also aware of the University of Cape Town's research activities, related to techno-economic evaluations, policy and grid integration of renewable energy in South Africa in general (not specifically CSP).

> *(R11) "UCT I think has some experience in the engineering faculty…The students that I know of that work on renewables were working more on the grid integration side. So almost an Eskom perspective on how to deal with renewables on the grid rather than technology and value chain."*

The University of Pretoria, Gauteng was mentioned in the context of research related more towards optimising the heat transfer fluid, rather than the technology as a whole.

> *(R2) "There is direct funding going to the University of Pretoria and while we [STERG] focus on the applied research, Pretoria is on the fundamentals of heat transfer etc. It is nice and complimentary."*

Additionally, the University of Kwa-Zulu Natal was noted as having a dedicated research team.

> *(R2) "University of KZN is quite active. They are called GSET (Group for Solar Thermal Dynamics)."*

Minor mentions were given to the North West University in the context of piloting work and the University of Limpopo in the context of modelling capabilities.

Finally, several participants acknowledged the CSIR's research involvement in renewable energy in general, but expressed the sentiment that they were more focused on the promotion of wind and PV.

> *(R12) "I know that the CSIR is looking specifically more on wind and solar PV, but they do also have a small set of expertise in thermal energy storage. The*

thermal storage refers to using the heat generated by CSP different forms and not just the salt storage, so different types of thermal storage solutions. So, it is something that can be used in another application but you would have to use very energy inefficient ways to first generate that heat."

(R13) "We also contacted CSIR about 3 years ago, they have a renewable energy group within their organisation. They promote renewable energy, and the first time we there they focused on wind and PV."

Many respondents then went further to expand on what the focus areas of utility-scale research are as well as the relevance of further R&D activities. One academic expert further elaborated that their focus areas have moved away from incumbent technology towards the further development of solar tower technology (see Section 2.1.2.1.4).

(R2) "over that last 5 years and certainly still making a big a leap forward stepping away from the parabolic trough plant into the receiver plant and as a consequence to that being a research group we have been focusing our attention throughout on next generation stuff."

Whilst several industry experts and a RE consultant expressed that they did not see the need for further utility-scale research in general due to the maturity of the technology. It was felt that only marginal gains could be realised from further research into the solar concentrators and the HTF.

(R3) "the utility scale stuff is mature technology- it's been around for some time and there are big plants being built in Saudi Arabia and Spain and the US and Australia."

(R7) "The technology isn't looking for fundamental scientific breakthroughs. The technology is mature enough, the phase of the life of the development of the technology is one where you would optimise and improve on existing principles. There are 2 or 3 ways to concentrate the light from the sun, you can do it on a flat mirror or a curved mirror where these other guys have been doing it through a magnifying glass. There are 2 or 3 methods you can capture heat, you can put it into a heat transfer or a molten salt – that's about it."

(R13) "I am wondering, is how much can you still improve technology for CSP. There is a couple of conventional units in the whole process, like thermal storage, turbine, steam production, the tower and the mirrors… how much can you improve on efficiency… So, it's not necessarily technology development, it's improving the manufacturing."

Mention was also made of R&D activities aimed at non-utility scale research.

> *(R2) "Earlier in the year we won another horizon 20/20 project together with the German DLR and South African Mintek on high temperature using CSP technology providing high temperature process heat for mining applications. We are intending to do much more work with the DLR."*

However, respondents outside of academia only mentioned failed small-scale application projects, citing lack of available funding (F6) as a reason for this.

> *(R7) "Ripasso Energy has got a unit installed closed to Upington and I suspect that the Upington plant may be decommissioned and again because of economic reasons."*

> *(R7) "The BBE project failed because of technical reasons. They had originally built the power plant at Rosherville, Eskom's test facility and that worked very well. Then the scaled it up and they couldn't get it to work at Sibanye. I think they couldn't make it work as it was a matter of having deep enough pockets to solve the technological problems as they come up."*

In line with this comment around small-scale challenges, lack of financial support to fund knowledge development in CSP was cited as a major barrier to furthering research efforts.

> *(R1) "When I was last involved, I was aware that renewable energy investments in HCD [human capacity developments] were only considered once other R&D areas were funded. Areas such as astronomy and the SKA, shale gas exploration and exploitation, nuclear energy were vastly better supported. In my view, all of these are misguided areas for investment and will not likely be sustainable beneficial areas for SA."*

> *(R8) "If you go any of the large international CSP firms that have hundreds of millions of Rands worth of technology fund backing, we don't have that in South Africa…The DST spent over a 5-year period, a billion Rand on hydrogen without achieving anything; I don't think they spend a cent on CSP. They would have been better off if they had taken the money they pumped into hydrogen and spent it on CSP."*

In this regard a parallel was drawn between the magnitude of funding directed towards CSP research in South Africa as compared to the USA.

(R1) "Baseline investments by the U.S. DOE in CSP R&D tend not to dip below $50m per year, even during administrations that are not supportive of CSP or renewables. That very roughly implies that the U.S. invests about 250 times more annually in CSP R&D than SA does. Given that the current deployment of CSP in SA is in the same order of magnitude as that in the U.S. and also that the pipeline of CSP capacity is similar in both countries (if not stronger in SA), the funding disparity points to how low a priority this topic is in SA."

Policy challenges also featured as a main barrier to CSP knowledge development, more specifically the lack of alignment between government departments, lack of policy certainty and the fact that CSP does not feature prominently in the IRP as the least cost model does not incorporate it due to the higher cost. The following quotes highlight these themes, the first two provide support for the lack of alignment and policy certainty respectively, whilst the last two collectively illustrate the concerns and effect of the IRP model.

(R4) "Problem for us is policies don't talk to each other; when one government department wants to drive a policy, they don't consider the connectedness that could be leveraged from either DTI or from the DST. It's the Department of Energy policy, they want to own it and they want their logo on the papers and the whole egoistic thing, it's a sad story."

(R5) "I think you can have a whole lot more done but it is also difficult to do it like I said because of the nuanced nature of the fact that policy shifts and moves so much or that you don't actually have pure knowledge as investors of where government is in future going to procure."

(R6) "The barrier in my view is the price of the CSP – I think that is what is stopping the development of CSP because the integrated resource plan, it's a least cost, so when they develop the plan, they always go for the cheapest option, so the fact that it is more expensive, it doesn't get selected by the planning model. Then if it is not in the plan, we don't do it."

(R9) "Knowledge development is generally steered towards areas of activity and demand. When there was support for CSP in SA (during initial REIPPP rounds), there was phenomenal knowledge development, many CSP conferences held in SA, etc. The present uncertainty and lack of support has resulted in a much-reduced rate of knowledge development."

Some respondents also felt that the rate of local knowledge development was greatly reduced by the fact that the skilled knowledge that was available in-country was lost to international companies due to the limited local opportunities.

> *(R2) "Schlaich Bergermann obtained the IP of the Helios stat that Sasol developed back in the days and they continue development and brought it as a commercial product which is the so called Stelio Helio stat and this is a ground-breaking technology. Award winning…It is sad story, when something moves elsewhere and then comes back."*

> *(R7) "So, way back, they started a CSP themselves, before we had the programme. And then they advanced it, and people within Eskom, made the studies, and all was good and then for some reason, they decided not to continue. The point is they understood the technology very well. From there, the very same people who worked for Eskom they went and joined Abangoa, and then they did the project."*

Respondents from both academia and industry remarked on the CSIRs active focus away from CSP towards PV and wind as a hinderance towards CSP knowledge development.

> *(R2) "CSIR used to be, but they shut it down. They had a paradigm shift and said that they would only look at PV stuff. They might come back one day but killed their CSP research…"*

> *(R13) "They believe that CSP was a no go. CSP was expensive, it was before the prices of CSP dropped, they say it's too expensive and there is little expectation that the cost will drop significantly because the technology is pretty mature they say CSP is a no go, it's too expensive."*

Other challenges mentioned were the small size of the South African market limiting the opportunity for on-the-job learning and lack of local IP ownership and willingness of international companies to partner locally to transfer knowledge (F3). A comment was also made that South African's in general have difficulty in adopting a new technology and that this mindset is forming a barrier to further CSP knowledge development.

> *(R1) "I tend to think that the SA innovation chasm is also at play. The SA stakeholders fundamentally do not believe that significant innovation will make it, therefore they don't do it sufficiently well to get through the valley of death. A self-fulfilling situation."*

Most respondents felt that the level of knowledge development was not sufficient to develop a local competitive CSP industry (see quote below), with only two people expressing opposite views.

> *(R5) "There will always be more work that can be done maybe from a state perspective to give that comfort to investors to develop CSP. But certainly, we are not anywhere close to being the leaders in this technology compared to the likes of Spain, the United States and more recently now Saudi Arabia. Certainly, there can be more than can be done."*

Although encouragingly, several interviewees expressed that South Africa certainly has the calibre of people to develop such skills, as is demonstrated by the prevalence of South Africans in international operations.

> *(R1) "I believe firmly that SA has all the knowledge and skills needed for the whole lifecycle [of CSP development]…"*

> *(R2) "Increasingly you find South African people running the show and I think that is a natural motion. I wouldn't say that we have been able to keep up with the requests for people from the industry. We only train highly skilled engineers…"*

5.3.3 F3 – Knowledge Diffusion

Exchange and diffusion of information between actors is important to accelerate development of the TIS and beneficiate the knowledge developed by sharing lessons-learnt in technology development, facilitating discussions between interface roles to avoid integration issues, to build local capability (if none exists) and aid in policy formation (Hekkert et al., 2007; Miremadi et al., 2018). These types of exchanges therefore occur between a number of different actors and via a number of platforms.

In light of this, respondents were asked to comment on whether they were aware of knowledge exchange occurring between academia and industry (including the national power utility provider Eskom), between industry and Eskom and from international companies to local academic institutes and firms. Finally, they were asked to express their view on whether knowledge diffusion was sufficiently developed to expand the South African CSP industry into an internationally competitive one.

Only 2 respondents felt that there was knowledge exchange happening between academic institutions and industry through the mechanism of conferences. It was also noted that these conferences also facilitated knowledge sharing between academic institutions.

(R2) "We [STERG] put a lot on emphasis on our students attending conferences and the biggest conference is Solar Paces...In 2012 Stellenbosch started own local conference which is SASEC, which is PV, CSP and all sorts of solar thermal applications but that is purely a research environment. We as a research group have our annual Symposium which is open to other researchers in the country. The guys from Pretoria, UCT and UKZN come. We have one day research presentations and a second day which we call the industry day. We tend to get all industry role players in South African to come. We got most of the companies to come and even Nedbank. This is huge benefit for our students to get industry contacts and network and to hear from industry what their needs are and for industry to learn what we do."

(R11) "The work at Stellenbosch is solar thermal and is very clearly informed by industry's needs…"

One academic expert also commented that post graduate students also interact directly with industry by running on-site training courses.

(R2) "2 or 3 of our graduates are up in Katu running training courses. Training operators and plant maintenance staff."

Two respondents expressed that they didn't know if there was interaction between academia and industry, whilst most felt that there was little-to-no networking between academia and industry. Various reasons were cited for this, such as industry halting CSP research:

(R2) "…the Sasol trail dropped when they stopped funding us. Eskom is a bit different. They were a substantial funder of ours for a while and then they also called us one day and said that it would stop."

Also, the fact that the South African CSP industry is young compared to the incumbent power generation industry, therefore it is difficult at this stage to inform what this interaction needs to look like.

(R10) "It's hard to foresee now without having the technology implemented and us working on it, what would be the advancement in terms of what research with need to be done in this area. So, once it's implemented there will definitely be much more, now it's just a hypothetical looking at case studies around the world, what were the shortfalls etc"

Similar to the challenge mentioned in relation to knowledge development, one academic expert noted that knowledge diffusion between academia and industry is impeded by skilled resources immigrating due to lack of local opportunities.

> *(R1) "SA creates its own barriers to beneficiate the knowledge that has been developed. Instead, really good (world class) graduates have emerged from SA that now support the SA CSP industry by taking employment in large overseas firms having local presence (Mott MacDonald) or the graduates have immigrated to the best CSP technology development firms (SBP – Stellio) or labs (Fraunhofer, DLR, Sandia)."*

Whilst an industry expert felt that this kind of knowledge exchange was difficult to maintain as it is fostered through a relationship with a particular individual who may leave.

> *(R4) "…you will find universities, depending on the strength of the lead researcher, a particular industry will have relations with the university. But why industry is really funding that research is because they know professor so-and-so, and maybe he used to work for a particular company. Once that Prof leaves or retires, usually that is the end of the centre and the collaboration."*

The majority of the participants felt that there was insufficient knowledge exchange between Eskom and industry, with the main reason cited as it being a deliberate decision by Eskom's management to not develop the technology further due to misinformation and vested interests in incumbent fossil-fuel technology.

> *(R4) "…they are a state-owned company and they have a development agenda, but not in this technology"*

> *(R6) "I would say the resistance is more about competition. They see CSP as a competitor, or renewable as a competitor to their own plant, and that could be the problem. But in terms of knowledge, I think they understand that. Obviously, they can't do technology"*

> *(R11) "I don't know at a higher level, at a strategic decision-making level, there is also a lot of misinformation flying around Eskom about renewables in general and CSP specifically and there are a lot of vested interests that would not be that happy with renewables playing a greater role."*

An alternative view was that even if Eskom wanted to become involved in RE, that they are limited by policy to do so.

(R4) "No Eskom is a little bit trapped in a tight spot. When you look at other countries, your power utilities are actively taking part in renewable technologies, whereas in South Africa, because of the heavy regulations that we have, Eskom is limited to play within the exiting regulation environment which doesn't quite allow them to play actively in the IPP space in terms of the renewables."

Other participants expressed that there is little to no knowledge exchange happening between Eskom and industry and gave a reason related to industry not wanting to share IP.

(R1) "There is little denying that CSP IP owning vendors keep their secrets tightly wrapped up and they don't have a habit of sharing deep knowledge. When advisory firms get involved for any party (i.e. for the owner or for the lenders, etc), they also keep IP and technoeconomic info very secure at the request of their customers etc in order to maintain a good reputation. The reason may be due to the lack of maturity and other factors relating to players wanting to survive a very tough category not yet making it big."

Those that did feel there was interaction between Eskom and industry attributed it to the compulsory requirements of the REI4P, or Eskom's historic involvement with CSP projects. The following two quotes illustrate these points respectively.

(R5) "In this case, you cannot build the power plant without actually sharing with Eskom the technical elements of it, because the power is going to feed out to the grid and Eskom needs to know how the grid will react to this power. Over the last 4- or 5-years Eskom has been coming up the curve, like everyone in South Africa, in terms of understanding how CSP works and its impact on the grid."

(R7) "The BBE linear Fresnel plant that was built on Eskom premises at Rosherville, the first pilot unit, was the one that failed so there must have been some exchange of information."

Participants were almost evenly divided when questioned on whether they felt there was knowledge transfer from international companies to local companies. Those that answered yes typically provided an anecdote on how they had personally experienced interaction with international companies.

(R13) "We then did a landscape of what companies were working in the commercialisation of CSP and we visited them to get more information. We approached one to develop a plan for commercialisation, but the costs where are so high I think that in the end it did not make commercial sense to install CSP."

Whilst those that answered no mostly cited that the lack of international collaboration is due to international companies wanting to protect their IP.

> *(R4) "What is in their best interest is to keep bring in experts from Europe mostly, because most of those guys are European. They will not want to relinquish knowledge to a local party, who can carry on, and basically close them out of the market; they don't want to breed a competitor locally."*

> *(R9) "However, there is some resistance for international firms to freely share knowledge. This seems to be related to protecting their competitive edge, and, to promote the successful image of the technology (not freely sharing failures experienced on previous projects)."*

Several respondents were unsure of whether knowledge transfer taking place between international companies to local companies, but felt that it must be happening through the local content requirements of the REI4P.

> *(R11) "There is definitely an international presence and through the mechanisms of local content requirements and BEE requirements that there is an assumption of knowledge transfer happening but we don't have that proof or we haven't seen that. And it is not exactly clear as to what level."*

Although, the same respondent questioned the level of complexity in the exchange that could be happening through the compulsory local content requirements.

> *(R11) "It could very well be just around the mounting of the systems for example but we might not have anyone in South Africa that could design a whole CSP systems or understand the technology intellectual property that is owned by the international company. There is a level of sophistication that is a determinant of how much transfer is happening."*

In stark contrast, the academic experts expressed that knowledge exchange between local and international academic institutions is strong.

