# Master Thesis SIM

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## Technological Innovation Systems in Developing Countries

*How can the mitigation strategies of South Africa be accelerated?*

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## Abstract
In order to identify the underlying dynamic processes of technological change the Technological Innovation System approach can be used. This study does so in a developing country context, identifying drivers and barriers to the development of the renewable energy technologies in South Africa. Two case studies on solar and wind energy technology are analyzed, providing policy recommendations to accelerate in-country mitigation strategies of South Africa and providing insights in the applicability of the TIS approach for analyzing the development of renewable energy technologies in a developing country context. Further, this study proposes a new sustainable motor of change, suggesting that international pressure and lobby, and national guidance for the technology influence and start the innovation system of renewable energy technologies in such a context.

**Keywords:** Technological Innovation Systems; Developing Countries; Motors of Sustainable Innovation; Mitigation strategies; Policy recommendations; Renewable energy technology; RET; Solar energy; Wind energy.

## Abbreviations

| | |
|---|---|
| AC | Alternating Current |
| ANC | African National Congress |
| BBDO | Batten Barton Durstine & Osborn |
| BOS | Balance of System |
| BWEA | British Wind Energy Association |
| CEF | Central Energy Fund |
| CIA | Central Intelligence Agency |
| CIGS | Copper Indium Gallium (di)Selenide |
| $CO_2$ | Carbondioxide |
| CSP | Concentrated Solar Power |
| CST | Concentrated Solar Thermal |
| DC | Direct Current |
| DE | Duurzame Energy |
| DME | Department of Minerals and Energy |
| DPE | Department of Public Enterprises |
| EIA | Energy Information Administration |
| EIA | Environmental Impact Assessment |
| EIB | European Investment Bank |
| EPIA | European Photovoltaic Industry Association |
| ESMAP | Energy Sector Management Assistence Programme |
| EU | European Union |
| FAO | Food and Agriculture Organization |
| FCCC | Framework Convention on Climate Change |
| GDP | Gross Domestic Product |
| GEEREF | Global Energy Efficiency and Renewable Energy Fund |
| GEF | Global Energy Fund |
| GHG | Greenhouse Gas |
| GWEC | Global Wind Energy Council |
| GWh | Gigawatt Hour |
| HAWT | Horizontal Axis Wind Turbine |
| HCPV | High Concentrated Photo Voltaic |
| IEA | International Energy Agency |
| INEP | Integrated National Electrification Programme |
| IPCC | Intergovernmental Panel on Climate Change |
| IPP | Independent Power Producer |
| IRP | Integrated Resource Plan |
| ISMO | Independent System and Market Operator |
| KWh | Kilowatt Hour |
| MW | Megawatt |
| Mtoe | Megaton oil equivalent |
| NASA | National Aeronautics and Space Administration |
| NERI | National Energy Research Institute |
| NERSA | National Energy Regulator South Africa |
| NGO | Non-governmental Organization |

| | |
|---|---|
| NIMBY | Not In My Back Yard |
| NIS | National Innovation System |
| NREL | National Renewable Energy Laboratory |
| OECD | Organisation for Economic Co-operation and Development |
| PPA | Power Purchase Agreement |
| PV | Photovoltaic |
| R&D | Research and Development |
| RDP | Reconstruction and Development Plan |
| RE | Renewable Energy |
| REFIT | Renewable Energy Feed-In Tariff |
| REFSA | Renewable Energy For South Africa |
| RET | Renewable Energy Technology |
| RIS | Regional Innovation System |
| SA | South Africa |
| SAPVIA | South Africa Photovoltaic Industry Association |
| SAWEA | South African Wind Energy Association |
| SAWEP | South African Wind Energy Programme |
| SELF | Solar Electric Light Fund |
| SESSA | Sustainable Energy Society of Southern Africa |
| SIDS | Small Island Developing States |
| STP-motor | Science and Technology Push motor |
| TFST | Thin Film Solar Technology |
| TIS | Technological Innovation System |
| UNDP | United Nation Development Programme |
| UNEP | United Nations Environmental Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNICEF | United Nation Children’s Fund |
| UNIDO | United Nations Industrial Development Organization |
| US | United States |
| US DoE | United States Department of Energy |
| VAWT | Vertical Axis Wind Turbine |

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# 1. Introduction

The development and implementation of renewable energy technologies (RETs) has become internationally important with the quest for sustainability as the initiator. The IPCC report (Bernstein et al., 2007) shows several emissions scenarios and goals to achieve, which require new and more sustainable technologies to be developed and used. Those RETs should mitigate GHG emissions and thereby decrease climate change. The UNFCCC implicitly assumes the cooperation of nations worldwide, whether they are developed or developing, as these are asked to contribute to mitigation actions (UNFCCC, 1992). The IPCC and UNFCCC both point attention to developing and supporting new technologies in order to achieve their goals. However, as of their socio-economic context developing countries should not be forced to mitigate at inappropriate economic and social costs. The UNFCCC, just as well as the IEA and OECD, considers technology transfer as a means to achieve the development of RET's in developing countries (IEA/OECD, 2001). Technology transfer is defined as ''a process by which expertise or knowledge related to some aspect of technology is passed from one user to another for the purpose of economic gain.'' (Schnepp et al., 1990, pp. 3). The UNFCCC in art. 4.5 states 'The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties…' (art. 4.5 UNFCCC, 1992; art. 10c UNFCCC, 1998). More than 165 countries accepted and assigned this convention and this approach of technological diffusion.

Shove (1998) however, questions the underlying assumptions that knowledge flows linearly from the world of research into the world of practice and translates into action by programs of technology transfer hastening the 'uptake' of proven research results. Only if considerable efforts to assimilate new technologies are made by recipient countries, the technology transfer will be realized (Pack and Saggi, 1997). Barriers, such as transactions costs, intellectual property rights and lack of skilled personal, regulatory frameworks, technical standards and institutional capacity, limit the uptake of more efficient technologies by developing countries (Worrell et al., 2001; Ockwell et al., 2008; FCCC, 1998). The IEA, OECD, and UNFCCC by means of the IPCC, acknowledge that solutions for these problems in transfer and development of renewable technologies should go beyond the linear and small project approach of conventional technology transfer. A framework relating actors, organizations and institutions, while incorporating institutional, political, financial, economical and informational concepts in a dynamic and systemic fashion, would lead to an improved implementation and diffusion of renewable energy technologies (UNFCCC, 2000; IEA/OECD, 2001; Seres et al., 2009; Worrell et al., 2001). This required interactive and systemic framework that enables an effective process of technology transfer can be provided by innovation systems.

Innovation systems give insight in the dynamics of actors, organizations and institutions and are able to affect the rate and direction of technological progress in society (Edquist & Lundvall, 1993; Patel and Pavitt, 1994). This innovation system approach is recognized by the UNFCCC as useful in fostering and encouraging innovation in developing countries (UNFCCC, 2010; OECD, 2010). The basis of the innovation system approach comes from the books of Lundvall (1992), Nelson (1993) and Edquist (1997) that describe the National Innovation System (NIS) approach. Though many different definitions exist, most of them are in line with the one of Edquist (2004): 'All important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion, and use of innovations.'