> *R1 "Yes, strongly. I can speak for my own students and my own experience. SU CSP experts have been able to continuously collaborate and diffuse knowledge both ways with all leading international experts and institutions."*

> *R2 "From our own perspective in the research environment, I think we are extra ordinately imbedded in the international research in CSP...Our direct partners that we interact regularly with is SANDIA and SDLR and those are two of the*

biggest names out there. We have close ties or links to almost everyone. We regularly participate in consortiums we try to form for proposals."

All participants, bar one, felt that knowledge exchange was indeed forming a barrier to further development.

(R10) "Yes, definitely it is. It is a stumbling block and it is something that is inhibiting us. It will take much longer to develop something if you don't have a partnership or collaboration. We've realised this and found the importance of finding the right partner."

(R11) "If we do want to set up the industry then needs to more knowledge exchange happening specifically with local subsidiaries or companies that would somehow be able to own the intellectual property and be able to commercialise it in South Africa and I don't think that we are there yet."

Where one participant noted the potential for the two industry bodies to improve knowledge diffusion.

(R3) "Then we've got two industry bodies that cover solar thermal. You would hope that they would be a vehicle for knowledge diffusion and exchange, unfortunately they are not."

Interestingly, one participant highlighted the need for further knowledge exchange with policy makers – which was not specifically probed in the questions.

R9 "There is a barrier, more specifically the knowledge exchange with policy makers. I don't believe policy makers have sufficient understanding of the capabilities, costs, benefits of CSP."

5.3.4 F4 – Guidance of the Search

In a resource constrained society well-defined goals (e.g. in the form of incentives or policies) are required in order to focus activity along the desired path (Miremadi et al., 2018). In line with this, respondents were asked to comment on the visibility of goals and policy aimed at the development of CSP in South Africa. The role of the DST and dti were also assessed in relation to their support of this sector.

The overwhelming sentiment was that there are currently no clear and visible goals aimed at the development of CSP.

(R3) "Definitely not, when you look at the map of solar radiation around the world and you see how well-endowed we are in the world in the Northern Cape and you

compare that with Spain and Australia and the USA and Morocco, you start to see that we might be missing out on a very important opportunity here to export power. So, it is definitely not clear, the goals have not been established."

Several participants felt that this lack of clarity was due to lack of specificity in the IRP in defining the goals.

(R10) "If you are running a fleet of 47,000 MW's, you need to be able to say that of these 47,000 MW's I have in terms of coal I'm going to offset this by at least 5% renewables. No one tells you that."

Whilst others felt that it was rather the fact that renewable energy goals were unclear due to a political agenda to pursue nuclear in favour of other forms of new energy.

(R3) "…we are all desperately waiting for the IRP, which they were going to suddenly expedite around the time when…the nuclear deal was still on the table… they were going to desperately try by working overtime but it was all to try and push through nuclear at the time."

(R10) "people have a bad taste in their mouth after nuclear was pushed so hard and this left a big question around where renewable sit."

It is noted that several interviews were carried out prior to the release of the IRP 2018, and in these interviews, respondents expressed that the delay in release of the document left the RE industry without clear goals for an extended period of time.

(R5) "we have an IRP that is from 2010 and so if we are speaking about outright policy certainty no, then we don't have that right now. It is very critical that the IRP comes out so that it can provide that certain level of policy support so that us as the power sector, we know where to focus now."

Many post-release interviews raised a concern that the new IRP sets no further procurement goals for CSP.

(R3) "it seems that it was 3 or 4 months ago that everyone was talking about this IRP and that CSP had been removed from the mix altogether. Now I couldn't find a specific reference to this, usually engineering news would have written about this but I couldn't find anything obvious. Is an alarm that CSP has dropped off the radar in terms of government high level policy, which is a huge barrier. So that high level by-in at a utility scale is totally lacking more so in CSP than wind and solar"

With one participant implying short-sightedness on behalf of the government, given international plans to continue with CSP development.

> *(R9) "The draft IRP indicates that we will not be including CSP in our future plans, while other areas like Australia, Middle East, North Africa, India and China continue developing CSP at a rapid pace."*

The majority of the participants responded negatively to the question on whether there is sufficient supporting policy to further develop CSP.

> *(R1) "There is no policy that tangibly supports this to my knowledge."*

> *(R9) "Developers want policy certainty and reduced risk. This is definitely not exhibited in the current SA environment."*

> *(R12) "Well I am not aware of any policies specifically supporting the renewables outside the REI4P and that was more commercial process than the support for development, where just bet on the lowest cost that was selected. So, it wasn't really incentivising much development."*

Many expressed that the lack of policy direction is due to lack of alignment in policy makers in different divisions.

> *(R5) "But this is a function of many different role players that have different objectives and that don't always necessarily sing from the same book. It is also difficult for them to do that because they are running under different mandates; where the DTI wants to encourage local manufacturing job creation but the Department of Energy's mandate is to actually provide power at cheapest cost to end users. There is always a tension between the DTI and the DOE in relation to those types of things. I suppose good and natural tension but if you get right on the top and centralisation potentially what we are trying to achieve is X it would be must better."*

> *(R8) "you know the [policy] architecture emanates from a particular department with their own view point…then later one has to find the links. Someone with a mandate to work in that space would have to find their way through the myriad of other possible interfaces, one would literally have to find it out on your own time and space, to connect those dots."*

> *(R12) "There has been expectations created through the various routes of the IRP, of their view where they think the energy cost might end up. But I'm not sure of how well aligned those goals where with the industry."*

Whilst some felt that it was rather due to a lack of clarity in policy, as a consequence of the absence of a future vision as to how the South African CSP industry should develop.

> *(R6) "There should be a rationale behind why you want to promote it. You don't promote technology at all costs. You promote it because you see a future – that in future this is what I am going to get out of this. You promote it because you want to sell the IP into the future or you promote because you think in future it will be cheaper. So, there should be those kinds of forward looking, but at the moment, I don't think that's a clear vision in terms of what is it that we see into the future about this technology."*

Only one respondent noted that CSP development could be positively, yet indirectly influenced by emission reduction regulations.

> *(R10) "I think the only policy right now that is driving it indirectly is the emission reduction policies. Emission reduction tells you that you will be charged a carbon tax, you will be charged sulphur and nitrogen tax and heavy metals. But it doesn't tell you that you need to go use this technology to offset it, it is something that you need to do on your own as an organisation."*

Some respondents felt that the dti should be playing the role of advancing industrialisation efforts through local content requirements.

> *(R3) "I think they need to get back onto the localisation aspect and push that. Because that is a lot of what is encompassed in the key term of a just transition. This term just transition is the term that is understood by most stakeholders such as labour and the private sector. Localisation is a key part of that, how do we localise the supply chain how do we link in with real radical economic transformation? And I think… they need to reinvigorate it and I think the dti can do a lot better."*

And that currently they are more focused on providing tax incentives.

> *(R7) "The dti's main tool and driver is with incentive schemes like tax holidays and things like that and that operates through the Income tax Act. That Act provides a number of incentive schemes that is administered by the dti. There are quite a number of those things that are applicable to renewable energy in general. There is R&D, depreciation, you can depreciate twice what you. There is accelerated depreciation. There are Sections 12B. 12i and 12J of the Income Tax Act. Quite a number of them are administered by the dti. The dti role is to mainly act as a store front for SARS tax incentive stories."*

However, counter to this the dti representative was able to provide a comprehensive list of incentives available to those that wish to enter the CSP sector, which are also provided in (GreenCape, 2017).

Then with respect to the DST, one academic expert felt that the DST has played a significant role to date in developing local CSP technology through their funding mechanisms.

> *(R2) "The DST does play a significant role, they are the reason why we are. They made the decision 10 years ago to start funding us and why we existed for the last 8.5 years. I think the DST is playing their part quite well so far. We are in strong conversations with the DST currently about commercialisation of our Heliostat product in a role that one day might move the conversation to the dti."*

Whilst one industry representative felt that the DST could be more active.

> *(R6) "I think it would be nice to have our own technology. If we had our own technology that we want to push as a country, I think that would be great…"*

One academic expert felt that the dti and DST should collectively be more involved in aiding small businesses to participate in the CSP sector.

> *(R1) "For small SA, dti and DST should be playing a strong role. If they don't if/when CSP truly gets rolled out, it will be the international community that benefits, just as is the case in most technologies being brought to SA."*

Whilst an industry expert suggested that funds should be channelled via the DST and dti towards the development of a national CSP centre that can coordinate R&D and industrialisation efforts.

> *(R4) "if we are going to have another bid window of this IPP's you might want to set aside a percentage of their revenue or something, that goes into a centre, a national centre that does the coordination."*

5.3.5 F5 – Market Formation

To challenge incumbent technology, markets often need to be artificially created and protected to foster demand for the new technology (Suurs & Hekkert, 2009). In this vein respondents were probed on what they viewed the CSP market to be, what the role and impact of the REI4P has been on market formation and whether they viewed market size to be a barrier in the further development of CSP.

There seemed to be varying interpretations on how to define the size of the market. One respondent felt that there were two distinct markets, namely utility and non-utility scale.

> *(R3) "When I look at CSP you have to look at it on two scales. A utility scale stuff related to the REI4P and then you've got to look at the smaller stuff, which is not quite as easy to deal with because obviously it's not part of one big programme…"*

Whilst another felt that the market was rather defined by the peak tariff.

> *(R7) "I think the market is defined by the peak tariff, which is necessitated by the consumption behaviour of the country."*

Which was supported in another comment by a different participant.

> *(R3) "And round 3.5 they introduced a special tariff for generating at peak, CSP because that is obviously the benefit of CSP, you can dispatch the power when you need it. So, they incentivised CSP by giving a higher tariff at peak times which is early morning and evening when everybody comes and turns on their water heaters and so on. Essentially creating the space for utility scale production."*

Two respondents expressed that the size of the market is defined purely by the procurement amount dictated by the ministerial determinations.

> *(R6) "I think it is more about the CSP technology getting an opportunity to be in the plan so that we can procure it. Otherwise if it is not in the plan…. So, then it boils down to price, because to win the plan, you need to be competitive. So, at the moment, the CSP is not competitive."*

> *(R11) "The reality is that the entire CSP market in South Africa is determined by whether or not and how much an incumbent will be procuring…"*

Another participant expressed that CSP should rather be considered a niche market, when compared to PV and wind.

> *(R13) "if you look at the coal markets the CSP is very, very small compared to PV and wind, I think that shows that it is much cheaper and easier to install PV and wind and that CSP has, I would say, has a niche market."*

All respondents agreed that the REI4P has been the sole mechanism to create a utility-scale market.

> *(R3) "The REI4P was implemented exactly to create the space."*

Although there seemed to a mixed response on whether the participants felt that it had been successful in this endeavour or not. Respondents who felt the REI4P was successful in developing a market mentioned factors such the programmes ability to create incentives, where one participant offered the successive price drop, the socio-economic benefits attained and the energy security aspects as evidence of its success.

> *(R3) "So, if you look at the cost of CSP in the early days (I now speak under correction you'll have to look at the report), it was way up in the R5 range. So that was to create that space… we were doing so well. I'm not an analyst but I just get the feeling that the public/ private partnership, the most ambitious private public partnership undertaken was so well formulated because it took into account your social stuff coming your way security aspects and also primarily driven by the climate agreement commitment."*

Those that felt the programme had not created enough of a market expressed that the procurement targets in the REI4P (stemming from the IRP) were too low and that the restriction placed on the size of the projects themselves limited CSP from attaining the economies of scale required to bring the cost down.

> *(R5) "No, due to the size of the allocation of CSP within the REI4P I don't think it has been enough. What was introduced in, you actually see it in a lot of places around the world, Morocco, UAE and the United States, you are looking at gaining economies of scale by having a bigger power plant. We are still restricted, I think only in the last bidding window was it expanded to 150 megawatts per project, where initially it was restricted to just 100 megawatts. If you see what is happening in places around the world, they are look at 300+ megawatts per power plant."*

Another criticism levered at the REI4P was that the tariff for CSP was incorrectly set.

> *(R11) "In my personal opinion they probably messed up the way that they designed the tariff and the tariff structure and the tariff caps. If you look at how CSP has been put in other markets specifically in the Middle East, it has been a flat requirement, maybe for like a 24-hour power."*

The majority of respondents felt that the market size, as dictated by policy, is definitely forming a barrier to the further development of CSP. Particularly post the IRP 2018 announcement.

(R1) "The market is currently blocked due to intentional and/or unintentional policy. If the market can be unlocked, then yes, it could help the innovation system."

(R9) "Market size limited by policy. No CSP allocation in draft IRP. No incentive to develop CSP capability in SA."

5.3.6 F6 – Resource Mobilisation

A technology cannot reach its full commercial potential without funding and skilled human resources to accelerate it through the various stages of development (Hekkert et al., 2011). To ascertain whether sufficient financial and human resources are available in the South African CSP TIS, respondents were asked to comment on the role of the REI4P in creating sufficient financial incentive to develop the CSP market, whether they were aware of funding availability for CSP development and if they thought the availability of local skilled human resources is forming a barrier to CSP progression in the South African market.

The majority of respondents felt that the REI4P has not provided sufficient financial incentive to develop CSP in South Africa. One respondent felt that the fact that our tariffs are not internationally competitive was evidence for this.

(R3) "I'm actually saying no that there hasn't been sufficient incentive. If international projects are coming in as low as 7 cents per kWh then we've done something wrong."

Whilst others felt that the flaw in the programme is that it doesn't allow for entrepreneurial experimentation (F1) as only proven technology can tender. Therefore, funding is not available to local entrepreneurs as IP is largely held by international companies.

(R4) "Just having one commercial policy in terms of REIPPP is not good enough to simulate or catalyse R&D. Because remember, those technologies in the REIPPP programme are financed by banks and banks are risk averse, they are looking for proven technologies, they know it's not experimental, it's not innovative."

(R7) "No, we are a technology and price taker in the CSP industry. We are not a leader and we don't have any of our own technology. The REIPPPP is structured in a way so that it is not allowed. You have to have proven technology to bid into the REIPPPP."

Although the same respondent did acknowledge that without the programme there wouldn't even be the small CSP industry that exists today.

> *(R7) "You have a couple of the plants running, you've got Abengoa, Bokpoort and now they're building Katu and that wouldn't have happened without the REIPPPP… So, we do have a CSP industry, which was developed by REIPPPP."*

Then with respect to funding availability, there seemed to be an almost even divide between those that believed there was sufficient funding and those that didn't. Several respondents cited interest by local banks, local funding institutions and international entities.

> *(R6) "Yes, the first one we had IFC, the Americans funding that, the DFIs as well. So, I think from a funding point of view, I am not that worried about it."*

> *(R8) "given the fact that there are a few institutions a few DFI's, the IDC's, even the DBSA, when it's a large-scale project they also have keen energy focus. I suppose there is a reasonable landscape for being able to do that, I mean case by case, it has to have a strong business case."*

> *(R10) "I think there is a lot of interest around the financial sector around the energy space right now locally. Our Big Four banks have been on these IPPs like you can't believe. They have been watching the markets so carefully with respect to who are the players that are coming in, whether the IPP deals are taking place or not because there is something in it for them as well."*

Those that expressed that funding was limited, cited a lack of confidence in local capability and policy as the main reason for lack of international funding:

> *(R4) "They have not come here and invested in developing technology locally because, as they say, we can organise the football world cup but leave this stuff to them, we are not good at it. This has happened with renewable energy and battery technology, that has been the trend."*

> *(R5) "But internationally speaking I do know that there is general fear from international players who do finance this industry, the international development funding institutions, that do fear that there is no certainty and this has removed their appetite to continue supporting the technology."*

and unfavourable returns as the reason for limited local funding.

(R1) "In terms of investment funding, we found that all corporate players don't like the risk/reward profile and we determined that only parastatals and government are applicable."

(R5) "No. I remember several years ago Sasol were trying to develop their own CSP project and I heard at some points mines talking about it but it was not economical. So, whoever was looking at it was not looking at it from a very long-term perspective."

On the topic of skilled human resources, most felt that the availability of skilled human resources would not form a barrier to developing the CSP TIS further, it merely requires a clear signal that this is a priority area (F4).

(R1) "This is not a barrier. I found that human resources are quick to build up to a suitable level. As I have a lot of international experience, I found that modern-day South African's don't lack potential."

(R8) "Yes, I would say that we do in the general resource pool, certainly I mean, if they can develop satellites and sell them to the Middle East and to NASA. So, from a technical skill prospective, I think it will go where the money flows, if there is capital. If something like this could be capitalised properly sure."

(R10) "SA may not be a technology leader, but there is much capability residing here. I don't believe this to be a barrier. I believe that if CSP were given adequate support, capabilities can be developed."

Although one academic expert cautioned that if the CSP industry does pick up momentum quickly that the pace may be faster than the talent currently in the pipeline.

(R2) "You have to recognise that the CSP market has rolled out at a very moderate pace and at that pace it has been enough. If there is a proper roll out and they put down a 400 or 500 megawatt a year, then it might be a different story."

The majority of those that mentioned they thought it was a barrier cited the fact that the REI4P requires proven technology, which at this stage has to come from overseas.

(R6) "I don't think there is enough. I think the CSP mainly the highest skilled people, they came from outside of the country."

(R7) "The technologies in the REIPPPP are all purchased technologies and everybody is flown in."

5.3.7 F7 – Counteract Resistance to Change/Legitimacy Creation

Counteracting resistance by incumbent regimes often requires active political lobbying by advocacy coalitions. An indication of success in this regard is social acceptance of the new technology that ultimately leads to demand being created for it, and resources mobilised to this end (Bergek et al., 2008). To establish the influence of both advocacy and counter lobby groups on the development of the South African CSP TIS, participants were questioned on their awareness of these two types of groups and their actions. Additionally, these series of questions sought to establish whether the bidding process of the REI4P was perceived to be highly bureaucratic and time-consuming, which could be a tactic of counter lobby groups to increase the barriers to entry.

Most participants stated that they had not seen any direct advocacy of CSP, despite its many advantages.

> *(R2) "Standard news media like News24 you not finding that kind of profile on the current state of affairs."*

> *(R3) "I don't think that the public understands the benefits of CSP. If you look at the CSP plant, I think it's one of the most sexy renewable technologies out there, from a visual point of view, but also the technology…. it's got everything going for it, so if the costs are coming in line then it just blows this concern that renewable energy can't be stored out of the water. So, if we could get back to some coherent modelling on what CSP power is baseload. This is always a criticism of renewable energy is that it cannot give baseload."*

> *(R4) "…you do not have anyone who actually talks to what this technology is, what the promise is in terms of economic stimulation this technology possesses. We don't have enough, call them scientific communicators in the media space."*

> *(R7) "I have seen a lot of people doing it in PV but not in CSP"*

Additionally, it was noted that the socio-economic benefits of the CSP projects that are being realised through the requirements of the REI4P are absent from the media.

> *(R3) "…the 50 km radius stipulations around the communities being owners of the plants and the local economic development spend. You know, that's amazing and you'll never hear that, it's not highlighted sufficiently in the media and I really don't understand it."*

> *(R3) "I think of the actual community trust ownership of the plant, and I think that one of the CSP plants has up to 40% ownership of the plant by the community –*

this is incredible…. Now why aren't we highlighting this as good practice? If you look at the 19bn that's going to flow into these communities in the next 20 years. So, I just think it's phenomenal… and I know that there is a lot of criticism around the community development part and that maybe it was done too top down etc. But this is unprecedented in any other industry, and it's never acknowledged by the mischief makers and the fake news proponents."

Many blamed the lack of media coverage on the two local CSP industry bodies being ineffective in advocating the technology locally, especially compared to PV lobbyists. Respondents also expressed that the fact that there are two industry bodies could also be causing confusion.

(R2) "We have oddly two lobbying groups for CSP. The one is SASTELA (that is the old one). The opinion of the industry at some point was that it was not functioning as it was supposed to and industry eventually last year founded STASA and we are a member of both. I would think that STASA was involved in the past when it came to the new IRP but saying that while we used to receive newsletters, they have been a little bit quiet recently."

(R3) "Then we've got to industry bodies that cover solar thermal. You would hope that they would be a vehicle for knowledge diffusion and exchange, unfortunately they are not. The first industry body was called SASTELA, but industry bodies these days, associations, the whole structure of them is actually questionable and their relevance is also questionable. SASTELA have struggled to fulfil their mandate and a lot of their members have gone over to a new industry body called STASA (the solar thermal Association of South Africa). I but I think they are so busy fighting IPP fires that they are also not able to advocate exchange and disseminate knowledge I don't think they even have a website."

(R6) "In CSP you have two different associations at the moment, we call them associations, or two lobby groups that have in essence been working together. If they had done their job then the market would have been very different. I think it would have achieved similar to what the wind and the solar PV industry have achieved in driving its own messaging."

Where one respondent even suggested that there is a conflict of interest with one of the industry bodies who are run by the same company that manage the Nuclear Association.

(R3) "SASTELA it's interesting because they are run by an outfit called Van Der Walts, which is an association management service. Which is strange because

they also ran the Nuclear Association and also there is a whole lot of weird conflicts of interest. End of the day they are just not capacitated to engage and I think they are being hollowed out and now most of the members are with the new industry body.

Although one participant suggested that this had not always been the case and that previously the Industrial Development Corporation (IDC) had promoted CSP, by highlighting the localisation benefits that CSP could deliver.

(R3) "I know that in the early days of the REI4P the IDC was instrumental in pushing CSP, champions of this particular technology. It was all around localisation and the supply chain benefits because you literally manufacture plant on-site. So, they were pushing that heavily. I think there are even some good report from the IDC on CSP localisation specifically. It was actually held up as the poster child of localisation."

It was also noted that in the past there had been some rivalry between PV and CSP groups that played out in the media.

(R3) "Then you've got the solar PV lobby group, and you do get this tendency for competition amongst the industries. So, you'll find the wind industry through Sawaya and SAPIA for the Solar PV industry, there's a lot of friction between them. And you'll find a little bit of anti- (although it has calmed down now a bit), but maybe 2 years ago you would have found that the rivalry between solar PV and CSP…"

Some respondents however felt that CSP had in fact benefitted from positive media attention.

(R1) "Media and lobbying are/were quite friendly from my experience."

(R6) "The two positives that I have seen is that it is labour intensive, so it creates a lot of jobs. Then secondly, the only positive of it is the storage."

(R12) "I think they are mostly driving a positive image around CSP and also trying to sell it; all the environmental and health benefits as well. Mostly in the news they have reported positively."

The majority of respondents also noted that CSP had been the subject of much negative media attention related to the argument of rather advancing coal and nuclear energy.

(R1) "…political weight was with coal and nuclear. This has almost destroyed the CSP potential."

(R2) "Resistance is related to nuclear vs the renewable. Well it wasn't really an argument at any point, right. Yes, certainly there has been a delay, it has killed everything, right."

(R7) "The arguments of job losses by the coal truck driver and whether it is sufficient to stop the REIPPPP programme is absolutely short sighted. The fact that government can even consider delaying the REIPPPP because of pressure groups is madness. There is also a political agenda associated with that because the politicians and the system we have in South Africa benefits from this imperfectly functioning coal powered or fossil fuel industry, because that is our main natural resource."

(R12) "…there is also another half of the industry, the more unionised half which is reflecting more on the negative aspects of renewables. Their argument is that it will influence the jobs of the coal industry and miners, so they are trying to shine it in a more negative light."

(R6) "CSP… it is similar to coal, obviously we threaten the coal industry, because all of a sudden now, you can generate electricity without using coal and still the plant will perform more or less the same as a coal plant. So that is a threat to the coal sector…

This participant went on further to expand that the power of these groups was so great that they managed to influence the inclusion of CSP into the IRP.

(R6) "*But, I think what happened in South Africa, especially those who are involved in the coal sector, they felt, you know, this is the technology that we should really try and shoot it down as quickly as we can. And I think whatever strategy they use is effective in slowing the inclusion of CSP in the plan. Because they know it all starts from the plan. So, if you make sure that it doesn't get included there, you have killed it. I don't think anybody had the courage to still say, let's include CSP because of the criticism associated with it. In fact, what they did, they just say renewable is expensive – they just generalize the whole thing. But you know that they actually criticism is going to CSP, because that's the one that is the biggest threat to coal."*

Other respondents noted that CSP had been used as a proxy for all renewable energy.

(R9) "…media and propagandists have lumped the REIPPP with CSP (and renewables). People now link the image that Foreigners have benefitted from the REIPPP and jobs are lost due to the REIPPP, with CSP and renewables in general. This is unfortunate, since CSP could actually offer significant localisation and job potential in SA, provided it is structured appropriately."

According to the responses received, the main negative message being propagated by the counter lobbyist was around the high cost of CSP.

(R3) "So I think CSP has gotten a little bit of a bad reputation because it is always viewed as the most expensive technology."

(R4) "Everyone who communicates on CSP its not neutral ok, they would have taken a side of either this is expensive, or this is good technology and we should do it."

(R5) "It has a bad effect even up to a point where the DOE, you can see how reticent they are to stand about the technology, they keen asking quite a lot of questions and I believe it's for this IRP they have been asking a lot of questions over the last nine months. A lot of questions on how to make it more efficient, how to get it to a point where it is a lot cheaper."

(R6) "I think the main criticism of CSP is the price. Because people realise that we need to hit this plant from a pricing point of view so that it doesn't get an opportunity to grow. For me, if you continue doing the plants and you can learn from it and then you can make it cheaper all the time. PV was expensive as CSP when we started, but because of the competition, people became more and more creative."

(R11) "if you look at social media you come across these cost figures for renewables that are mentioned; these are mostly from round one of the REIPPP programme, which has been expensive. That is not a secret. It fails to mention for example the latest procured costs. Similarly, it will only look at the CSP costs but not the other technologies. They are cherry picking the most expensive ones to make their case to say it's not a competitive technology system."

However, it was largely felt these negative sentiments were uninformed.

(R1) "There are proponents of nuclear power in SA that have uninformed (lacking data) opinions of renewables."

(R5) "I think in the times of the black outs with Eskom, the media was regurgitating a lot of what was being said which was not factual."

(R9) "The capability and benefit of CSP is not easily understood. Perception is generally guided by non-factual statements."

It was also noted that the CSIR seemed to be perpetuating a negative perception around CSP, through their focus on and active advocacy of PV and wind in their government and industry interactions.

(R13) "the CSIR, they have a negative perception, they didn't believe in it. For example, they said it would never make it because we do not need storage, we will deal with the fluctuations in a different way. Their view was to compensated it with gas to power."

Respondents were also almost evenly divided when it came to their opinion on whether bureaucracy was a barrier that needed to be overcome to further advance CSP. Those that felt that it wasn't expressed that the permitting procedures are no less laborious for CSP than they are for any other RET tendering for the REI4P.

(R4) "Not if you are working on the REIPPP programme, because a lot of things are predetermined and you just follow the steps A to Z."

(R7) "It's the same as any other plant. CSP is not given a different requirement, so whatever red tape is there, it applies to everyone."

Whilst those that did cited that the REI4P tender requirements are too stringent as compared to international standards, and even more so for CSP which requires additional environmental impact assessments compared to other RET, due to the use of water.

(R7) "It will take at least 3 years to prepare a REIPPPP tender…The amount of work you have to do is…we worked fairly closely with some of REIPPP tenders for wind, PV and CSP. The one client for every tender they submitted, they took a bakkie load of documents to the IPP office."

(R6) "You must remember they have got, they also use water in the CSP. The PV, they don't, you just use it for cleaning the PV panels. There you use it in your boilers to create steam, and then they also create a dam for pulling the water there. A small dam, and then they need to then purify the water and clean it again. So, they need different licenses for that, which the PV industry doesn't need. So, there are a couple of things that you have to comply with when you do a CSP

plant as compared to a wind or PV plant. So, the requirements are much more stringent in the CSP from an environmental point of view. Also, the fact that they use oil, and the oil might leak.

(R10) "Definitely the red tape and bureaucracy is something that's limiting the progress. If you ask the Germans or the Koreans to come and build more power plants in South Africa you would get a very different answer as to how we are going to negotiate those deals."

5.4 Results for Research Question 2

RESEARCH QUESTION 2: Based on the results of the TIS analysis, what are the key interventions that need to take place to realise the potential of South Africa becoming a global competitor in this arena?

The aim of this research question is to understand what measures are required to realise the development of a local South African CSP industry. The attainment of this kind of development necessarily implies that the RET is sufficiently developed in South Africa and that there are no barriers to its diffusion i.e. it is contingent on the development of a mature South African CSP TIS. This section will therefore first examine the respondent's suggestions as to how to improve the performance of the TIS, these responses have been group by function. Further insights from the literature and policy suggestions are incorporated into the discussion in Chapter 6.

With respect to entrepreneurial activity, respondents expressed that focused entrepreneurial activity towards areas where South Africa may have competitive advantage is required to develop a competitive industry.

(R4) "What we can do is focus on our competences, if we are good with development of the very ultra-low iron mirrors for CSP that is what we should focus on. If we are good with IP on the drive, that are used to move the mirrors, or we are good in the structures – that is what we must focus on and become a supplier to the world."

Participants felt that the knowledge development function would benefit from an increase in local IP ownership, either through purchasing the IP:

(R8) "Then if one wants to break in at scale one would have to purchase IP or maybe go into some sort of joint venture with agreement with someone from overseas."

(R10) "We are in a situation right now that technologies we bought over 30 years ago we want to try and acquire the intellectual property rights- why didn't we do it back then? So, let's learn from that, the plants that we are building right now, the CSP technology that we want to invest in going forward with let's see if we can buy intellectual property."

or by increasing R&D to further develop local technology.

(R6) "…we need to do research ourselves – for us to be a competitor in CSP, we need to have our own technologies which we can go out there in the world and develop."

It was also suggested that R&D should also focus on reducing the overall cost of the RET to accelerate uptake.

(R1) "R&D is needed to reduce the cost and the quantum's per project."

An industry expert also suggested that in the future R&D projects could be jointly scoped with industry to ensure relevancy to industry, by focusing some of industries most pressing problems in power plant capability. Success with boiler leaks and potential wind RET projects were used to illustrate how this could be carried out for CSP in the future.

(R10) "What I do know is around the energy sector, the institutes that are developing research and innovation around this specifically, taking care of problems that we are having and experiencing on our power plants, we are using it really well. For example, we have issues around boiler leaks…it was one of the areas that we approached universities and said help us...from this interaction we've gotten to the place where we've understood what the problems are with the technologies that we are currently using… On the wind farms we are actually having a problem now with lightning strikes. So, there must now be a way of how do we protect these blades from lightning strikes, so this will go onto one of the topics for research."

Finally, two participants felt that South Africa improve knowledge development by duplicating the knowledge centre model used in Spain. Participants expressed that in their opinion part of the reason Spain has been able to establish such a successful CSP industry is because they have a dedicated centre to facilitate technology demonstration and advance specialised training.

(R4) "Yeah, if you look at Spain…They basically created a huge solar park, where they have a pioneering CSP technology being developed – from the mirror, to the

gearing drive, to the wiring systems, all the way to the thermal system that you use, to the generating system. They have different types of CSP technologies and they allow private companies to co-locate and do their development in that site where you have a concentration of skills, concentration of support, the technicians are supporting everyone there and they have done it very well. And, they did it ahead of their launching of their IPP programmes mostly across Europe. So, a lot of European countries go in there to concentrate their research instead of duplicating... So, it positioned them to be the centre, the hub, the place to be if you are developing technology."

(R6) "When I went to Spain, I saw the very same company of Abangoa, they were doing a solar PV with…. Even the CSP, they had a CSP plant that they were running to prove to the lenders that it can work, like a demo plant. You need to do that if you think you have got an idea and you think it can work."

Several suggestions were made to improve knowledge diffusion. These included setting clear technology development goals.

(R4) "If you look at NREL in the US and the Sandia initiative, they have set themselves long term goals of collaborating with other research centres and university's and industries to reduce, they will tell you they are reducing a particular component of a solar plant by so much percentage by 2020."

(R10) "Some of the discussions in this area going forward are to have conversations with the Department of Energy, and let's establish with the Department of Energy what their requirements are in terms of educating our workforce."

Leveraging the local content requirements in the REI4P to increase local enterprise development.

(R10) "I think the leveraged opportunities that can reside is, with those who have been given opportunity to play in the IPP space, you can have service level agreements to do supplier development on smaller firms coming in. So, if you have some form of relationship there that says we are going to contribute."