However, the mitigation and technology transfer goals are international. Support should thus besides financial be so for technology as well (UNFCCC, 2010). The international context of searching for and transfer of renewable or mitigating technologies does not set boundaries on geographical characteristics; boundaries of innovation systems set to nations can thus be regarded as a constraining characteristic. Using the boundaries of a specific technology is therefore more appropriate. This is described by the Technological Innovation System (TIS) approach (Hekkert et al., 2007, Bergek et al, 2008), in which a TIS is defined as ''a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology''(Carlsson and Stanckiewicz, 1991, pp. 93) and further ''technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services.'' (Carlsson and Stankiewicz, 1991, pp. 93). Functions are processes within a TIS that contribute to build up of a TIS. A TIS encompasses seven system functions that contribute to the systems' performance and influence each other; entrepreneurial activity, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilization, and creating legitimacy/counteracting resistance to change (Hekkert et al., 2007). These system functions are required to map, describe, analyze and support the dynamic interaction during technological change. By mapping these system functions over time, the system functions and the dynamics between them can be described and analyzed (Hekkert et al., 2007), and thereby barriers and carriers of technological change can be discovered (Negro, 2007). The TIS approach, by means of system functions, can provide handholds for recommendations for accelerating technological development.

It does not indicate TISs can be applied to developing countries, it only states that the system functions perhaps can be used as a blueprint by developing countries to shape the context of new technologies. However, if they are applicable, that would constitute an important addition to theory. In addition, analyzing a TIS in a developing country contributes to understanding where financial or technological support should aim for. It might even bring designs of institutions and organizations for society forward. However, caution is required, when differences are too large and thus insurmountable or when the TIS approach just does not work for developing countries; pursuing it would be detrimental.

A case study in a developing country would enable to study, whether the TIS theory fits a developing country. It would indicate whether a TIS can be build up in that developing country or that it is unfeasible to build a TIS in a developing country. Van Alphen (2008) has already studied the TIS approach in a developing country and gained useful insights about knowledge infrastructure and demand articulation, but he applied it to a small island developing state (SIDS) and thus further research to the applicability of TIS in non-SIDS developing countries is required. The African country South Africa is not a SIDS and tries to acquire support for stimulating mitigation actions (Wills, 2010). The South African government in their White Paper on Renewable Energy (2003) has set targets at 10000GWh (0.8 Mtoe) renewable generated electricity in 2013. The development of the RETs solar and wind energy play an important role in the strategies displayed in the White Paper. South Africa has instituted a Renewable Energy Feed-In Tariff (REFIT). By that, the National Energy Regulator South Africa (NERSA) tries to promote and stimulate the private sector to invest in renewable or off-grid electricity (EIA, 2010). South Africa can be regarded as a two-tiered economy, partly developed and partly developing, with only the most basic infrastructure and many characteristics associated to developing countries, including division of labor and uneven distribution of wealth and income (US

Department of State, 2010). Though this study indicate some similar insights and adjustments to the list of system functions required to use the TIS approach in a developing country as Van Alphen (2008), one should start with the system functions as described in theory, since the focus is on another type of developing country.

Investigating the applicability and usefulness of the TIS approach to solar and wind energy technology used to produce electricity for this country would contribute to the dual goal of improving scientific understanding and developing a useful framework for technological innovation in South Africa. Support can be strengthened when the TIS indicates the barriers and drivers for RETs development.

The main question thus becomes: How can mitigation strategies of South Africa be accelerated?

Against the background provided above, the main question is divided in sub-questions that together lead to the final answer.

- *How do the TISs of solar and wind energy look like in South Africa?*
- *What components of the TISs of solar and wind energy in South Africa should be improved to support the process of technological development?*
- *What barriers or carriers can be identified in order to increase the development of mitigating technologies?*

With the answers to these questions, one can conclude on the usefulness of the TIS approach in South Africa, derive recommendations for improving their technological development of specific technologies, and identify key processes, barriers and carriers within the TIS, that require attention and support. This approach might achieve results that could be useful for more than just the country under study. When another developing country has similar institutional and demographic features, it will be able to gain from the insights from South Africa. Further, the applicability of the TIS approach, with adjustments to the context, should enable to analyze and thus support technological development in other developing countries as well.

## 2. Theoretical Background

This chapter follows the sequence of the introduction. First, it elaborates on technology transfer and next it addresses (National) Innovation Systems (NIS). NIS will be explained shortly and will be used to make clear the transition to Technological Innovation Systems, which is extensively explained.

### 2.1 Theory on Technology Transfers

For the aim of this study is to accelerate mitigation strategies and thus the development and implementation of RET's in developing countries, theory on technology transfers is likely to be useful. In his study, Kumar et al. (2006) state that technology transfer is an effective mechanism for developing countries to advance the technological development. However, like the IEA and OECD (2001) state:

> '*Technology transfer is not simply about the supply and shipment of hardware across international borders. It is about the complex process of sharing knowledge and adapting technology to meet local conditions. It strengthens human and technological capacity in developing countries. It promotes commercial markets for climate-friendly technology.' (p. 7)*

Ockwell et al. (2008) indicate two different theories on how technology transfer develops capacity. Both, theory of accumulation and assimilation, acknowledge the long-term importance of knowledge for developing technological capacity in the recipient country. However, there is a difference in how this knowledge is created (Ockwell et al. 2008).

Accumulation theories assume the creation of knowledge by capital investments. Capital investments are automatically followed by the required increased learning, which is needed for the capacity building. This accumulation theory incorporates the transfer of capital goods, services or design. However, these types of transfer are more likely to increase the production capacity instead of the technological capacity in the recipient country (Ockwell et al., 2008). The underlying assumption of a linear relation between knowledge transfer and technological change cannot hold and the one way language of technology transfer should be scrapped (Shove, 1998).

The more evolutionary assimilation theory, assumes that learning is a key factor for capital investments to become successful (Ockwell et al., 2008). Here, the required knowledge for developing technological capacity is acquired by knowledge transfer. The knowledge transfer thus is the central issue in ensuring that technology supply leads to successful capacity building (Ockwell et al., 2008). This theory incorporates the transfer of skills and know-how for operation and maintenance and the transfer of knowledge, expertise and experience for generating and managing technical change. This kind of transfer contributes to the required new technological capacity since ''it is the generation of new technological capacity that is most likely to ensure the long-term uptake of, and further advances in the development of low carbon technologies in recipient countries'' (Worrell et al., 2001 in Ockwell et al., 2008 pp. 4106).

Technology transfer thus proves to be useful if the recipient country is able to absorb the technology and knowledge that will be flowing in and thereby gains technological capacity (Kuhlmann and Arnold, 2001). This increases the opportunities in recommendations for developing country mitigation policies, since it enables international support. However, this requires that a minimum amount of absorptive capacity is present. Absorptive capacity is linked to the concept of cognitive distance what is explained by Nooteboom (2000) as the gap that exist between holder and receiver of knowledge. New knowledge can be very useful, but only if it links to, though does not overlap, the knowledge already available to the receiver. If the knowledge is so new that the receiver does not understand it, then the knowledge is useless. For example, if developed countries and their firms are willing to share their knowledge there might still occur problems, because of a lack of absorptive capacity of recipient countries and their firms. Absorptive capacity can thus be interpreted as 'the domain of cognition: the phenomena one can *make sense of*, i.e. which one can perceive, interpret, evaluate.' (Nooteboom, 2000, p73). It is restricted by the amount of human capital that possibly can absorb a specific technology. This implies that a developing country should already have some knowledge of the specific technology and the gap between knowledge of the developed and developing countries should be neither too small nor too large.