Partnering through the BRICS coordination to develop a central hub in South Africa to export power or RET to the rest of Africa.

(R10) "There is some partnering that can be done between the BRICS coordination, I think from the BRICS we know that China and India are producing

some of these specialised parts. So, there is no reason why we can't say let's start engaging with our partners as part of the BRICS Alliance to try and see if we can get some manufacturing capability as part of an agreement in South Africa. What this means for these other countries is that when we expand into Africa, which is going to be the next huge electrification boom, then there is obviously business there for them."

By far the most commentary aimed at improving the overall TIS was focused on the guidance of the search function. Many participants felt that policy certainty alone would be enough to catalyst CSP advancement.

(R2) "Certainty for a market, stability in long term commitment to the technology and I think that unlocks everything else. That immediately gives long term prediction of money flow and a long-term big pie where anyone can do this…"

(R4) "Policy will simulate demand, and not just policy, but policy certainty. So, you can have a policy but if its short-lived, you know if you make an investment and say ok I need 3, worst case, 5 years to recover my money, and if a policy doesn't give me certainty that the programme will live beyond 3 years, I am not going to do it. I am going to go to a country where they give me certainty that is the nature of it."

Others expressed that policy alignment along the entire value chain would unlock the CSP potential in South Africa.

(R10) "Be able to create a market that has both intellectual property rights as well as manufacturing capability to be able to perform some of this work to make it lucrative for South Africans and for the South African energy market to be involved."

Counter to the sentiment that local content is a hinderance to development, one respondent suggested that the dti could use this as a vehicle to justify import tariffs on CSP to develop a local industry.

(R8) "So, you've got a significant local content to build into your product, therefore you can run to the DTI and say, listen it is time to make some rules here so let's put some import barriers on the current CSP products being imported. So that could play to the benefit of someone like that. That means you also need to have a bit of energy to go around lobbing and get it positioned as a SA Inc enterprise or set of enterprises, that would be a second important prerequisite."

Another respondent recommended that the government incentivise modular scaling, in line with the small REI4P programme. The implication being that this would encourage SME participation.

> *(R10) "Modular scaling, where you could have had incentives to do smaller scale. We want to do 100 MW which is huge. If you said that within those incentive schemes that you wanted to go smaller and modular, for example we've got small hydro that produces 5-6 MW that not a lot of people know about that is producing electricity that is feeding into the grid. So rather than wanting to go so big rather incentivise to start smaller and then do a build up after that."*

Several respondents were strong proponents of changing the entire energy policy landscape, from the current prescriptive one (i.e. one that dictates both the installed capacity and the specific RET mix to achieve it) to an open energy market.

> *(R1) "Open the market to power producing options that the market brings rather than prescribing technologies in legislation."*

> *(R9) "Why does the IRP specify technology? If the concern is cost and emissions, then specify the constraints and let the appropriate technology be chosen. The only reason to specify a technology is to provide initial incubation support if you believe that the technology requires this support in the short term to be competitive in the medium/long term and provide other benefits."*

> *(R12) "the biggest enabler would be an open energy market; the ability for anybody to source energy from any supplier. So, it would not just be all of us shackled to Eskom, so try decouple Eskom from the grid provider. That sort of model is available in a lot of countries."*

Suggestions to advance resource mobilisation merely included observations that more funding and more human resources are required.

> *(R5) "…finances for large scale projects and commercial projects."*

> *(R6) "we need to put resources into CSP to develop those technologies. It is all well and good to say we will do research, but if we don't put money where our mouth is, you will have the policies, but it will not happen."*

Although, as evidenced by many prior responses, many participants feel that if government indicates confidence in the technology, sets goals associated with it and therefore demonstrates a strong business case, funding and capacitation will follow accordingly.

Finally, two suggestions were made regarding how to increase lobbying for CSP. The one involved promoting the technology via social media.

> *(R3) "It's unadulterated energy from the sun that's not converted to electricity. That's just amazing and these things are just not sufficiently highlighted by the industry itself, whereas I think if you took some drone footage of our CSP plant and made a little YouTube video that it would go viral. People would likely think it's from Morocco or USA, and no, it's right here."*

The other involved creating an opportunity for environmentalists and the unions to come together to find a common solution.

> *(R10) "So, the lobbying that needs to take place needs to be strategic. So, from the perspective that there are influential players that are strategic, and there are influential players that are by numbers, and those two need to find a common ground. Because whilst the greenies and the environmental rights groups are driving this they just don't have the numbers to be heard, and I don't think they have political weight they are not as well connected as for example a COSATU and a NUMSA – that says we want what is best not only for our people but also for our country from an environmental point of view. And that conversation just has not taken place."*

5.5 Results for Research Question 3

RESEARCH QUESTION 3: What are the future opportunities for CSP in South Africa?

CSP technology presents a number of opportunities in South Africa; however, these need to be understood in the context of the South African environment, as well as the changing global CSP landscape. Given that the general advantages of CSP are covered in sufficient detail in Section 2.1.2, this section aims to rather explore the respondents view on what the general challenges for CSP are over other RETs, then more specifically what the main challenges are in the current South African context. This section will then conclude with the participants assessment on what potential CSP holds in South Africa.

Participants felt that the main challenge for CSP is that the global market for this technology is much smaller than other RETs, which is in part due to the limited number of locations receiving sufficient solar radiation.

> *(R12) "…the problem with CSP is that it is a small world market, so there is not that many places where it can perform optimally where it has the right solar*

resources (so it has to be very warm desert like conditions with low dust and sand-storms and these sort of things prohibit it, so not like you can build it anywhere in the Sahara). So, the location and the market is probably quite small compared to other renewables."

Respondents noted that the global installed CSP capacity is not yet sufficient to drive the technology down the learning curve.

(R1) "…global deployment needs to get over a hump so that the learning rate can kick in."

(R7) "… thing that has driven renewable energy is the learning curve and back in 2014 we did quite a lot of work on learning curves of different technologies and in the learning curve you plot on the Y axis your cost per MW installed and your X axis the cumulative number of MW's installed. What you get is a very strong function of your cost coming down per cumulative MW installed. In some cases when you have a technological breakthrough you have a discontinuity in your learning curve, but if you don't it is really a total volume installed. The driver is the total amount of plant installed that is the thing that drives the learning curve. In order to drive your learning curve, you need to have a market that is big enough to install many many units."

This is part of the reason that CSP is in general more expensive to develop compared to other RETs.

(R1) "Unfortunately, there is this so-called double valley of death in CSP which implies that going from low TRL R&D to prototype to pilot can be very expensive. A rough order of magnitude for this is $100m for a large enough pilot that can earn bankability for full commercial scale."

One respondent noted that another disadvantage of CSP is that it can't be built in a modular fashion like wind and solar i.e. to justify economics the initial size of a CSP plant needs to be quite large. This is in contrast to wind and solar, where one is able to build several smaller plants over a period of time to reach the required capacity. This necessarily means that large capital investments are always required for CSP, compared to other RETs.

(R13) "I think one of the disadvantages of CSP relative to wind and solar, could be is that with wind and solar you have a lot of small units, so everyone can put a small unit and all together is a lot of megawatt and gigawatt. If you look at CSP

projects, usually CSP side, you have to build once, it's one system, it's not an add on add on. So, the initial investment in general are much larger."

Respondents noted a variety of challenges of CSP in the South African context. Although many challenges have been discussed in the previous section, those discussed in this section emerged from the interviews when the respondents were unconstrained by the boundaries of a specific TIS function.

One such challenge mentioned were along the lines of the social issues caused by the strong foreign presence in the towns in which the CSP plants are being developed.

(R3) "They talk about solar babies, so there is exploitation around local community's things that go on."

(R3) "So that was a very interesting dynamic, this anti-foreign thing that the labour movement is bringing up i.e. that all of these people working on these plants are foreign.... And as I looked around they are foreign. A lot of Asian workers a lot of Spaniards. So, the likes of NUMSA do certainly have a point."

(R11) "…there is a lot of work on the community impact of renewables, specifically in the Northern Cape has been talking about the fact that these companies bring in a lot of Spanish workers or UAE workers and they have had an impact on the local economies, such as increased prostitution and drug use and that."

As well as the tension that exists between the locals and foreign internationals working on the plants themselves.

(R3) "The Bokspoort solar plant it was quite interesting they were still building it and the owners of the plant, it was towards the end of the building so all of the Spanish where on site managing the building process. But also, the soon-to-be owner were also on-site, and you could pick up a lot of friction. The occupational health and safety officer that took me around he was literally having to hide from the Spaniards."

This influence was reinforced by the following observation regarding the local accommodation in the Northern Cape.

(R7) "They say nowadays that if you go to Upington that you get guest houses that provide services in Spanish, because Spain is where most of the technology came from."

As was found in Section 2.4.1.4, policy emerged as a major challenge. Specifically, the length of time it takes for a policy to be released, lack of alignment of different policies and policy uncertainty.

> *(R4) "the policies in this country are very slow to come out, and if they do come out they are in conflict with the rest of the other existing policies. It spooks not only investors but also technology developers, because you have to develop something for the market and the market place; where you don't see policy certainty we actually can't invest."*

With the same participant reinforcing that if policies are stable, then investment and innovation will not be a barrier for further development.

> *(R4) "if you stabilize policy and you give the market an indication of demand in terms of the technology into the future…funding or investment will not be a problem. People are ready to invest in their own plant, to produce high quality, low iron content reflecting mirrors, high stakes for concentrating in CSP, you won't do it if you don't know you can recover your money."*

Interestingly, despite the many benefits of local content cited in the media and literature, two participants expressed that they felt local content requirements are in fact forming a barrier to advancing RETs in South Africa. The prevailing sentiment was that local content enforcement leads to a situation where South Africa sacrifices long term wins for short-term gains.

> *(R7) "I think things like local content are counterproductive…my view is that energy is one of the building blocks of economy, so the cheaper and more reliable energy you can provide it, the better the economy will grow. What they do in the REI4P is force a false inflated economy by forcing people to have certain local content and local participation. That increases the price of the energy, which puts a burden on the economy as a whole and has an impact on the competitiveness of the economy. If government were to accept that you do not have to do local content and local participation in everything, but if you can rather create an environment in which business can flourish. In other words, reduce the cost burden of energy on the economy, then it is fine if you get someone that comes in from Spain to build a CSP plant and operate it… So, it's not just that cost in economy increases it is that our international competitiveness decreases…They should have a view that says, the cheaper we can make the electricity, at whatever cost, the better it would be for the South African economy as a whole. If we lose 100 jobs because we didn't enforce local content in the building of a*

CSP plant but the cost impact on the electricity, on the grid price, is such that we can create another 10 000 jobs and that multiplier effect..."

(R10) "guys with the CSP technology are saying, no we want the supplier and that supplier. And this does not work with our Preferential Supplier Procurement Act in South Africa. The Preferential Procurement Act in South Africa states that we should be able to supply an opportunity for all. We should open this out to an open market and have it on a bidding system, on tenders received which is based on other mandatory and qualitative criteria, and we will do an evaluation on that which will eventually end up coming down to price. So, there is some synergy that is missing in that where we say that we want to be able to have a technology that is implementable according to their conditions, in a full value chain of who their suppliers need to be and then we say NO that we want to choose who those people need to be. So, there is a big big gap between those two."

One respondent also questioned the need for RETs in general in South Africa. Citing potential lack of demand (due to energy efficiency measures quelling climate change concerns in the near future and lack of economic growth leading to a reduction in electricity needs).

(R13) "if you look at the pessimistic assumptions… we have increase in energy efficiency and also very low economic growth and closure of very high intensive electricity businesses (like smelters and these sort of things) that move from the country because of our non-competitive electricity prices on the whole world scale….Then you could quickly see a scenario where South Africa, we don't see really economic growth and then we also don't see increase in electricity. Couple that with the Eskom electricity assets that we still have to maintain, even when we shut down that asset that would mean that we are only running to a deficit of electricity generation somewhere in 2040. When only in that time frame we may need to build new equipment to provide to the grid. In that scenario will you only see some growth of renewables very later on in South Africa."

As well as major challenges from incumbent technology.

(R13) "I don't currently see a scenario where we are going to decommission Medupi and replace with it with a CSP; I just don't think that's going to happen anytime soon. It might be that we don't have a market for any renewables in South Africa."

However, despite these challenges, many participants were optimistic about the potential CSP has to add value to the economy of South Africa.

(R1) "SA has demonstrated the ability to innovate in this space and could have the potential to catalyse CSP deployment in SA as well as capitalise on the commercialization of the technology globally…. CSP is at a stage and potential contribution similar to the value of the Fischer Tropsch technology to SA."

The main opportunities cited were the potential for the development of a manufacturing industry,

(R11) "I think CSP is probably easier from a manufacturing technology perspective to localise. I know that at a point there was a lot of interest from the South African automobile manufactures to get involved with CSP. They were looking at their own plant sitting idle because I think they would be able to retool some of their plants and be able to provide a lot of the components for CSP plants."

(R12) "think the whole value chain can even be built in South Africa and even for the steam pipe lines, that whole system. If you look at the salt storage, again I think those vessels are also quite easy to build, so I think the only portion that is left (that you are going to have to incentivise) is the mirrors. Then the last bit is the solar towers, which a lot of it is very specialised metallic alloy's…I think we make those chrome-titanium whatever special alloys in South Africa."

Resulting in job creation, of which out of all RETs, CSP was noted to have the highest job creation ability per capital spend.

(R9) "CSP technologies create the more jobs in terms of capital investment and operating expenditure, in comparison to most other generating technologies..."

It was also expressed that if South Africa were to develop manufacturing capabilities, that this could be exploited in conjunction with the abundant solar resources to provide electricity to parts of Africa.

(R11) "…there is demand and sufficient solar resources like in Namibia, Botswana and other places around the area. None of these markets are doing CPS yet and Namibia is probably the first. Botswana is making the same noises but it is very early stages."

(R11) "We know that the market in Africa is untapped, there are so many homes that need to be electrified, basic services that need to be provided. So, it is not to

say that it's going to just stop in South Africa, I believe there's going to be big expansion into Africa. And if you can set up the infrastructure well enough in South Africa, it will be the hub for the rest of Africa and the DTI can play in this space…."

(R12) "…we have quite a bit of ideal location for CSP in South Africa just compare it world-wide between South Africa and Chile. So, there is no reason why we can't generate electricity for the whole continent, well at least the southern area of the continent through renewables, and CSP could potentially play a role like that."

The future ability of CSP to provide baseload power (thereby reducing our dependence on fossil fuels and addressing energy security issues), as well as its capacity to play a more significant role in delivering peak power were also mentioned.

(R5) "… we need to continue procuring from coal because it is currently the only base load technology that we actually have in the country without us having to do massive imports like we would on nuclear. And we don't have local gas so it would mean that we need to import gas, which further puts strain on our economy because our balance of payments would be warped, we already import a lot of Brent crude which means we are exposed to dollar movement and if we do gas, from a base load perspective, then we would be exposed to more currency movement. We can then view CSP as that base load renewable energy..."

(R4) "There may be special cases for people with services who might want to ride through you know the evening peaks, and to make sure they have their own supplies based on 24 four hours..."

Although, the ability of CSP to continue to provide dispatchable power into the future emerged as a controversial topic. With some respondents expressing that there is a declining demand for peak power.

(R7) "I see that at least with industrial clients, that the daily consumption behaviour is starting or has started for the last 5 years to change. There has been a concerted effort to move away from using electricity in peak times. A lot of our mining clients stop their compressor house and pumps during peak times. The Ferrochrome smelters turn down production during peak times. So, you are sitting with a market that just could disappear..."

(R12) "if you look at world driver's, energy efficiency is starting to play a bigger role; you see a lot of countries are actually having models of almost no peak

electricity production. So, in a lot of the place's electricity, for the last few years, has been stagnant or even reducing because of drivers of energy efficiency."

Others outright expressed that CSP lacks the ability to compete with advancements in battery storage technology.

(R7) "I think 2 to 3 years from now that energy storage in Lithium ion batteries is going to outprice CSP, if not already the case. So, the selling point of CSP is the ability to store and that is being replaced with PV plus battery…There is a lot of work happening at the moment on the utility scale batteries using Vanadium redox flow batteries…. ideal for grid storage. There is a pilot plant being built in East London IDZ to manufacture palladium flow batteries electrolyte utilising technology that comes from China. The battery technology itself comes from China, but the electrolyte is local."