Large international organizations, such as the IPCC (Seres et al, 2009), UNFCCC(2000), IEA and OECD (2001), engaged in technology transfer, all face the fact that the accumulation theory and its linear approach of technology transfer is not competent to deliver increasing absorptive capacity and thereby sustained uptake and development of technology in recipient countries. Problems with the implementation of renewable technologies supported by technology transfer from abroad encounter barriers, such as lack skilled personal, lack of effective financing and lack of consumers' awareness (Worrell et al., 2001). These problems should not be solved separately, but in a systemic fashion. The large international organizations, as stated above, should switch to the evolutionary assimilation theory, which gained greater support from analysis of empirical evidence on technology transfer, and assumes knowledge to be a key factor for investment to become successful (Ockwell et al., 2008, Nelson and Pack, 1999). Hereby, it is acknowledged that absorptive capacity is required to enable further development and implementation of renewable energy technologies. Although this approach increases technological capacity of the recipient country, it still only assumes that the developed country transfers knowledge to developing countries, prior to capital investments in whatever mold. Therefore, this does not meet the iterative and dynamic system incorporating actors, organizations and institutions, sought after by the UNFCCC (2000), IEA and OECD (2001) (Seres et al, 2009). This paper proposes innovation systems as means to understand the underlying process of technology transfer; it captures the required characteristics and enables analysis of technological capacity and development.

## 2.2 Innovation Systems

The innovation system theory mentioned in the introduction started with the national innovation system like described by Freeman (1987; 1988). He considered the upcoming of the country Japan, and found that various institutional factors in Japan contributed to their development. Government, company R&D, the education system, social treatment of labor and long term strategic investments all added up to the rising of Japan. Freeman calls these various institutional factors 'the National System of Innovation'. An innovation system can be defined as *'all institutions and economic structures that affect both rate and direction of technological change in society'* (Edquist and Lundvall, 1993). 'Their governance is based on co-evolutionary development of, and stable exchange relationships among, the institutions of science and technology, industry and the political system.' (Kuhlmann and Arnold, 2001)

Figure 1 presents a schematic model of what is now understood by an increasing number of analysts by a NIS, though it is a heuristic aid and not a tool (Kuhlmann and Arnold, 2001). It shows the classification of the components, the actors, organizations and institutions, of the innovation system and the links between them that are present in an innovation system. All participating economic structures and institutions are assigned to specific parts of the system; to Demand, Industrial System, Intermediaries, Education and Research, the Political System, Infrastructure or Framework Conditions. Further, it shows the direction of influences of the components and thereby it makes the mutual dependency visible; e.g., framework conditions and infrastructure encompass institutions and financial background that influence the other parts of the system, however these institutions can be altered by the political system or the industrial system (Edquist, 1997). This heuristic aid can help to identify the presence and state of groups of actors and shed light on the structure of the solar and wind technology systems in South Africa.

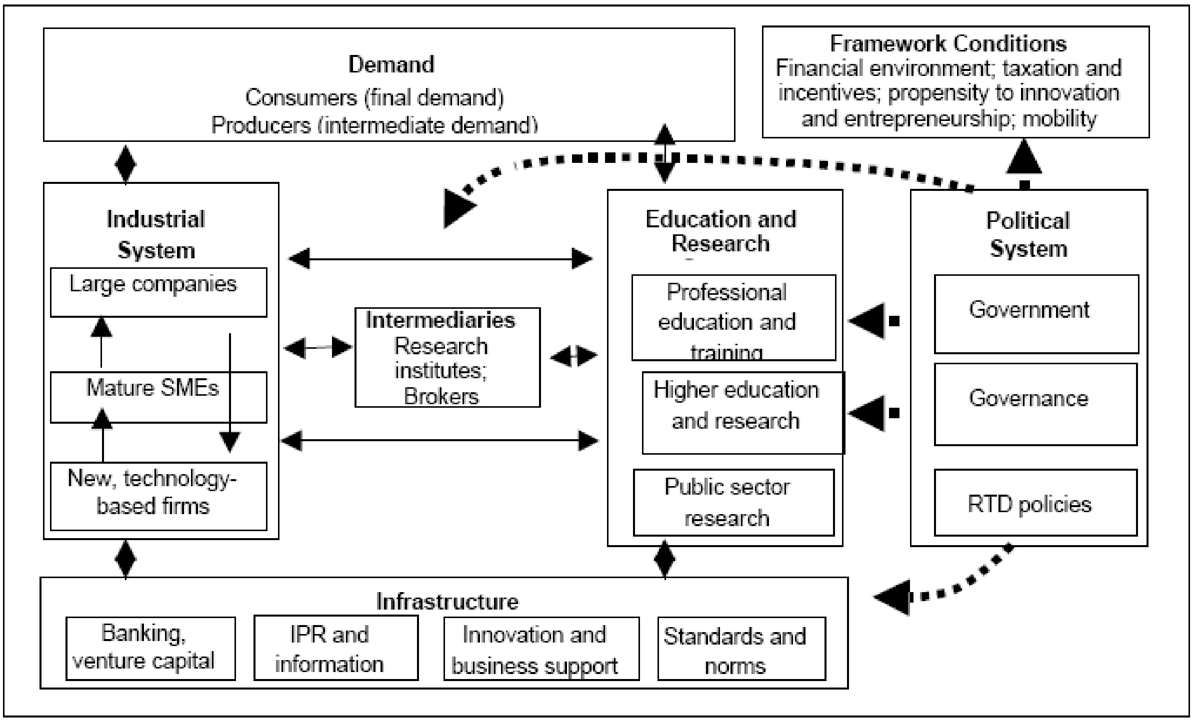



**Figure 1 A National Innovation Systems Model. Kuhlmann and Arnold (2001).**

However, theory has developed and several kinds of innovation systems came into being with their own boundaries and focus, e.g. regional innovation systems (RIS) and technological innovation systems (TIS) (Hekkert et al, 2007). This last approach enables to study the innovation system of a single emerging technology (Jacobsson and Johnson, 2000), thus a TIS is less complex than a NIS or a RIS; it only focuses on one technology instead of a whole nation or region. Further, new emerging systems differ from mature ones; the configuration of actors and institutions related to an emerging technology changes over time (Carlsson, 1997). A TIS approach enables to study a system during development, diffusion and implementation of an emerging technology (Negro, 2007).

Carlsson and Stankiewicz define a technological innovation system as *'a network of agents interacting in the economic/industrial area under a particular institutional infrastructure (…) and involved in the generation, diffusion and utilization of technology'* (p93, 1991). This implies that there are no geographical or physical boundaries to the innovation system, what is justified by the fact that a technology or the related knowledge is nearly never embedded in just one single region, country or sector (Hekkert et al. 2007). Therefore, in investigating technological change one should not be restricted by geographical or sectoral boundaries. More important are the institutions and organizations related to the specific technology. The institutional arrangements are all norms, values and laws that regulate the process of innovation of technologies (Carlsson and Stankiewicz, 1991) and form the rules of the game played by the organizations. Those organizations can be firms, government, knowledge institutions or NGO's. The institutions and organizations can influence and form each other, e.g. firms should obey to laws created by governments, but by means of lobbying, they are able to adjust or create laws (Edquist, 1997).