(R13) "…we tried to assess whether it would make sense or not, we compared it with wind plus batteries and it didn't."

Whilst, there were several strong proponents of CSP that noted that despite developments in battery storage, CSP still remains highly competitive.

(R1) "Long range forecasting at the moment suggests that even in 10 to 20 years from now, CSP (with storage as an intrinsic thing) is superior in terms of cost ($/kWh) when storage is higher than 6 hours. The future will see a range of storage options and I firmly see an "all of the above" scenario. There is little reason to view them [PV+ battery] as competitive."

(R1) "A note on PV + battery: Some PPA tariffs quoted in the PV community show extremely low numbers (like in the 2-3 US cent/kWh range). But in every instance, you only need to look at the battery rating (total charge energy and duration of discharge) to realise the battery size in these low-cost systems are vanishingly small and insignificant in the system. When it was constructed, Crescent Dunes, a single 110MW tower in Nevada had more storage capacity in its hot tank than all grid connected battery storage in the world combined. Another example, the 100MW battery that Tesla famously put into Australia provides roughly 5 minutes of grid stability. When compared with 110MW at 11 hours of storage, the Crescent Dunes storage is about 140 times bigger by electricity supply."

(R2) "Yes. Look at the competitive rate tariff and just do the sums. Look at some ambitious battery costs and build that onto a PV plant, there is still miles to go. It is probably one of the bigger risks for the technology and there are millions going

into the global research of batteries. The status now is that there are miles to go to be able to compete with multi hour storage on megawatt based that we see in CSP."

However, there were some participants that expressed uncertainty as to the future of the two technologies, noting that both RETs coupled with battery storage and CSP alike were on a downwards cost trajectory, and that there was uncertainty as to which would be more cost effective in the future.

(R9) "CSP with significant storage is still more economical than PV or wind with battery storage (utility scale) – for electricity generation. This is a changing landscape, as both CSP and battery costs have a reducing cost trajectory."

(R12) "…just look globally on where the cost of PV is going it is become very cost competitive. Some countries are even citing twenty South African cents per kWh. So, those are becoming quite cheap. So eventually also with battery technology catching up; maybe there will be a future point where PV plus batteries will also be able to provide a stable electrical supply. Or at least be able to provide during the peak times of the day where we use the most electricity, so then maybe you don't need as much PV to provide that base load power."

Finally, several remarked that the future of CSP may lie in small-scale applications.

(R2) "You need the space of CSP to talk about CST so it is not power we generated in the concentrating system it is solar energy. Then we can operate with entry set-up plants and preheat ore up to 600 or 700 degrees prior to it going into a smelter and that all leads to reduction in stuff (e.g. reduction in electricity consumption, and a reduction in diesel consumption if they use diesel burners) ... A lot of innovation is happening in that space, and this outside of any utility scale stuff, outside of PV or wind interfering too much."

(R3) "But I think more of an acknowledgement of energy services rather than electricity would be a very good thing. To look at a building or a facility as a complex system and that maintaining temperature needn't be through electricity but could be through intelligent design and the use of solar thermal energy, rather than using electricity to heat (rather use the sun directly). So, as we start to move into the green building realm that's where that stuff comes in."

(R9) "CSP can also be used for industrial heating processes and for the creation of solar fuels (much more suitable than PV and wind with batter storage)."

6. Chapter 6: Discussion of Results

The point of departure for this study is the premise that South Africa has the potential to leverage existing resources and infrastructure to develop an export competitive CSP industry. This kind of industry could deliver significant benefits to the country in the future (see Section 2.2.3), and include factors such as permanent job creation (in manufacturing and post-sale servicing), higher annual wages for workers and significant contribution to the GDP through various multiplier effects (WWF, 2015). Following this, the aim of the study (as outlined in Section 1.2) is two-fold. The first objective is to assess the maturity of the South African CSP TIS in relation to its readiness to develop an export competitive CSP industry. Then, based on these results, the second objective is to suggest appropriate action (including policy recommendations) to achieve this ultimate objective.

Three research questions were therefore put forward to achieve these aims (Chapter 3). Research question 1 seeks to evaluate the current state of the innovation system through the mechanism of expert interviews with key stakeholders active in the South African CSP TIS. Research question 2 aims to identify how the CSP TIS can advance from its current state towards the envisaged end-state using the mechanism of policy intervention and research question 3 aims to probe the expert's opinion on the future prospects of this industry, within the context of South Africa and the progress achieved to date.

6.1 Discussion of Results for Research Question 1

RESEARCH QUESTION 1: What is the level of maturity of the CSP sector, as determined through the application of the TIS framework?

The extent to which each system function is fulfilled in the South African CSP TIS is given in Section 5.3, Figure 22. These values are based on the average score from the ratings provided from the sample set of 13 experts consulted in the course of this study. Entrepreneurial experimentation (F1), guidance of the search (F4) and legitimacy creation (F7) were viewed as the most problematic areas in the TIS. Resource mobilisation (F6) and market formation (F5) were rated as slightly more mature and knowledge development (F2) and knowledge diffusion (F3) were seen to be the most developed. However, given that the most fulfilled function (F3) only scored 2.7 out of 5, it is clear that the TIS is generally poorly developed and further interrogation is required. Therefore, Sections 6.1.1 – 6.1.7 will draw insights from the interviews with the 13 experts in order to further expand on these findings.

6.1.1 F1 – Entrepreneurial Activity

Participants felt that the poor performance of this function is largely due to the fact that the firms in the South African CSP industry are foreign. This is confirmed upon closer examination of the developers and EPC companies awarded the tenders for the 7 CSP projects as part of the REI4P. As can been seen in Table 11, the developers and EPC firms originate from Saudi Arabia, France, USA, with the majority of firms from Spain. There is only one local firm, Emvelo involved in the development of the Ilanga CSP project. Indeed, this situation is likely a consequence of the observation made in the literature that the CSP industry is an oligopolized branch of the global energy industry, where CSP knowledge is concentrated in only a few global companies (Lilliestam et al., 2018; Vieira de Souza & Gilmanova Cavalcante, 2017). This of course has ramifications for both (F1) and (F2) if these providers are unwilling to enter into partnerships (F3) with local companies.

Aside from Emvelo, there appears to be only one other local company, GeoSUN, involved in providing solar monitoring services to the CSP industry (GeoSUN Africa, n.d.). Stellenbosch University also have a piloting facility where they are developing heliostat technology with funding from the Technology Innovation Agency (TIA), an initiative of the DST (STERG, n.d.-b). In contrast, a cursory search revealed that Spain appears to have at least 8 – 12 active companies developing and supplying various CSP components (Xprt energy, n.d.).

Table 11: Main developers and EPC firms for the South African CSP projects under the REI4P (Relancio et al., 2016)**.**

<table>
<tr><th>Project Name</th><th>Main Developer(s)</th><th>Developer (Country of origin)</th><th>EPC</th><th>EPC (Country of origin)</th></tr>
<tr><td>KaXu Solar 1</td><td>Abengoa</td><td>Spain</td><td>Abeinsa</td><td>Spain</td></tr>
<tr><td>Khi Solar 1</td><td>Abengoa</td><td>Spain</td><td>Abeinsa</td><td>Spain</td></tr>
<tr><td rowspan="2">Bokpoort CSP</td><td rowspan="2">ACWA</td><td rowspan="2">Saudi Arabia</td><td>Acciona</td><td>Spain</td></tr>
<tr><td>SENER</td><td>Spain</td></tr>
<tr><td rowspan="2">Ilanga CSP1</td><td>ACS Cobra</td><td>Spain</td><td rowspan="2">ACS Cobra</td><td rowspan="2">Spain</td></tr>
<tr><td>Emvelo</td><td>South Africa</td></tr>
<tr><td rowspan="2">Kathu Solar Park</td><td>Engie</td><td>France</td><td>Acciona</td><td>Spain</td></tr>
<tr><td>PIC</td><td>South Africa</td><td>SENER</td><td>Spain</td></tr>
<tr><td>Xina CSP</td><td>Abengoa</td><td>Spain</td><td>Abeinsa</td><td>Spain</td></tr>
<tr><td rowspan="2">Redstone CSP</td><td>ACWA</td><td>Saudi Arabia</td><td>Acciona</td><td>Spain</td></tr>
<tr><td>SolarReserve</td><td>USA</td><td>SENER</td><td>Spain</td></tr>
</table>

The observation that local firms are mostly active in the non-specialised services (e.g. construction) was also made in Relancio et al., (2016) who noted that the CSP jobs created thus far have been on the “lower value end of the supply chain” (p. 110002-6). This is unfortunate given that the production of basic components holds the lowest potential for developing an export competitive industry, estimated at only 10% of the worth of the overall plant (WWF, 2015). Therefore, even though the local content threshold requirements have been progressively increased (Eberhard & Naude, 2016), they have failed to be specific on the nature of the skills transfer. This, coupled with the observation that the international firms appear to be reticent in allowing local resources to work on their plants, brings into question whether there is meaningful knowledge transfer (F3) occurring. In this case, knowledge transfer would be considered a form of knowledge development i.e. ‘learning-by-doing’ (Lundvall et al., 2002), an essential precursor to stimulating local entrepreneurial activity given that the majority of commercial CSP knowledge lies with international companies . It therefore appears that potential long-term entrepreneurial activity has been sacrificed in favour of immediate job creation.

In addition to the challenge mentioned above, the expert interviews also revealed that policy uncertainty is a major challenge to entrepreneurial activity (this will be explored in more detail in Section 2.4.1.4), as well as the availability of funding due to the cost of the technology. This latter challenge however is not exclusive to South Africa, and has emerged as a general problem for developing countries attempting rapid and widescale deployment of CSP. In the case of Morocco and India, public financial institutes have aided in reducing CSP tariffs through cooperation with national policymakers who ensure a stable policy environment (Frisari & Stadelmann, 2015). However, until such a time as South Africa can provide such assurances, exploring innovative financing models to improve entrepreneurial activity may prove fruitless.

Although the REI4P has been applauded for its success and cited as an example of a successful auction mechanism to stimulate RET uptake, the requirement that only proven technology be tendered has been cited in the expert interviews as a barrier to entrepreneurial experimentation. It was felt that this condition stifled participation by small local companies who could not compete at the scale required with established foreign firms.

The expert interviews also revealed that the lack of a local value chain, due to lack of IP ownership, was a challenge for entrepreneurial activity. This particular challenge was framed as one with knock on effects i.e. because local companies do not own IP for specialised components (e.g. the mirrors), there is an inability to establish a local value chain. Accordingly, because there is no local value chain this increases the cost of the technology, limiting the number of new entrants able to participate. This observation appears to contradict that of Relancio et al., (2016) that noted supply chain optimisation was an area that had made significant progress. The study went on further to cite that collaboration between developers/EPC contractors and local industry has resulted in the creation of local companies that have optimised the project's supply chain, thereby facilitating more competitive tariffs.

Finally, the delay in the signing of the PPA was mentioned as a factor that has caused a major barrier to entrepreneurial activity in the South African CSP sector by creating uncertainty in supply-chain investments. Although in this case the delay was particularly prolonged, this type of issue is cited as a common problem with auction-style incentive programmes that result in intermittent markets between bids (Lilliestam et al., 2018). This problem has no obvious solution as predefining a long stream of auctions several years in advance limits the flexibility of policy-makers to adjust auction requirements in line with technology advancements (Lilliestam et al., 2018).

Therefore, with this current paucity of entrepreneurial activity in South Africa it is unsurprising that (F1) received such a low score by respondents. However, it is interesting to note that prior involvement of the private sector companies Sasol and BBE indicate that entrepreneurial activity may have in fact been much stronger in the past. Given that the presence of a weak entrepreneurial function is typically a signal of a weak innovation system as a whole (Reichardt et al., 2016), it is again unsurprising that the CSP TIS was found to be generally undeveloped.

6.1.2 F2 – Knowledge Development

The expert interviews revealed that there is a strong CSP research base in South Africa, with several large local universities engaged in solar thermal research. The focus of these research groups spans topics from thermofluid research, socio-economic and development studies, techno-economic evaluations, engineering optimisation of incumbent technology and technology development directed towards new generation CSP. The most prominent of these research groups is the Solar Thermal Energy Research Group (STERG), based at the University of Stellenbosch. As can been seen from their group description and mission, there is an alignment of research focus with the potential aspiration for South Africa to develop an export competitive CSP industry (STERG, n.d.-a) .

Group description – *STERG was the first university research group in South Africa dedicated to solar thermal energy research. Our primary mission is to train students and deliver research outputs in Concentrating Solar Power (CSP).*

Vision – *To be a world leading university solar thermal and CSP research group delivering graduates that will enable South Africa to achieve its solar energy potential from within and to be competitive abroad.*

Additionally, their website mentions a variety of industry and international research collaborations, as well as a research chair in CSP funded by Eskom. As noted by Hekkert et al., (2011) the existence of special professorial chairs at universities funded by companies is a clear indication that educational institutes are poised to provide relevant skilled labour. Furthermore, one of the academic experts mentioned their focus area has moved towards the development on solar tower technology, which is well aligned with the academic and industry literature that indicates growth in commercial tower technology for utility scale applications (Fuqiang et al., 2017).

However, it emerged in the interview process that much has changed in the last few years, with many industry players halting CSP research – most notably Sasol and Eskom and the CSIR focus shifting towards wind and PV research. Additionally, it was noted that academic institutions are finding difficulty accessing funds. The general sentiment was that this wasn't as a result of a deficiency in budgets of known funding entities, but rather that CSP technology is not a priority in South Africa and different government departments are focused on driving their own agenda resulting fragmenting available funding.

Industry experts and the RE consultant also expressed that they had reservations on the relevance of further CSP research, stating that the technology was already mature. This is in opposition to the literature that notes that unlike PV, which is at the lower end of its learning curve, CSP is an immature technology with significant cost reduction potential (Lilliestam et al., 2018). This comment in conjunction with industries focus moving away from CSP the points to a potential disconnect between the way academia and industry view further opportunities in CSP.

It therefore seems that the reason this function ranked as one of the most developed in the CSP TIS is due to the legacy of established institutes. However, the absolute value of this function is still fairly low (<3), reflecting the changing landscape towards less support of CSP research. This is further evidence by the alumni page on the STERG website that shows the placement of their graduates in various international CSP companies, highlighting that whilst the local universities are well equipped to train highly skilled CSP engineers, the skills are not retained in the country due to a lack of in-country opportunities. Both an academic exert and the IPPP official noted the irony that this locally developed technology and skill was the very same knowledge that had to be sourced internationally for the local CSP developments.

The majority of respondents viewed the current level of knowledge development as a barrier to further advancing the TIS. Although the general sentiment was that the calibre of local South Africans is not lacking, rather the opportunity. This is somewhat supported by Relancio et al. (2016) that found South Africans held the required skills and were competitively priced in the market to support a local CSP manufacturing industry.

6.1.3 F3 – Knowledge Diffusion

Through the interview process it emerged that there are 4 main actors involved in knowledge diffusion in the South African CSP TIS: local academic institutions, international academic institutions, industry (mostly foreign companies) and the local power utility provider Eskom. The academic experts interviewed felt that there was good knowledge exchange occurring between local and international academic institutes and to a degree between local academia and international firms. The primary vehicle through which this exchange has been occurring is the SolarPACES conference, which has been described by Craig et al. (2017) as “the most referred to academic and industrial conference on CSP technologies in the world” (p.19). This conference was in fact hosted by a South African delegation in 2015, which indicates a global acknowledgment of the South African CSP involvement. Additionally it was noted by the local academia representatives that knowledge is being exchanged between local academics and industry, whereby STERG graduates are facilitating training courses on-site in Kathu, and through technical tours to the Northern Cape sites (STERG, 2017). Additionally, there was mention made of a local annual symposium hosted by STERG that brings together South African research institutes (universities and research centres), international academics, invited speakers from industry (e.g. Abengoa) and even potential local financing institutes. Although, outside of the interviewees from academia, there was very little awareness of these events.

As was mentioned in Section 6.1.2, there is very little current participation from South African corporates in the South African CSP TIS due to a deliberate choice on their parts to stop CSP research. These actors are therefore not active in disseminating knowledge within the TIS.