Theory has developed and during the last two decades, several papers indicated activities, or system functions, that should be able to give insights in reality and its dynamism. Lundvall (1992), Edquist and Johnson (1997), McKelvey (1997), Galli and Tuebal (1997), Liu and White (2001), Johnson (2001) and Smits and Kuhlman (2004) proposed different sets of activities required to map, describe, analyze and support the dynamic interaction during technological change. However, the mentioned activities, or system functions, overlapped sometimes or missed activities that were present in other studies. Finally, Hekkert et al. (2007) proposed a resumptive set of functions integrating and summarizing the previous indicated important activities for describing and explaining changes in TISs. It does so by including the activities, or system functions, that contribute to the goal of the innovation system (Hekkert et al., 2007); a system function is defined as 'a contribution of a component or a set of components to a system's performance' (Bergek, 2002 in Negro, 2007 pp. 28).

In that sense, TISs seem appropriate to steer the innovation process of a technology in a developing country towards sustainability in order to add to mitigating GHG emissions. However, the innovation system approach mainly has its foundations in developed countries (Arocena and Sutz, 2001; Van Alphen, 2008) and can therefore not without consideration be applied to developing countries (Schøtt and Jensen, 2008). Braga and Fink (1998) also state that innovation management models are based upon developed countries' firms and again applicability to developing countries is not straightforward. Arocena and Sutz (2000) and Gu (1999) indicate that many institutions relevant to innovation do not exist in developing countries and that therefore the innovation system concept might be more of a prescriptive approach to them. Van Alphen (2008), in the first attempt to apply a TIS framework to a developing country, adjusted the list of system functions to the situation of the Maldives. Since here another type of developing country is concerned, it starts with the original system functions as described by Hekkert et al. (2007). However, the relevant insights of Van Alphen (2008), Arocena and Sutz (2000) and Gu (1999) are incorporated within the functions.

The seven system functions and their explanation as proposed by Hekkert et al. (2007) are:

- F1: Entrepreneurial activities
- F2: Knowledge development
- F3: Knowledge diffusion through networks
- F4: Guidance of the search
- F5: Market formation
- F6: Resource mobilization
- F7: Creation of legitimacy/counteract resistance to change

With the function 'Entrepreneurial activity' the essential role of the entrepreneur, turning potential into actions, is recognized. They are needed to allocate new business opportunities and they are willing to take advantage of those opportunities. Their risky experimentation delivers knowledge that might add to the development and diffusion of the technology. Mapping the number of new entrants, of diversification activities of incumbent actors and of experiments with the new technology enables analysis of this function.

The second function is ‘knowledge development’ or in put in other words ‘learning’. According to Lundvall (1992), it is the most important process for modern economies. R&D and knowledge development encompass ‘learning by searching’ and ‘learning by doing’. Drawing on insights of Van Alphen (2008) regarding developing countries, there might be a lack of knowledge infrastructure available. Van Alphen (2008) replaced this function, by ‘creating adaptive capacity’, which tracks and describes the capacity of people and organizations to adapt to new circumstances or to acquire new skills. This important insight cannot be ignored. However, the lack of a knowledge infrastructure is not clearly visible in South Africa. ‘Creating adaptive capacity’ and related to that ‘International flow of knowledge’ will be thus be taken into account within the function knowledge development. In order to map knowledge development, R&D projects, patents and investments in R&D should be taken into account. Further, the learning curves identifying increase in technological performance are important.

The third function ‘Knowledge diffusion through networks’ is incorporated since exchange of information is essential. Using a network for exchanging information or newly developed knowledge increases the chance that the organizations related to the technology and the institutions supporting the technology are up-to-date, in other words they are ‘learning by interacting’. Research agenda’s, policy decisions, and norms and values are then conform the state-of-the-art. To analyze this function, one should map the number of workshops and conferences for the specific technology, just as well as the network size and intensity.

The function ‘Guidance of search’ makes sure that specific technological options are chosen by, e.g. government policy, R&D outcomes or experiences with premature technologies. Picking a direction is important since resources are normally limited and society might have preferences. Van Alphen (2008) states that picking a direction or so to say, ‘Articulation of demand’, is important for developing countries, for the host country should match their specific needs and demands to the technological solutions of the developed country instead of guiding the search within the developing country. Again, this is not to be ignored, but due to the different context of available knowledge development institutes e.g. universities and public research institutes, cannot be replacing the function ‘Guidance of the Search’ totally. Therefore, the articulation of demand is to be taken into account within this function ‘Guidance of the Search’. Further, guidance is an interactive and cumulative process between the actors of the technological innovation system, while the technology keeps changing. Expectations can be important in this process of determining the direction of R&D, when they converge and generate momentum in a specific direction (van Lente, 1993; Van Lente and Rip, 1998). It requires mapping of targets set by governments and industries for specific technologies and of the number of articles that raise expectations for the technological development to analyze this function. These articles can be positive and negative, counting this enables to gain insight in the state of the debate.

The fifth function ‘Market formation’ encompasses the protection, support or advances for new technologies. Most inventions are not well developed and assumingly have less added value than embedded technologies, although their potential is higher (Rosenberg, 1976). Therefore, a protected space is needed in which these technologies and the actors incorporated can learn and develop technologies and expectations, without intense competition. This explicit formation of protected markets can be done by e.g. creating niche markets, favorable tax regimes or consumption quotes. Counting the number of niche markets, mapping tax regimes and environmental standards that increase or decrease chances for the specific technology, makes analysis of this function possible.

Resources are an important input for activities in innovation systems. As already mentioned in 'Guidance of search', resources are limited and can only be spent once if they are available. The sixth function therefore is 'Resource mobilization', what contains the allocation of resources to the specific activities in the system. Mapping this function is difficult and can best be done by interviewing actors. To be able to analyze this function it should be clear whether the actors perceive the access to resources as problematic.

The seventh function is 'Creation of legitimacy/counteract resistance to change'. New technologies should integrate in the existing regime or might compete to it. Vested interest will thus try to oppose the new technology. Therefore, lobbying and advocacy coalitions might turn out to be very important. They can adjust the existing regime in such a way that legitimacy is created for the specific technology. For analysis of this function, mapping the rise and growth of interest groups for a specific technology and their lobby actions, is required.

By mapping events, actions and institutions pursued by the actors and organizations of the system, and allocating them to the system functions, the way the system functions are served and thus the 'functional patterns' can be derived (Bergek, 2002 in Negro, 2007 pp. 28). An analysis over time of these so-called 'functional patterns' help to identify and analyze the character of, and interaction between components of the innovation system during the development, diffusion and implementation of technology (Negro, 2007; Edquist, 2001). A TIS thus sheds light on the underlying dynamic process of technological change, it goes beyond the structure of a NIS, Figure 1 A National Innovation Systems Model. Kuhlmann and Arnold (2001).Figure 1. A TIS approach can identify barriers and carriers of technological change for emerging technologies.  Therefore, this research will use TISs to study the emerging solar and wind technologies in South Africa.

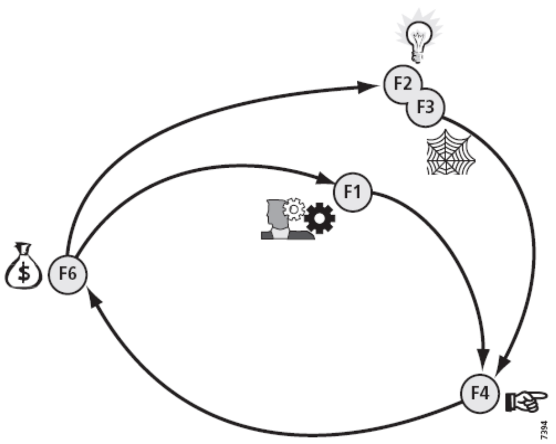
Allocating events of the specific technology to these system functions enables analyses of functional patterns over time. Thereby, these system functions can contribute to the identification of barriers and carriers of renewable energy technologies.

These seven functions can interact and influence each other. It is a non-linear dynamic model in which multiple interactions between the functions can occur. The functions are positively related and by interacting and influencing each other, they lead to virtuous cycles in processes of change (Hekkert et al., 2007). Jacobsson and Bergek (2004) describe this process as a transition from a formative stage, with several barriers, by means of institutional alignment to a more self-sustaining technological system, with more rapid and sustained diffusion of new technologies. However, the opposite is possible as well. When functions have a negative influence on other functions, than that will lead to a vicious cycle, causing the breakdown of an innovation system.

There are, based on the seven system functions, patterns identified on how technological change comes about. Remarkable is the identification of similar patterns in the multiple cases (Suurs, 2009). These specific orders are identified as virtuous cycles, being initial patterns for starting and building-up a TIS (Hekkert et al., 2007; Suurs, 2009). The ‘motors’ visualize and describe the links between and presence of the system functions during several stages of development. The ‘motors’ described differ in power and extent.

## 2.3 Motors of Sustainable Innovation

The first ‘motor of sustainable innovation’ is the Science and Technology Push (STP) motor in Figure 2 (Suurs, 2009). Suurs (2009) explains that this motor starts with positive expectations and research outcomes on the technology. These will guide the direction of search (F4) and thereby allocate resources to specific development directions or research fields (F6). So, a boost for knowledge development and thereby knowledge diffusion will occur (F2 and F3). These can in turn raise expectations, they will give new insights for the direction of search (F4) and hopefully they will positively influence some entrepreneurial activity (F1) which is typically weak in this motor. These firms may participate and invest in risky projects aimed at realizing pilots and demonstrations, and thereby contribute to the expansion of the R&D programs. This thus forms a cycle, since it influences the guidance of search (F4) again.



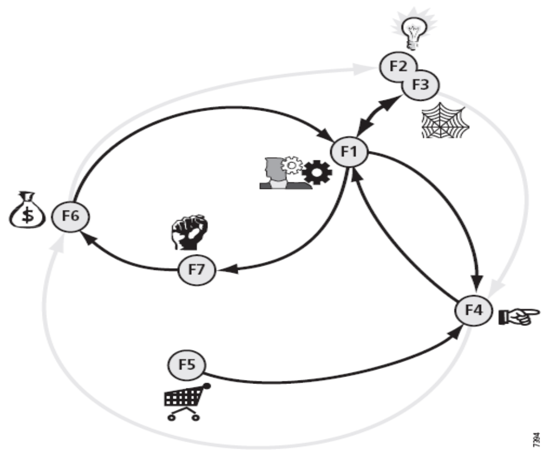



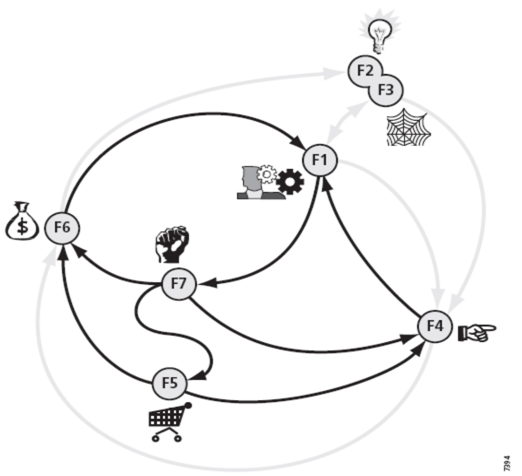

**Figure 2 The Science and Technology Push Motor (p211)**

**Figure 3 The Entrepreneurial Motor (p215)**

**(Suurs, 2009)**

The second ‘motor of sustainable innovation’ is the Entrepreneurial motor, Figure 3 (Suurs, 2009). This motor is mainly about the entrepreneurial activities (F1) like experiments and demonstration projects. These will be started if there are societal or financial gains to be acquired in the future. The expectations will thus lead to entrepreneurial activity, but also influence together with the projects the direction of search (F4). This will reinforce the entrepreneurial activity (F1) again. Meanwhile, the entrepreneurs try to acquire resources (F6) by lobbying (F7) for example the government. If all goes well, both cycles will increase the fulfillment of the entrepreneurial function (F1). Special to this motor is the tight link between the entrepreneurs (F1) and the knowledge development and diffusion (F2 and F3). This occurs because of the possibility to study feasibility, while projects are taking place. Another characteristic is the existence of niche markets (F5), not formed by the technological innovation system itself. These might influence and strengthen the guidance of search (F4) and present business opportunities for the entrepreneurs (F1) (Suurs, 2009). In Figure 3, the grey lines represent the links of the STP-motor.

The third motor is the System Building motor, Figure 4 (Suurs, 2009). This motor -as can be seen in figure 3- in fact only adds the presence of market formation (F5) to the system. Though it was already weakly present in the Entrepreneurial Motor, it now forms a loop within the system and thereby creating the dynamic feedback circle that is required to start virtuous cycles. The market formation is supported by the lobby (F7) for institutions that support the technology as a whole and not only a specific project. This creation of market space will open up new resources (F6), since the technology is more legitimate and investors appreciate the reduced risk of the technology. Further, the market formation will enhance insights in what is needed and expected of the technology and thereby it influences and strengthens the guidance of the search (F4).



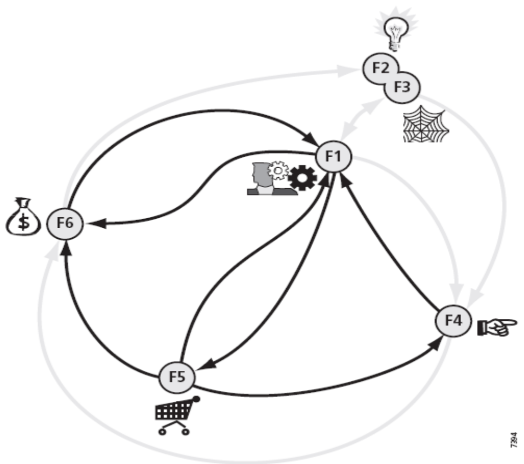




**Figure 4 The System Building Motor (p219)**

**Figure 5 The Market Motor (p224)**

**(Suurs, 2009)**

The fourth motor is the Market motor, Figure 5 (Suurs, 2009). All functions participate in this motor except for the support from advocacy coalitions/lobby (F7). This function is not important anymore since market formation (F5) is not any longer a political issue. Formal regulations and directly linked entrepreneurial activity (F1) take care of the market formation (F5). The market formation (F5) itself raises new opportunities on the market and thus positively influences entrepreneurial activity (F1) by causing new entrants to start in the specific technology. The entrepreneurial activity also raises the required money and does not need to lobby for resources by e.g. governments anymore. This phase can generate the momentum to compete with the embedded regime and take part in it or overthrow it (Suurs, 2009; Hekkert et al. 2007).