There was also a general sense that there was little knowledge exchange occurring between Eskom and the CSP developers/EPC contractors. Some felt that this was due the international companies wanting to guard their IP and others felt it was due to Eskom’s decision to cancel their CSP project. In fact, it was implied that Eskom may actually be a counter force in knowledge dissemination by propagating misinformed information around CSP due to vested interests in incumbent fossil-fuel technology.

Then participants were fairly evenly divided with respect to the knowledge transfer from the international developers to local firms. Some indicated that they had interacted with these international firms with a view to partner to develop CSP (they did not expand on whether this was as a joint venture or licencing agreement), others expressed that they weren't aware of any but assumed that it was occurring according to the local content requirements of the REI4P. However, this again brought to light the discussion around the level of complexity of this knowledge transfer i.e. whether it is only basic skills and not necessarily skills that could enable local industrial development. Some respondents outright expressed that there is no knowledge transfer and that this lack of international collaboration is due to these companies wanting to protect their IP. As can be seen in Table 11, there is only one South African company involved in project development, and it is not clear if this is due to other South African companies attempting and failing to partner or if it is indeed reticence on the developers/EPC contractors' side to share IP.

Apart from being a problem in the South African CSP TIS, Lilliestam et al. (2018) notes that lack of knowledge transfer from the limited number of firms with tacit knowledge of CSP component manufacture and CSP plant operation, poses a large risk to further development of the global CSP industry. This risk was however not framed as a lack of willingness of incumbent firms to do so, but rather that these firms will unexpectedly leave the market.

Despite the fact that this function scored the highest on the TIS analysis, almost all participants felt that knowledge exchange was forming a barrier to further development, which is also reflected in the low score in absolute terms. Craig et al. (2017) notes that South African's are CSP technology receivers, since the utility-scale technology present in the country was first developed in the home countries of the companies awarded the tenders. Therefore, if knowledge transfer is measured as the number of emerging companies and/or companies that have been capacitated to participate at commercial scale (either in the design, manufacturing or construction of the plant), then indeed the knowledge diffusion function in the South African CSP TIS is unfulfilled.

This observation also has ramifications for (F2). Edsand (2016) puts forward that knowledge development (F2) in a TIS occurs via two mechanisms, through the development of new technical knowledge domestically or through the transfer of knowledge (F3). Knowledge development through this latter channel is most prevalent in the case of a developed country transferring knowledge to a developing one, as is the case in the utility-scale CSP TIS. Consequently, the lack of knowledge transfer noted by the participants becomes a barrier for knowledge development.

6.1.4 F4 – Guidance of the Search

In general respondents felt that clear goals had not been set with respect to the development of CSP in South Africa. To understand why this is the case it is useful to refer back to Section 2.2.1, which explains that renewable energy goals in South Africa are set in the form of ministerial determinations that dictate both the technology and the amount of that particular technology to be procured by a certain date. These determinations then become formal targets once the IRP is promulgated. According to TIS literature, this type of target setting by a government is a clear indicator of the visibility and clarity of user's requirements (Hekkert et al., 2007). However, despite the existence of such a process, participants expressed that CSP goals were not clear as 3 revisions (with 3 different CSP allocations) of the document had been released since the promulgation of the 2010 IRP. The latest revision was released in August 2018 for comment, after a prolonged 2 years between revisions. This means the renewable energy industry has been without fixed goals since the promulgation of the IRP 2010 in 2011. As it stands, the IRP 2018 allocates no further capacity to CSP with all additional renewable energy to be sourced from a mixture of PV, wind and a balancing source such as gas. If this IRP is promulgated no additional utility-scale CSP plants (beyond those listed in Table 11) will be built in the near future. This is likely the main contributing factor to the low score received for F4. Other, more minor factors are discussed below.

Respondents also expressed that another major factor raising uncertainty around the government's commitment to CSP, and renewable energy in general, was the substantial delay in the signing of the last round of PPAs. This kind of delay is highly damaging to investor confidence (Lilliestam et al., 2018; WWF, 2015) and is likely to have ramifications for further investment in CSP in South Africa as the Redstone CSP project was one of the 27 delayed projects.

Several interviewees expressed that CSP would benefit from an alignment of policy makers with another other. There was a general sense that different divisions in the government seem intent on pursuing policy towards their own gain, without due concern for the synergies that may come from co-operation (e.g. aligning the DEAs agenda to mitigate emissions with the DSTs mandate to develop scientific research in the country) or the confusion that stems from a lack of alignment (e.g. the potential conflict of Department of Energy's goal of pursing least cost energy conflicts with the dti's mandate of establishing local industry). Aside from two respondents, all interviewees felt that the DST and dti should be more active within their respective mandates in developing CSP.

6.1.5 F5 – Market Formation

Hekkert et al., (2011) suggests that a useful way to assess a market is from the demand side, by understanding who is creating the demand and whether it is specific. This sentiment has strong links to (F4), as a clearly articulated demand signals clear user expectation around a technology. Hekkert et al., (2011) further makes a distinction between government and private companies demand.

In the case of the South African CSP TIS, governments demand is manifested through the REI4P, which was acknowledged as the sole mechanism to create a utility-scale market. It has provided a protected space to allow a somewhat unproven technology to develop (unproven in the sense that commercial scale CSP did not exist in South Africa prior to the REI4P) (Miremadi et al., 2018). Although the REI4P has been successful in creating a market, some respondents felt that the programme may have been more successful if the size of the individual projects had been increased. Indeed, as noted in (WWF, 2015), CSP plants generally tend to benefit from economies of scale when they are in the range of 130 – 170 MW, where the largest projects under the REI4P were 100 MW. Additionally, several respondents expressed concern that unless the CSP procurement targets are increased that the CSP market will not grow in the future as it is not possible to develop utility-scale projects outside of IPP tender programmes. This is supported by the study by Relancio et al., (2016) who's respondents also expressed a concern that the forecasted volumes in South Africa were not sufficient to justify a new manufacturing sector.

Then with respect to private company's demand, respondents again mentioned the withdraw of companies like Sasol from the CSP industry as a clear indicator of a lack of private sector demand. It was also discussed that the main reason private companies would be interested in CSP is to decrease peak demand electricity costs and that many industries have already put energy efficient measures in place or have instituted programmes to cut down activity during peak times, so this market may in fact disappear in the future.

It seems therefore that this function scored moderately (relative to the other functions) as the REI4P has been able to create a market, but still low in absolute terms because the future prospects are limited.

6.1.6 F6 – Resource Mobilisation

Financial and human resource mobilisation are the two main components that are used to examine the fulfilment of the resource mobilisation function. Through the interview process it was found that the majority of the participants felt that the REI4P had not generated sufficient financial incentive to develop a CSP industry, largely as it does not create space for local entrepreneurial activity (F1) as only proven technology can tender. Although, as show in Figure 16 There was a general view that if the government makes a clear commitment to the technology in the future (F4), then funding from either local or foreign financial institutions would not be a barrier, although other respondents felt that there is still a hesitance to fund RET in general. This latter view is supported by recent literature that shows whilst financing of RET by both public and private entities has increased it is still small in comparison to fossil fuel investments (Mazzucato & Semieniuk, 2018). This is largely attributed to the risk profile of RET, which are capital intensive and generally immature technology (Craig et al., 2017).

There was a general sentiment that the availability of skilled human resources would not form a barrier to the further development of the TIS if this technology was prioritised in the future. This is supported by WWF (2015) and the (F2) functional analysis in Section 6.1.2 and is likely the reason this function did not rate as low as (F1) and (F4).

6.1.7 F7 – Counteract Resistance to Change/Legitimacy Creation

Although there are two CSP lobby groups in South Africa, SASTELA (Southern Africa Solar Thermal and Electricity Association) (SASTELA, n.d.) and the more recently formed STASA (Solar Thermal Association of Southern Africa) (STASA, n.d.), most respondents expressed that they had not seen much direct advocacy in the media. It was noted that this is in stark contrast to the highly active South African PV and wind lobby groups that appear to be effectively promoting these two technologies. It was also expressed that the fact that there are two lobby groups might be counter to the objectives of promoting this technology. Some respondents that had been involved in the South African CSP TIS for a few years noted that this was not always the case and that SASTELA had been quite active in the past. These statements seemed to be corroborated upon an examination of the two industry bodies respective websites, where at time of writing, the STASA website was void of content beyond the landing page (STASA, n.d.) and the SASTELA website (SASTELA, n.d.), though much more populated, contained fairly dated material. Interviewees expressed that these lobby groups should be using social media more effectively to promote CSP and its technological and industrialisation opportunities. This is in-line with Edsand (2016) that noted the Internet and social media has the benefit of shaping public opinion at a far more rapid pace than just a few decades ago. However, the counter is also true, in that it can also be used to disseminate negative messaging around the technology.

This seems somewhat true of CSP, where the majority of respondents also noted that CSP had been the subject of much negative media attention, propagated by parties with strong political influence, fuelled by a specific political agenda to protect coal assets and promote nuclear energy (e.g. NUM and NUMSA see Section 2.2.2). It was also suggested that the political weight of these groups was sufficient to have caused the delay in the signings of the PPA, thereby delaying the entire REI4P. Some respondents also felt that CSP had been used as a proxy for all renewable energy; therefore, any negative implications of job losses from coal as a result of increased renewable energy uptake were associated with CSP alone. By far the largest counter argument made against CSP is the cost compared to other forms of energy, but as noted by most participants, this is largely uniformed as the price quoted often doesn't take the storage into account in the value. It is also noted that the CSIR, who is involved in extensive RET modelling for the country, is actively pursuing PV and wind technologies over CSP. This modelling is informing both government and industry and could be a contributing factor to why CSP was excluded from the IRP.

The overall low score of this function reflects that the interviewees felt that the negative media attention and political influence of the parties propagating these messages far outweighs any positive media attention created by the 2 CSP lobby groups.

6.1.8 General Discussion of the TIS Results

TIS literature states that the innovation system should be evaluated with respect to its phase of development, to see if it is developed enough to move onto the next phase. According to Hekkert et al., (2011) there are 5 stages of development, *pre-development* where a protype is produced that signals that the technology works, *development* triggered when the product enters the market (usually by the first commercial application), *take-off* when the technology is diffused and the market grows, *acceleration phase* characterised by rapid diffusion and *saturation* where diffusion stabilises (Edsand, 2016; Hekkert et al., 2011). If one were to evaluate the current state of the South African CSP TIS, it is likely somewhere on the spectrum between development and take-off as there is a commercial application, but it seems questionable as to where there is fast market growth. For the sake of simplicity, it will be assumed that the TIS is in the take-off phase.

In the take-off phase the two most critical functions are (F1) and (F7) as entrepreneurs should be highly active building the system, to establish legitimacy of the technology. Guidance of the search (F4), resource mobilisation (F6) and market formation (F5) are seen as the next critical, whilst knowledge development (F2) and diffusion (F3) are seen as the least important (Hekkert et al., 2011). If one considers the results of the analysis above it can been seen that there is a large disconnect in the way the South African CSP TIS is currently fulfilled relative to what it should be i.e. the most under developed functions are the ones that should be the most developed, whilst the most fulfilled functions are the least important at this stage. This could be due to the fact that in the past there seemed to be a much stronger support for local CSP development than what exists today. Therefore, in the ‘old’ TIS, more resources were allocated towards CSP development (F6), there were much clearer goals associated with CSP (F4), there was an industry demand for the technology (F5) and this led to a well-developed (F2) and (F3), which resulted in entrepreneurial activity (F1). However, since then a variety of challenges befell the South African CSP industry (as discussed in the previous sections) resulting in decreased support from industry (i.e. F4 and F5 dropped in development), IP that had been developed was sold, leading to a loss of both F1 and F2. However, due to the well-established research presence F2 and F3 were able to remain fairly strong. These have then been taken into the ‘new’ TIS, which is much more focused on relying on knowledge diffusion from international CSP companies that have already developed and commercialised CSP technology. Suggestion for how to further develop the South African TIS are given in Section 6.2

6.2 Discussion of Results for Research Question 2

RESEARCH QUESTION 2: Based on the results of the TIS analysis, what are the key interventions that need to take place to realise the potential of South Africa becoming a global competitor in this arena?

Before commenting on which policies can be instituted to improve the fulfilment of the TIS functions it is important to first understand that any proposed policy instruments aimed at advancing a particular emerging technology should be aligned to the policy goal associated with that technology. To further elaborate, a policy goal in respect of a particular technology refers to the governments vision of what that technologies societal contribution should be. Hekkert et al. (2011) further suggests that RET policy goals can be categorised along 2 dimensions; (1) A dual environmental and energy goal, where the policies are aimed at reducing dependencies on fossil fuels to both mitigate GHG emissions and ensure energy security and (2) an economic goal, with a focus on developing emerging RET sectors into globally competitive industries to increase local economic growth. Although the two goals are not necessarily mutually exclusive i.e. if one is achieved it may have an unintended positive effect on the other, it is important that the main focus of promoting a specific RET in a country is understood as it will inform what the most appropriate policy action is.

The quarterly report released by the IPPP office states that the REI4P was established "…as one of the South African government's urgent interventions to enhance South Africa's power generation capacity" (IPPP Office, 2018, p.1). In support of this, the tender process is heavily weighted in favour of the price of the RET (70% of the scoring is allocated to cost). This seems to suggest that the governments primary aim is energy security. Therefore, policy aimed at accelerating the development and diffusion of RET should be focused on increasing RET capacity at least cost. However, the objectives of the REI4P are also cited as "Procuring energy while contributing to national development objectives" (IPPP Office, 2018, p.1). Accordingly, the programme has assigned 30% of the tender scoring to local economic development criteria, which far exceeds the value of 10% stipulated in the government's national procurement legislation. Additionally, the weighting of the local content thresholds within local economic development criteria have been progressively increased with each round (Relancio et al., 2016), which may be an indication of a shift in governments priorities. These two primary objectives therefore seem at odds with each other under Hekkert et al. (2011)'s two RET policy categories. Therefore, given that the government's main reason for advancing RET is unclear, the following policy suggestions will be divided by those that could advance an environmental/energy goal and those that could advance an economic goal. However, it is noted that underpinning both suggestions is the assumption of policy certainty, because without this neither approaches will be effective.

6.2.1 Policy and Action in Pursuit of an Environmental/Energy Goal

In this type of policy goal, the deployment of CSP would be directed towards contributing to GHG emission reductions, guaranteeing supply of energy at lowest cost and reducing fossil fuel dependence. There are several actions that need to take place in a coordinated manner to achieve this.

Firstly, the role of the lobby groups needs to become far more prominent. The two CSP lobby groups would need to increase the legitimacy of the technology by highlighting its benefits. Part of this would be to start a media campaign to educate the public on the reason why the cost of CSP is higher than PV or wind i.e. that it has built-in storage (and that the method of pricing CSP in the REI4P has been carried out to reflect this value –

see the tariff discussion in Section 2.2.3) and that if a true comparison were to be made against PV and battery that CSP would be the forerunner (although this may not always be the case – see Section 6.3) (Feldman et al., 2016). The CSP lobby groups could also form an advocacy coalition with climate change lobby groups leveraging, off the obvious synergy that RET in general are needed to meet South African climate change commitments (IRENA, 2018a), and that their share in the future energy mix needs to be increased dramatically from the ca 30% envisaged by 2030 (see Section 2.2.1). By comparison a developing country like Brazil that has given priority to the national deployment of renewable energy aspires to have ca 75% of its energy mix from renewables (Vieira de Souza & Gilmanova Cavalcante, 2017). This then needs to be taken a step further to highlight that the proposal in the IRP 2018 to use gas as a means of balancing the intermittency of PV or wind is a step in the wrong direction as gas is still a fossil fuel. Additionally, the CSP lobby groups could capitalise off the current debate as to whether there is in fact a secure supply of gas available to South Africa in the future (see for example (Newman, 2016)). The ultimate goal of the campaign would be to influence the procurement target in the future energy mix to be higher than the mere 600 MW stipulated in the IRP 2018.

Then there are also 2 changes that can be made to the manner in which the tender process is developed for CSP under the REI4P. Currently PPAs are contracted for a 20-year period, therefore the cost of delivering the technology is worked out over this time period. However, the lifetime of a CSP plant is expected to be much longer (at least 30 years), which is much longer than the anticipated lifetime of a PV or wind plant (WWF, 2015). Therefore, extending the CSP PPAs to 30 years (in line with the expected lifetime of the plant), reduces the overall cost of CSP electricity providing a more competitively priced peak renewable energy source than is currently available. This strategy has already been employed internationally to achieve the lowest cost of USD $ 0.07 kWh recorded to date (Lilliestam & Pitz-Paal, 2018). Additionally, the capacity size of the individual projects should be increased from the existing limit of 100 MW, to take advantage of the cited economies of scale that are achievable between 130 – 170 MW (WWF, 2015).