### *2.3.1 Succession of Motors*

The more extended motors arise from structures build up by less powerful motors (Suurs, 2009). The succession of these motors suggests that ''TIS's develop into more complete (and more complex) structural configurations'' (Suurs, 2009, pp. 245). Identifying the specific 'motor of change' that currently drives the build-up of the TIS enables to identify barriers and carriers of the system. Support should be aimed at creating the right structural conditions for the system. When the right structural conditions are in place and outweigh the structural barriers a motor of innovation will likely expand. The motor may then transform into a next motor, hopefully with the final result of achieving a Market motor (Suurs, 2009).

This succession of motors enables to identify which barriers identified should be overcome to let the motors transfer to the next motor. Knowing what steps can be expected as a follow-up to the current situation strengthens the focus and the possibility to intervene when these steps are blocked by barriers. The analysis of the motors ca thus be used to accelerate the succession of motors and thus the implementation and development of technologies. In case of renewable energy technologies this thus accelerates the mitigation strategy of the country.

## 3. Methodology

The described cycles and loops in the motors of change contain dynamic and interacting activities between actors in the system. Such a dynamic system requires a method specifically applicable to address the processes of development and change (Negro, 2007). As stated for the motors of change, not only the fulfillment or passing the threshold of functions is important (Jacobsson and Johnson, 2000), but also the order in which the activities occur and influence each other can be important (Negro, 2007). The method of analysis thus needs to be able to display how the loops and cycles occurred. The activities, whether they are positive or negative to the development of the system and the sequence in which these events occur, need to be presented. Further, since results depend on the activities in history, the method should allow for qualitative analysis. The way the functions interact and influence each other can only be distracted from qualitative data. Therefore, a quantitative analysis gives the aggregated overview and identifies key points that require further qualitative analysis for identification of the dynamics of the TISs.

The sequence analysis has been presented by Abbot (1995) and Van de Ven and Poole (1990), indicating the importance to grab the dynamic process of innovation and technical change rather than just the end state that occurs. This is exactly the aim of the TIS analysis in this study. So, it applied a sequence analysis in combination with a TIS framework. The methodology is derived from Negro (2007) and Van Alphen (2008) and exists of seven steps that are carried out. This is applied to the TISs of respectively solar and wind technology in South Africa.

1. Literature search
2. Database classification
3. Allocation to functions
4. Summary Data and graphical representation
5. Historical storyline
6. Identification of patterns, virtuous and vicious cycles
7. Triangulation of results

1. The search for literature in journals, newspapers, periodicals, reports, and websites about PV and wind technology in South Africa for the period 1990 until 2010 is the first step. This literature research should identify the components of the TIS and their structure. Secondly, each event that relates to the development, diffusion and implementation of solar and wind technology is chronologically listed in a database.

Though data for the sequence analysis might be acquired through desktop research, personal contact and communication with experts in the field gives more in-depth knowledge and enables to identify how events can influence and reinforce each other. In fact, Hekkert et al. (2007) names function six, Resource Mobilization, as a function that is difficult to map and might require interviews with actors. However, interviews are likely to add to the obtained knowledge and events for the other system functions as well. To remain reliable an interview protocol is required. Though different actors might have different areas of interest and might put emphasis on some specific subjects, a standardized interview order ensures that actors from the same field encounter the same subjects during the interview, enabling comparison of their answers. In addition, a protocol with a list of subjects accompanied by some standardized questions, still allows experts to address issues they think are important. The advantage is that it enlarges the chance to come across all relevant events of the technology. Together, the desktop research and the interviews (Appendix C) should lead to identification of all relevant events and issues in the TISs in focus.

2. The database is structured by labeling each event to its description, its year of occurrence, the reference and the event category.

3. Allocation to functions implies that all events identified and categorized are allocated to the System Functions. In order to allocate in a good manner, the classification scheme of Negro (2007) is used, see table 1. This classification scheme has been developed in an inductive and iterative fashion by Negro (2007).

4. Adding up all events of a system function during a year generates a positive or a negative score. A positive score implies that there were more positive than negative influencing events incorporated by that system functions during that year. The specific system function can thus be expected to have a positive effect on the system functions to which it is related and linked. The scores are used to create graphs that represent the likely influencing behavior of the system functions, but not their content and context. A narrative elaborates on the system functions fulfillments, while this is a summary of the available data.

5. The narrative provides the context and content of the events and is able to clarify *how* instead of *if* change occurred, because of the information on chronological sequence of the events. In addition, the narrative is able to elaborate on how the functions are fulfilled. This addressing of order and sequence of events in combination with graphical representation allows for full understanding of how innovation processes took place. This step however, implies choices and interpretations of researchers; to increase objectivity the results are checked with experts in the field, and that is the main aim of the interviews described in step 1.

6. Identification of patterns, virtuous and vicious cycles is done by comparing the graphs to the narrative. Upward trends of functions in the graphs in combination with a sequence of events positively influencing and reinforcing each other, indicate virtuous cycles that try to gain momentum. The opposite is possible as well, downward trends in graphs and negative events causing absence of other events and thus leading to a hold on innovation processes. Further, the theory on motors of change (Suurs, 2009) plays an important role during the identification and analyses of patterns and cycles. It functions as an important feedback of theory to the found trend, patterns and cycles. However, the different context of a developing country is taken into account and therefore conclusions or analyses might in some cases differ from that theory.

7. The triangulation of results implies verification by experts in the field. Subject to this triangulation will be the completeness of the data, the historical storyline and the results from the analysis.

**Table 1 Classification scheme for measuring System Functions (Adapted from Negro et al., 2009 and Van Alphen, 2008).**

| Function | Indicator | Sign |
|---|---|---|
| **Function 1:** | Projects started | +1 |
| **Entrepreneurial activity** | Projects stopped | -1 |
| | Organizations entering the market | +1 |
| | Organizations leaving the market | -1 |
| **Function 2:** | Research projects | +1 |
| **Knowledge development** | Technological projects | +1 |