Furthermore, since the most competitive technology providers are mostly international companies (Craig et al., 2017; Lilliestam et al., 2018; Vieira de Souza & Gilmanova Cavalcante, 2017) it is important that knowledge transfer (F3) policies are put in place to ensure that the technology providers transfer knowledge that will result in the creation of sustainable and permanent employment in the South African CSP industry. At the very least this means that the local content requirements specified in the REI4P should be updated to specific both the quantity and the nature of the skills transfer required in the bid. This type of policy could also be a value aid in countering resistance from political bodies intent on maintain current coal assets, using the argument of loss of jobs (see Section 2.2.2), but this should be weighed against the additional costs that might be incurred as a result that would raise the price of the electricity. In conjunction, scientific funding bodies such as the DST should increase their funding available to CSP research to maintain a level of competence in the country.

Finally, the utility-scale CSP industry could also benefit from a REFIT policy (see Section 2.1.2.2) to incentivises small-scale CSP developments (e.g. provision of process steam to industry, heating and cooling applications in office buildings or remote locations) and increase the private sector market (F5) (Promethium Carbon, 2014). This would facilitate continued CSP learning (F2) outside of utility-scale applications, that could aid in bringing CSP down the learning curve, leading to further cost reductions in all CSP applications.

6.2.2 Policy and Action in Pursuit of an Economic Goal

In this goal, the aim of a RET development such as CSP, would be to boost economic growth of the home country through the development of an export competitive industry (Hekkert et al., 2011). Being export competitive in this regard means that South Africa becomes a technology leader in the design, manufacture and construction of a plant. The focus on increasing RET capacity for in-country use is therefore a secondary consideration to this, but it is still required to create a demand for the technology. An analogy to this would be the Chinese PV market, who through specific government directives focused on the manufacture of PV panels to become the world's largest supplier of this product (Vieira de Souza & Gilmanova Cavalcante, 2017), yet still has an electricity sector dominated by fossil fuels (BP, 2018).

The vehicle through which South Africa could achieve the objective of becoming export competitive is through a procurement-driven industrial strategy, such as the one suggested in WWF (2015). A demand-side auction programme such as the REI4P is still key to this kind of strategy as large-scale demand (and subsequent market formation – F5) needs to exist to attain a critical mass of technology to develop tacit knowledge around the design, manufacture, operation and maintenance of the plants. However, this needs to be supported by sufficient industrialisation policies aimed at building localised services and manufacturing. These include knowledge transfer (F3) through cooperation with an international OEM (e.g. licencing, joint venture agreements or enforced local content requirements) or R&D policy and funding support to develop own designs (F2) and import tariffs to incentivise local manufacturing.

This approach requires alignment between energy policy (to increase CSP procurement objectives, lower risk and incentivise investment), climate policy (incentivise RET uptake through mechanisms such as emissions taxes) and industrial policy (to incentivise manufacturing and knowledge development). The distinction between this strategy and the environmental/energy with respect to the REI4P, is that even when CSP is not the least cost option in the electricity mix it is deliberately retained because of the industrialisation objectives.

As was suggested in the interviews, one method of accelerating knowledge development and encouraging participation from both the private and public sector is to develop a centralised solar thermal knowledge centre in South Africa using public and private funding, such as the *Plataforma Solar de Alemeria* in Spain (CIEMAT, n.d.). This kind of research centre is aimed at developing and testing solar technology (F2) and fostering collaboration (F3) between academia, industry and international subject matter experts. It also provides a platform for piloting technology, so as to allow a prospective technology to accumulate sufficient hours on-line to demonstrate its commercial readiness (F2). This then lowers the risk profile of a technology, which encourages investment from potential investors (F6). The investment then increases the number of entrepreneurs (F1) able to enter the market (F5). Piloting also provides an opportunity to influence the design process to support manufacturing capabilities. Regular training seminars also ensure a pipeline of skilled human resources (F6) to address any areas with critical resource shortage.

6.3 Discussion of Results for Research Question 3

RESEARCH QUESTION 3: What are the future opportunities for CSP in South Africa?

This question seeks to understand what the participants view of the future of CSP in South Africa is within the global and local challenges facing CSP. Although many of the local challenges materialised through the process of the TIS analysis, additional barriers emerged that could not be categorised under a specific function.

Participants felt that the main global challenge facing CSP was the fact that geographical limitations and high capital costs have limited the number of CSP plants relative to PV and wind, therefore CSP has been unable to proceed down it’s learning curve to reduce its costs. This is supported by Lilliestam et al., (2018) that notes “…whereas PV has run through much of its learning curve, CSP is still an immature technology with large cost reduction potential left…” (p.194).

Several South African context specific challenges emerged during the interviews. The first one involves social issues that have arisen due to the large contingent of foreign workers migrating to the small towns in the Northern Cape where the CSP plants are located. Exploitation of local communities, prostitution and 'solar babies' were topics that arose during these discussions. It was also mentioned that there is tension between the local and foreign plant workers that can create hostile working conditions.

Interestingly, despite previous suggestions that local content requirement can be leveraged to create a local manufacturing sector, two participants expressed that they felt local content requirements are in fact forming a barrier to advancing RETs in South Africa. The prevailing sentiment was that local content enforcement inflates the price of electricity and that since electricity consumption is correlated with economic growth (Ozturk, 2010), South Africa should rather be pursuing the cheapest electricity and benefit from the multiplier effects that come from that, instead of focusing on the limited jobs that come from local content. Indeed, there is a growing body of literature on this discourse (Eberhard & Naude, 2016; Wlokas, 2015).

There was also some commentary around whether there will in fact be a need for RET growth at all, given the large coal infrastructure, plans for future coal growth and the overall reducing electricity demand due to energy efficiency incentives (e.g. the 12L tax incentive).

It is surprising that both grid integration issues and water scarcity were not mentioned as challenges in the South African context. The grid connection issues experienced by the first CSP plants built as part of the REI4P have been covered extensively in Relancio et al., (2016), whilst Craig et al., (2017) highlight the scarcity of water in South Africa as a major issue and suggest that the only way to overcome this is if air cooling is incorporated into the CSP plant design (as was done at the Khi development).

However, despite these challenges some participants were optimistic around the potential for South Africa to develop manufacturing capabilities in CSP and the job creation potential that would stem from that. Some felt that South Africa's future CSP potential did not lie with utility-scale applications, rather small-scale applications. There was also mention that South Africa could leverage CSP capabilities to provide electricity to other parts of Africa through transnational electricity purchase agreements. There was also a positive sentiment around CSP's potential to provide peak and baseload electricity in the future, although there were conflicting views as to whether PV coupled with battery is in fact more cost effective, with many respondents feeling that indeed it was. A closer examination of the literature however, shows that PV coupled with battery storage is far more expensive than CSP with storage for a similar level of dispatchability. The price difference becomes more pronounced in favour of CSP when more than 6 hours of storage is required (Lilliestam et al., 2018). However, studies indicate that PV coupled with battery storage under 6 hours may close this cost gap in the next few years (Feldman et al., 2016). Therefore, given that both technologies are on a downwards cost trajectory, it remains a question of innovation as to whether CSP is able to maintain its competitiveness in the future.

7. Chapter 7: Conclusion

7.1 Principle Findings

The point of departure for this study is that South Africa has the potential to develop an export competitive CSP industry by leveraging existing capabilities in innovation, manufacturing and construction and through exploitation of its abundant solar resources to provide a platform to pilot and commercialise this technology (WWF, 2015). This study therefore sought to first understand why, given this potential, South Africa has only the third largest installed capacity of CSP in the world at 300 MW, lagging far behind the USA (1 758 MW) and Spain (2 300 MW) (IRENA, n.d.-b). It then aimed to understand what measures can be put in place to realise this ambition. Finally, the study aimed to assess what are the future opportunities for CSP in South Africa.

The TIS framework was applied to the first question to identify problem areas (Hekkert et al., 2011). This framework forms part of innovation systems theory (Godin, 2009; Malerba, 2002; Planko et al., 2017) and acknowledges that an emerging technology develops and diffuses within a specific context and is influenced by a variety of elements. These elements are delineated within the TIS framework as a set of 7 empirically validated indicators, referred to as system functions (Miremadi et al., 2018). According to this theory, the extent to which the technology develops in its context depends on the fulfilment of these functions as well as the interaction between them (Hekkert et al., 2011, 2007). The maturity of the South African CSP TIS was evaluated by conducting interviews with experts and active stakeholders within the TIS. Through this process, system problems were identified and accordingly appropriate policy intervention were suggested in question 2 with a view to rectify the issues that are blocking the TIS from reaching maturity. Since one criticism of the TIS literature is that it restricts analyse to these pre-defined functions, which have been historically develop in the context of developed countries (Edsand, 2016), question 3 sought to understand what the participants view of the future of CSP in South Africa is within the global and local challenges facing CSP. The principal findings of the study are summarised below under the 3 respective research questions.

RESEARCH QUESTION 1: What is the level of maturity of the CSP sector, as determined through the application of the TIS framework?

The TIS analysis revealed an overall unfulfilled South African CSP TIS, with entrepreneurial experimentation (F1), guidance of the search (F4) and legitimacy creation (F7) being the most problematic areas in the TIS. Resource mobilisation (F6) and market formation (F5) were rated as slightly more mature and knowledge development (F2) and knowledge diffusion (F3) were seen to be the most developed.

This analysis also revealed that the current state of the CSP TIS does not necessarily reflect the historic one, where previously there seemed to be a much stronger support for local CSP development than today. In the past it appeared that more resources were allocated towards CSP development (F6) from government and private companies and there were much clearer goals associated with CSP (F4) in the form of substantial procurement targets. There was an industry demand for the technology (F5) and this led to a well-developed (F2) and (F3) with several university research groups, a special industry sponsored CSP research chair and active industry participation in research activities. This resulted in entrepreneurial activity (F1), with the establishment of a few local companies and private sector IP development.

However, since then there has been significant policy uncertainty and demand for CSP has decreased dramatically. This is reflected in both a decline in industry support and no further CSP allocation in the current draft of the IRP (F4). The reduction in demand and policy uncertainty has also resulted in a decreased market (F5), IP that had been developed was sold, leading to a loss of both (F1) and (F2). The two local CSP lobby groups have done an insufficient job at creating legitimacy for the technology, whereas politically powerful anti-lobby groups have managed to garner significant media attention and some believe have had the power to influence the current policy situation. However, due to the well-established research presence (F2) and (F3) were able to remain fairly strong, which is reflected in their current (relative) high rankings. Although, given that the majority of firms in the South African CSP industry are foreign (due to the REI4P requirement that only proven technology may tender), it seems that further knowledge development (F2) will come from willing knowledge diffusion from international CSP companies that have already developed and commercialised CSP technology, as opposed to in-country development through R&D.

The advancement of the current TIS therefore appears to be largely contingent on further allocation of CSP procurement targets in the IRP and sufficient support to develop entrepreneurial activity.

RESEARCH QUESTION 2: Based on the results of the TIS analysis, what are the key interventions that need to take place to realise the potential of South Africa becoming a global competitor in this arena?

Given the uncertain future of utility-scale CSP projects in South Africa, the researcher has suggested two sets of policy recommendations according to the two categories of policy goals suggested by Hekkert et al., (2015). (1) An environmental/energy goal, where the policies are aimed at reducing dependencies on fossil fuels to both mitigate GHG emissions and ensure energy security and (2) An economic goal, with a focus on developing emerging RET sectors into globally competitive industries to increase local economic growth. These policy and action plans are summarised below.

Policy and Action in Pursuit of an Environmental/Energy Goal

Lobby groups need to become more prominent in increasing the legitimacy of CSP with a view to influence the procurement target in the IRP (currently available for public comment). Then, with respect to the REI4P process, it is suggested that the contracting period of the PPAs awarded to CSP be increased from 20 years to 30 years in line with the much longer plant life of CSP plants (as compared to wind or PV plants). This would decrease the cost of CSP electricity significantly, making it far more attractive to the least-cost model used in the development of the IRP. Additionally, it is suggested that the capacity of the individual projects be increased from 100 MW to 130 – 170 MW to take advantage of CSP economies of scale achieved in this region. Policy also needs to be put in place to ensure transfer of knowledge from the international firms active in the South African CSP TIS and increased funding for CSP research. Finally, the utility-scale CSP might also benefit from a REFIT policy to incentivise small-scale CSP developments to facilitate continued CSP learning that could aid in bringing CSP down the learning curve.

Policy and Action in Pursuit of an Economic Goal

A procurement-driven industrial strategy is key to achieving the objective of becoming export competitive, which requires alignment of several different policies. In-country demand needs to be created (e.g. through a demand-side programme like the REI4P) to attain a critical mass of technology to develop tacit knowledge around the design, manufacture, operation and maintenance of the plants. This must be supported by strong industrialisation policies aimed at building localised services and manufacturing. This approach therefore requires alignment between energy policy (to increase CSP procurement objectives, lower risk and incentivise investment), climate policy (incentivise RET uptake through mechanisms such as emissions taxes) and industrial policy (to incentivise manufacturing and knowledge development). It was suggested that one method of advancing this goal would be to establish a centralised solar thermal knowledge centre in South Africa.

RESEARCH QUESTION 3: What are the future opportunities for CSP in South Africa?

Amidst the context specific challenges facing CSP, which include social issues (from the large contingent of foreign workers in the small towns of the Northern Cape), the debate on the benefits of local content requirement stipulations, grid integration issues, water scarcity and policy uncertainty, there was some optimism around the future prospects of CSP. This was mentioned in light of the potential to develop manufacturing capabilities in CSP and the job creation that would stem from that, as well as the potential to provide cost effective baseload and peaking renewable power. It was noted however, that whilst CSP is currently still cost competitive compared to its main competitor i.e. a combination of PV with battery storage, (Feldman et al., 2016), both technologies are on a downwards cost trajectory and it remains a question of innovation as to whether CSP is able to maintain this value proposition in the future.

Outside of the confines of the REI4P and the IRP, the only possible future for CSP is in small-scale applications – see for example (Promethium Carbon, 2014; WWF, 2017a, 2018). If indeed the IRP 2018 is promulgated as it is, then this may be the most promising short-term opportunity to retain a market for CSP in South Africa.

7.2 Implications for Future Companies

This study has significant ramifications for local businesses wanting to explore an opportunity to enter the utility-scale South African CSP market. These findings show an unfulfilled TIS with significant entrepreneurial barriers largely caused by policy uncertainty. Unless the required actors play their part to carry out the policy action plan outlined in question 2, entrepreneurs may need to rather explore opportunities to provide services to existing CSP installations, or venture into small-scale industrial applications.

7.3 Limitations of the Research

There are 3 main limitations to this study:

- Sample size and generalisability – the findings of this study are based on interviews with only 13 experts within the South African CSP TIS, which is most certainly not representative of the entire population. However, saturation was reached (Figure 21), which implies that data gathering stopped at an appropriate stage.

- Sample selection – As shown in Table 7, the sample comprised members from academia, industry, the national power utility, the media and the IPPP office. Although this covers many aspects of the CSP industry, it would have been valuable to incorporate insights from an NGO, an entrepreneur working the CSP industry and a plant owner/operator into the TIS analysis. Every attempt was made to contact such individuals; however, it was not possible to secure these interviews in the study timeframe.
- Interviewer bias in exploratory research – the interviewer may misinterpret an interviewee's response which will affect the reliability of the data. It was found that this was more prominent in the telephonic interviews, where facial and other bodily queues could not assist in resolving uncertainty. Attempts were made to reduce this bias (e.g. making a point of verbally clarifying to ensure the intended meaning was captured), but it is impossible to completely rule out bias and it therefore remains a study limitation (Saunders et al., 2011).

7.4 Suggestions for Future Research

One criticism of the TIS framework is that it is too narrowly focused on only one technology (Wirth & Markard, 2011), and although (F7) does explore the resistance that may arise from proponents of incumbent technology (Bergek et al., 2008), it fails to account for future competition that may arise from technology that is currently undergoing simultaneous development.