| | | |
|---|---|---|
| | Development projects (demonstration + pilot plant) | +1 |
| | Desktop studies on the technology (future of RE technology + performance of RE-systems) | +1 |
| | International flow of knowledge | +1 |
| | Creating Adaptive capacity | +1 |
| **Function 3: Knowledge diffusion through networks** | Workshops | +1 |
| | Conferences | +1 |
| | Reports | +1 |
| | Platform | +1 |
| | Roadmap | +1 |
| **Function 4: Guidance of the search** | Regulations by the government (positive expectation on RE-technology) | +1 |
| | Deficit of government regulations (negative expectation on RE technology) | -1 |
| | Specific tax regimes (positive expectation on RE technology) | +1 |
| | Deficit of tax regimes (negative expectation on RE technology) | -1 |
| | Positive opinions of experts | +1 |
| | Negative opinions of experts | -1 |
| | Positive expectations of experts | +1 |
| | Negative expectations of experts | -1 |
| | Articulation of demand (international context) | +1 |
| **Function 5: Market formation** | Regulation programmes | +1 |
| | Lack of regulation programmes | -1 |
| | Stimulation programmes | +1 |
| | Lack of stimulation programmes | -1 |
| | Environmental standards | +1 |
| | Lack of environmental standards | -1 |
| | Specific favorable tax regimes | +1 |
| | Lack of favorable tax regimes | -1 |
| **Function 6: Resources mobilization** | Subsidies for and investments in the technology | +1 |
| | Lack of subsidies and investments | -1 |
| | R&D subsidy programmes | +1 |
| | Lack of R&D subsidy programmes | -1 |
| **Function 7: Creation of legitimacy** | The technology is promoted by organizations, government (awards, brochures, competitions) | +1 |
| | Lack of promotion by organizations, government (awards, brochures, competitions) | -1 |
| | Lobby activities for the technology | +1 |
| | Lobby activities against the technology | -1 |
| | Positive opinions of experts branch organizations | +1 |
| | Negative opinions of experts branch organizations | -1 |
| **Context** | General events about renewable energy, technology description, exogenous activities to TIS | No sign (0), no allocation |

So, a global indication of types of information that are required for the analyses is given in the description of the functions that were obtained from Hekkert et al. (2007) and guides and supports the search for data. However, this is in no way restrictive, other events that relate to the technology or its actors and are of importance are taken into account. The events that are incorporated in this study are allocated to either positive or negative event categories that belong to specific functions, see Table 1.

This method enables incorporating a systemic framework, while identifying how technological change comes about. The motors of sustainable innovation make it possible to recommend adjustments to the TIS of solar or wind energy in South Africa, by the fact that subsequent or more extended motors are already identified by Suurs (2009). Further, the methodology enables identification of drivers and barriers for further development of renewable energy technologies, because of the insights in the related system functions and the underlying processes of technological change. Together, this leads to recommendation for acceleration of mitigation strategies in South Africa. On top, it leads to insights on the applicability of the TIS framework and the motors of sustainable innovation in a developing country context.

# 4. South Africa

## 4.1 Intro

To gain better insights in how the renewable energy technologies develop in the country South Africa requires some background information on its economy and energy use. This helps to identify or understand issues or processes confronted with in a not developed country context. The TIS theory and the methodology are mainly used in developed country cases up to now (Negro, 2007; Suurs, 2009), so there may be issues or processes arising in this specific context that have not yet been addressed by the TIS theory and methodology earlier on.

## 4.2 General

South Africa has nearly 50 million inhabitants and the population growths with roughly 1,2% per year. It has a parliamentary democracy and it is part of the Commonwealth. Education is compulsory to all children in the age of 7-15. However, education is in transition. Due to the apartheid system there were and still are differences in education across racial groups. South Africa is now trying to restructure the educational system into a single, nondiscriminatory and nonracial system with a standard educational system available to all (US Department of State, 2011).

## 4.3 Economical

South Africa has a Gross Domestic Product (GDP) of approximately $287 billion and a GDP per capita of $5.787 (US Department of State, 2011). It has many natural resources and is one of the large platinum, manganese, gold, chrome and coal producers in the world. These are their main export products, although motor vehicles and parts, and agricultural products add to the total export of $71.9 billion as well. South Africa imports of $75.7 billion exist mainly of machinery, transport equipment, chemicals, petroleum products, textiles, and scientific instruments (US Department of State, 2011). These export and import products show that South Africa mainly exports knowledge extensive products and has to import products that require knowledge that is more advanced.

One might question the development status of South Africa. To be clear, South Africa belongs to the non-Annex 1 countries under the UNFCCC classification (UNFCCC, 2011), the wealth is unequally distributed among the South African people and as of the year 2000, 50% of the population was below the poverty line (CIA, 2011; US Department of State, 2011). However, not all developing countries are similar, thus some extra information to address the specific development status of South Africa is needed. The World Bank list of economies puts South Africa in the 'upper middle income class' which means that South Africa gross national income (GNI) per capita is between $3,946 and $12,195 (World bank, 2011). That is, however still not the 'high income' class of the developed countries in which the TIS theory has been used until now. The CIA factbook (2011) states South Africa to have well developed *'financial, legal, communications, energy, and transport sectors; a stock exchange that is the 18th largest in the world; and modern infrastructure supporting a relatively efficient distribution of goods to major urban centers throughout the region'* (CIA, 2011). However, they also mention the daunting economical problems with *'poverty and the lack of economic empowerment among disadvantaged groups'* (CIA, 2011). The US Department of States (2011) goes a step further and considers the South African economy two tiered; partly well developed and partly with the characteristics of developing countries (US Department of State, 2011). The formal sector (mining, manufacture, services and agriculture) is well developed, but unemployment rates are above 20% (CIA, 2011; US Department of State, 2011). There is no strict distinction between or definition of developed and developing countries. South Africa seems to be a developing country (UNFCCC, 2011), on its way in the grey area in between developing and developed countries.

## 4.4 The Energy Sector

This research focuses on the electric energy sector, so the background of South Africa on the electricity sector is important to take into account.

The main primary energy source for electricity production in South Africa is the fossil fuel coal with 85%, followed by nuclear energy with 4%, and the rest is filled up with renewable energy sources like hydropower (US EIA, 2008). This strong reliance on coal is caused by the fact that there is an abundance easy accessible, low quality and therefore cheap coal reserves. On top, with the INEP program (Integrated National Electrification Programme) the government tries to provide electricity access to all households. In 1996, 64% of the households had no access to electricity. In 2004, this already decreased to 28%, mainly poor households. By 2012, all households in South Africa should have access to electricity. This adds significantly to the demand for electricity produced from cheap coal. Both, the cheap coal and the new and rising demand for cheap electricity do not help the shift towards other primary energy sources (Pegels, 2010).

The electricity system in South Africa is old fashioned due to a lack of investment in new capacity. Until the 1990s there was an abundance of electricity in South Africa, see Figure 6 Demand and Capacity (DME, 2008).