As has been discussed in Section 6.2 one of the main future competitors to CSP is the combination of PV with batteries (Lilliestam et al., 2018). At the moment, CSP with storage is still more cost effective than this combination (Feldman et al., 2016); however, there is current active research aimed at reducing the cost of both technologies that may close this gap in the near future. Therefore, the development of the CSP TIS is contingent not only on the fulfilment of the 7 functions, but also the simultaneous development of the PV/battery TIS. It is therefore suggested that the TIS analysis be expanded to include a 'competitor development' function, which prompts the researcher to identify the potential future competitors, their level of development relative to the TIS being studied and identify indicators that might be tracked which could show future preference of one technology over another (e.g. significant cost reduction in a raw material).

Additionally, as put forward by Edsand et al., (2017) exogenous factors from the wider context (termed Landscape Factors) such as climate change, environmental awareness, corruption, armed conflict, economic growth and unequal access to education affect the TIS either directly or indirectly. Figure 23 shows how Edsand et al., (2017) visualised the effect of these Landscape Factors on the TIS.

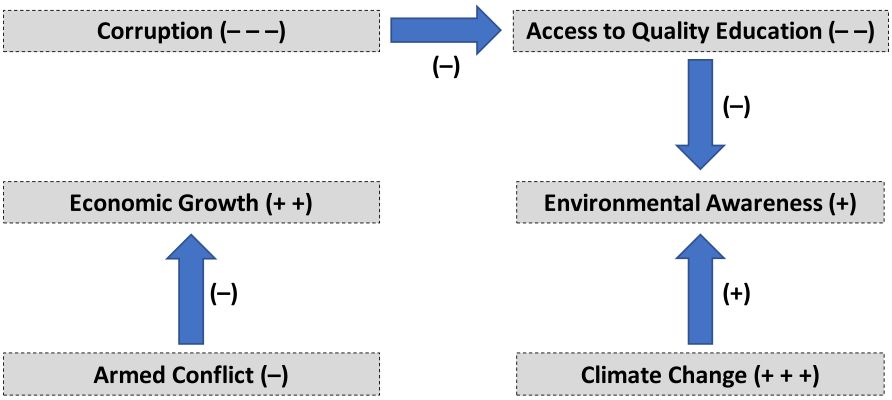


Figure 23: Influence of landscape factors on one another and the Columbian wind TIS. The (+) and (-) sign reflect positive and negative influence respectively on the TIS, with the number of signs reflecting the strength of the influence. Adapted from reference (Edsand, 2017)**.**

Yet these factors may not surface during the course of the TIS analysis, unless specifically probed. It was further suggested that these factors are even more prominent in developing countries. Indeed, some of these factors did emerge during the course of the interviews in this study (i.e. environmental awareness, corruption economic growth and climate change), however, because they may not have been completely relevant to the particular function they were mentioned in relation to, their full impact may not be captured in the current analysis. It is therefore suggested that if the South African CSP TIS is re-assessed in the future that these factors be included in the set of interview questions.

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Appendices

A. Informed Consent form and Interview Questions

Informed consent form

Dear Participant,

I am conducting research on the Concentrated Solar Power (CSP) industry in South Africa and am trying to find out whether there are any factors that are affecting the development and diffusion of CSP in SA. Our interview is expected to last about an hour and will help us gain insight into which areas are performing and which might require improvement. Your participation is voluntary and you can withdraw at any time without penalty. All data will be reported without identifiers. If you have any concerns, please contact my supervisor or me. Our details are provided below.

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Supervisor name: Prof David Walwyn

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Interview Questionnaire

The following questions will be used to guide the semi-structured interviews. The questions are structured around the structure factors within the technological innovation systems framework.

1. **F1 – Entrepreneurial experimentation and production:** *entrepreneurs serve to convert inputs (new knowledge, networks and markets) into outputs of new business opportunities.*

- Are you aware of any emerging firms in this area that are supporting the CSP sector in SA?
- Do you think that the environment (policy and economic environment) sufficiently supports the emergence of new entrepreneurs and firms?
- In your view, what do you see as the barriers to new firms and new entrepreneurs entering the CSP industry?

2. **F2 – Knowledge development:** *refers to how knowledge is developed in the innovation system.*

- Is there sufficient knowledge development along the entire supply chain of CSP (from manufacturing the components, to piloting, then engineering, procurement and construction of commercial plants, to maintenance of the plants) in SA?
- Are you aware of active research in renewable energy technologies (specifically CSP) by Universities and other research institutions?
- Is the amount and quality of knowledge development sufficient for the development of CSP in SA, or is it currently forming a barrier to the further advancement of CSP in SA (if so do you have any suggestions to improve it)?

3. **F3 – Knowledge diffusion (or knowledge exchange):** *this occurs through knowledge-sharing interactions of actors within a network.*

- How does knowledge transfer take place from knowledge institutes to the market and production (i.e. between science and industry)?
- Is there enough knowledge exchange between users and industry?

- Have there been efforts to transfer technology and learnings (successes and failures) through international collaborations or otherwise from international to local companies?
- Is knowledge exchange sufficient for the development of CSP in SA, or is it currently forming a barrier to the further advancement of CSP in SA (if so do you have any suggestions to improve it)?

4. **F4 – Guidance of the search:** *this function refers to activities that create visibility of needs and goals of technology users to aid in clearly directing the allocation of resources along a specific path.*

- Have clear goals been established (i.e. a vision for how the CSP industry and market should develop w.r.t development, growth and technological design)?
- Are their sufficient supporting policies to reach these goals and are they effective? If not, how could these be improved?
- Are the visions and expectations of actors involved sufficiently aligned to reduce uncertainties?
- What role in your view should the DTI and the DST be playing in the CSP sector?

5. **F5 – Market formation:** *this function refers to interventions that can be put in place to create protected space to foster sufficient markets and demand for the new technology.*

- Is the current and expected future market size sufficient to support rollout of CSP in SA?
- Does market size form a barrier for the development of the innovation system?
- Are there any incentives (if yes are these sufficient) to create a market for CSP in SA? (Related to tax incentives, subsidies, feed-in tariffs etc)
- What will assist local companies in accessing international markets?

6. **F6 – Resource mobilisation:** *refers to the allocation of financial and human capital towards knowledge development.*

- Is this level of establishment of CSP infrastructure sufficient to support the diffusion of the technology?
- Has the REI4P alone provided sufficient financial incentive for the development of CSP in SA?

- Is there any local or international funding available for CSP development in SA (aside from the REI4P)?
- Are there any investment opportunities/availability of funding for the CSP industry in SA?
- Are there sufficient human resources (skilled labour)? If not, does this form a barrier?

7. **F7 – Counteract resistance to change/legitimacy creation:** *refers to activities related to the active advocacy of a new technology that are required to counter resistance by members of an incumbent regime opposed to the advancement of the new technology.*

- What is the effect of media and lobbying groups on the perception of renewable energy (specifically CSP) and how has this impacted the development of the CSP industry in SA?
- What is the effect of lobbying by groups with strong economic and political weight in establishing advocacy and legitimacy of CSP in SA?
- How much resistance is experienced against new CSP technology implementation?
- What is the average length of a project? Is there a lot of resistance towards the new technology, the set-up of projects/permit procedure? If yes, does it form a barrier?

8. Please rate the performance of each function using the following scale:
   1 = very bad, 2 = bad, 3 = acceptable, 4 = good and 5 = excellent

9. Based on the results of the assessment, what are the key interventions that need to take place to realise the potential of South Africa becoming a global competitor in this arena?
10. What other possible challenges are there facing the development of CSP?

B. Consistency Matrix

Research Question	Sections in literature review	Data collection tools	Analysis technique
What is the level of maturity of the CSP sector, as determined through the application of the TIS framework?	Section 2.4.1 – 2.4.7	Semi-structured interviews Interview questions 1 - 7	Qualitative data analysis procedure.
Based on the results of the TIS analysis, what are the key interventions that need to take place to realise the potential of South Africa becoming a global competitor in this arena?	Sections 2.1, Sections 2.2.1 – 2.2.3	Semi-structured interviews Interview question 9	Qualitative data analysis procedure.
What are the future opportunities for CSP in South Africa?	Section 2.1.2 & 2.2.3	Semi-structured interviews Interview question 10	Qualitative data analysis procedure.

C. Data

Question 1

F1 – Entrepreneurial Activity

Themes	Codes	Frequency
Presence and types of South African firms	**firms_non-specialised SA firms**	11
	firms_limited	10
	firms_no recent SA firms	7
	firms_foreign	6
	firms_non-utility scale	6
	firms_previous	4
	firms_potential new	1
Lost opportunity to develop entrepreneurial activity	**lost opportunity_IP**	2
	lost opportunity_skills	2
Sentiments related to a supportive entrepreneurial environment	**supportive environment no**	9
	supportive environment partly	2
	list of dti incentives	9
Challenges and barriers to entrepreneurial activity	**challenges_policy general**	17
	challenges_funding & high cost	10
	challenges_IP & lack of local value chain	7
	challenges_policy_REI4P	6
	challenges_IRP delay	6
	challenges_PPA signing	4
	challenges_funding & technology maturity	4
	challenges_SME financing	3
	challenges_experience	3
	challenges_Eskom CSP Project	3
	challenges_knowledge transfer	2
	challenges_partnerships	2
	challenges_politics	1

	challenges_project size	1
	challenges_market size	1
	challenges_project size	1

F2 – Knowledge Development

Themes	Codes	Frequency
CSP research activities in South Africa	active research_universities	28
	utility scale research	11
	non-utility scale_research	7
	active research_universities_no	3
Challenges and barriers to knowledge development	challenges_financial support	7
	challenges_policy	7
	challenges_knowledge leaving country	5
	challenges_on the job learning	3
	challenges_CSIR	3
	challenges_international IP ownership	3
	challenges_market size	2
	challenges_partnerships	2
	challenges_PPA signings	1
	challenges_innovation chasm	1
Level of knowledge development as it pertains to developing a competitive CSP industry in South Africa	level of knowledge development_insufficient	9
	level of knowledge development_sufficient	3
	positive_local capability	7

F3 – Knowledge Diffusion

Themes	Codes	Frequency
Knowledge transfer between academic institutions	Academia academia	2
Knowledge transfer between academia and industry	Academia Industry_yes	5
	Academia Industry_yes_conferences	2
	Academia Industry_no	4
	Academia Industry_no_industry stop CSP research	2
	Academia Industry_no_industry too young	2
	Academia Industry_no_knowledge leaving country	1
	Academia Industry_no_tied to an individual	1
	Academia Industry_don't know	2
Knowledge transfer between Eskom and industry	Eskom Industry_yes_REI4P process requirement	4
	Eskom Industry_yes_history	2
	Eskom Industry_no_Eskom	5
	Eskom Industry_no_IP	2
	Eskom Industry_no_Eskom CSP project	1
	Eskom Industry_no_policy	1
	Eskom Industry_no	1
Knowledge transfer from international companies to South African academic institutes	International to local academia_yes	3

Knowledge transfer from international companies to South African companies	International to local companies_yes	6
	International to local companies_maybe_local content	2
	International to local companies_no_IP	5
	International to local companies_no	3
Level of knowledge diffusion as it pertains to developing a competitive CSP industry in South Africa	level of knowledge exchange_yes barrier	8
	level of knowledge exchange_no barrier	1

Codes	Frequency
general comments	1
industry bodies	1
informal knowledge networks	1
non-utility scale_knowledge networks	2

F4 – Guidance of the Search

Theme	Code	Frequency
Presence or absence of goals towards the development of CSP in South Africa	goals_no	7
	goals_no_regulations not specific enough	5
	goals_no_IRP CSP excluded	4
	goals_no_IRP delay	2
	goals_no_IRP nuclear focus	2
	goals_yes	1
Presence or absence of supporting policy	policy_no_lack of alignment	10
	policy_no	6
	policy_no_lack of vision	4
	policy_yes_emission reduction	3
DST and dti current role	dti role_current	7
	DST role_current	4
Future role of the DST and dti	DST & dti role_should be	3
	dti role_should be	8
	DST role_should be	5

F5 – Market Formation

Theme	Code	Frequency
Description and definition of the CSP market in South Africa	market size_definition	8
	market type_non-utility scale	3
	market types	1
Role and impact of the REI4P on market formation	market formation_utility scale mechanisms	6
	REI4P_failures	7
	REI4P_success	5
Role of the market size in the further development of the South African CSP industry	market size_barrier_yes	4
	market size_sufficient_no	3
	market size_sufficient_yes	1

Code	Frequency
market size_prospects	10

F6 – Resource Mobilisation

Themes	Codes	Frequency
Role of the REI4P in creating sufficient financial incentive to develop the South African CSP market	REI4P successful_no	7
	REI4P successful_yes	3
Funding availability	funding availability_local_yes	5
	funding availability_local_no	3
	funding availability_international_no	5
	funding availability_international_yes	4
Skilled HR resources	skilled HR_barrier_no	9
	skilled HR barrier_yes	6
	skilled HR_lost opportunity	1

F7 – Counteract Resistance to Change/Legitimacy Creation

Themes	Codes	Frequency
Advocacy groups and their actions	advocacy groups_lack	13
	advocacy groups_positive	9
	advocacy groups_negative	8
	advocacy_RE general	2
	advocacy groups_rivarly between RET	1
	past advocacy	1
Counter lobby actions	counter lobby_political issues	21
	counter lobby_uninformed information	5
Negative perception that has been created about CSP	negative perception_cost	13
	negative perception_CSIR	3
	negative perception_birds	1
Barrier formation through bureaucracy	bureaucracy problem_no	9
	bureaucracy problem_yes	7

Codes	Frequency
length of project	N/A

Question 2

Themes	Code	Frequency
Solutions to improving entrepreneurial experimentation	solution_focused entrepreneurial activity	1
Solutions to increasing knowledge development	solution_R&D	5
	solution_training centre	5
	solutions_IP	3
	solution_partnerships_industry focused R&D projects	2
Solutions to improving knowledge diffusion	solution_partnerships_private public	7
Solutions to improving guidance of the search	solution_policy certainty	6
	solution_policy_open energy market	4
	solution_incentives	3

	solution_policy_alignment	3
	solution_policy_local content	2
	solution_policy_reclassification	1
	solution_clear goal_social pact	1
Solutions to increasing resource mobilisation	solution_funding	2
	solution_resources	1
Solutions to improving legitimacy creation	solution_lobbying	4

Question 3

Codes	Description	Frequency
GenSA_electricity sector context	General comment around the South African electricity sector.	N/A

Themes	Codes	Frequency
General disadvantages of CSP over other RETs	Gen CSP_negative_small global market	2
	Gen CSP_negative_expensive to develop	2
	Gen CSP_negative_lack modularity	1
Challenges for CSP in the South African context	Challenges_social challenges	6
	Challenges_policy	2
	Challenges_policy local content	2
	Challenges_learning curve	2
	Challenges_lack of competition	1
	Challenges_planning	1
Technology competitor to CSP	Gen_CSP_competitor_still competitive	3
	Gen_CSP_competitor_uncompetitive future	3
	Gen_CSP_competitor_uncertain	3
Future of CSP in South Africa	Potential in SA_positive	8
	Future of CSP SA_utility scale	8
	Future of CSP SA_non-utility scale	6

TIS Analysis

Table 12: Summary of participants ranking of TIS functions

	1	2	3	4	5	6	7	8	9	10	11	12	13	Ave.
F1	1	3	2	2	1	3	1	2	4	1	2	2	2	2,0
F2	3	3	2	1	3	3	1	3	4	2	2	4	3	2.6
F3	1	4	2	2	2	4	3	2	3	3	3	3	3	2.7
F4	1	1	2	2	1	2	2	3	1	3	3	3	2	2.0
F5	2	1	4	3	2	3	2	1	2	2	3	4	2	2.4
F6	1	2	3	3	3	3	1	-	2	3	2	3	1	2.3
F7	3	-	2	1	2	2	2	2	1	1	2	4	2	2.0

D. Ethical Clearance

Gordon Institute of Business Science
University of Pretoria

30 July 2018

Potts Storm

Dear Storm

Please be advised that your application for Ethical Clearance has been approved.

You are therefore allowed to continue collecting your data.

Please note that approval is granted based on the methodology and research instruments provided in the application. If there is any deviation change or addition to the research method or tools, a supplementary application for approval must be obtained

We wish you everything of the best for the rest of the project.

Kind Regards

GIBS MBA Research Ethical Clearance Committee

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