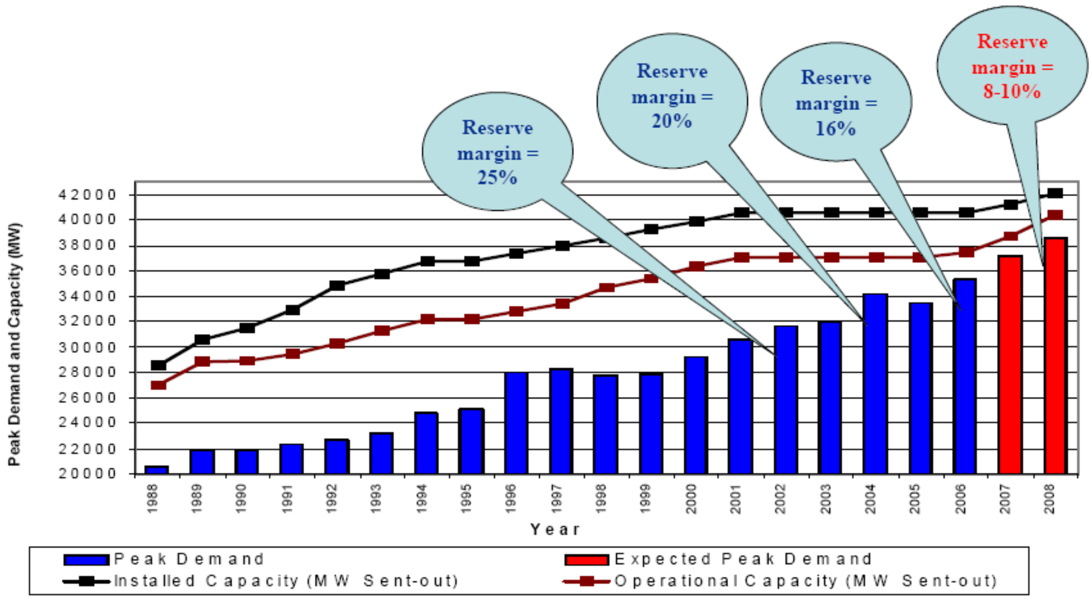



**Figure 6 Demand and Capacity (DME, 2008).**

However, a rising economic standard and the electrification program of the government caused a strong increase in electricity demand. A consequence of the use of such a high share of coal in combination with the mainly old-fashioned power plants from the sixties and seventies is that the average emission in South Africa is approximately 850g$CO_2$/kWh. That is twice as high as industrialized countries (Pegels, 2010). South Africa produces now roughly 1,1% of global GHG-emissions, and this might rise further since the electricity demand is expected to double by 2025.

This highlights the importance of decoupling energy and GHG emissions for South Africa (Pegels, 2010).

Further, the electricity sector also has a few remarkable characteristics. The state-owned power company Eskom dominates the sector; they produce 95% of all the electricity of South Africa. During 2007 and 2008, they had severe problems to deliver enough electricity during peak loads. They had 40GW installed capacity that gave them only a 10% margin to the 36GW peak demand (DME, 2008); faced with unexpected maintenance this lead to outages. This problem has been resolved by returning closed power plant to service (EIA, 2010; DME, 2008). This can only be seen as a temporary solution.

Besides having practically a monopoly on electricity production, Eskom owns and operates the national transmission system. According to Eskom, within the next 15 years approximately 40GW of new generating capacity is required to replace old generating capacity and to address the growth in energy use (GWEC, 2011). Renewable energy technologies should have their share in achieving this goal. The South African government in their White Paper on Renewable Energy (2003) has set targets at 10000GWh renewable generated electricity in 2013; this is equivalent to two 660MW combined coal fired power plants of Eskom. Further, South Africa has a Renewable Energy Feed-In Tariff (REFIT). The National Energy Regulator South Africa (NERSA) tries to promote and stimulate the private sector to invest in Independent Power Producers (IPP) that produce renewable or off-grid electricity (EIA, 2010). This implies however, that electricity-producing company Eskom has to buy electricity from other licensed Independent Power Producers (IPPs). Eskom buys this electricity, produced by renewable energy resources, at fixed prices and then needs to sell it again via their transmission system (Brodsky, 2010).

# 5. Technologies description

## 5.1 Technology of Solar Energy

There are different ways to gain energy from the sun. However, since this research is about electric energy, only the technologies that produce electricity from solar energy will be explained. The two most important are 'photovoltaic' (PV) and 'concentrated solar power' (CSP), these are focused on in this research. An overview of the worldwide development of the solar energy system is available in Appendix A - Solar Energy

***Photovoltaic***

This type of solar energy implies the direct conversion from light to electric power on an atomic level. The conversion is caused by the properties that some materials exhibit and is called the photovoltaic effect. These materials absorb photons of light and because of the energy and temperature increase release electrons. These electrons can be captured, what will result in an electric current that can be used as electricity (Knier, 2002).

This simple description can be expanded by explaining the properties of the material used. Most materials used for PV-cells are crystalline, that means they have a repeating and orderly pattern of atoms e.g. crystalline silicon (Green, 1982). These atoms have electrons that are surrounding the core of the atom in several bands. Now the energy of the incoming photon (light) can free the electrons to a state that they might 'travel' freely through the material. This 'travelling' can be directed by doping the semiconductor used for the PV-cells in such a way that one side is positive and the other is negative. This is called the p-n junction (Negro *et al.*, 2009). Now there are electrons flowing in one direction. If both sides are connected to electrical conductors, a closed electrical circuit can be formed. The electrons can be captured in the form of an electric current and that can be used as electricity, see Figure 7.

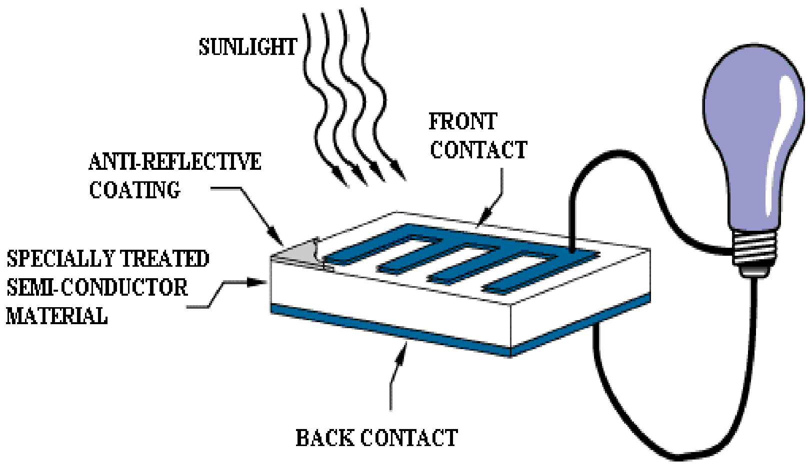



Figure 7 **Simple display of how a PV-cells Works (Knier, 2002)**

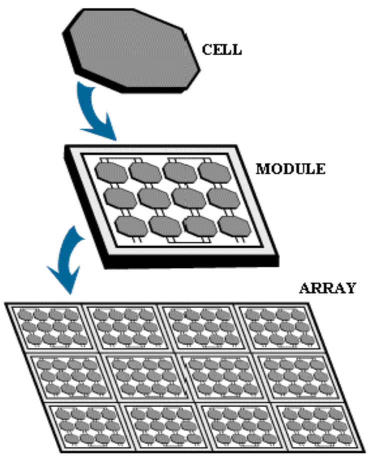



Figure 8 **Grouping of PV-cells (Knier, 2002)**

The PV-cells can be connected to each in a frame called a photovoltaic module. Such a module is designed to have a specific voltage, normally 12 Volt. The current is depending on the amount of light that hits the cells. These modules can be put to form an array. They can be put in parallel or in series, enabling to get the required voltage and current combination from the array (Knier, 2002), see

Figure 8. Due to the unidirectional current within the cell, a 'direct current' (DC) is obtained, whereas the grid and the applications in households normally use 'alternating current' (AC). An invertor e.g. BOS (Balance of Systems) is required to change the DC into AC and to synchronize it to the grid (Shum & Watanabe, 2007). The PV-cell accounts for 60% of the costs of the whole system for large ground mounted system, they account for 50% of the total costs for residential systems (EPIA, 2011a).

With respect to the efficiency of the PV-cells, it should be noted that not all electrons require the same amount of energy to get loose from the atom. The 'energy required' differs between types of semi-conductor material. If just one material is used, only the photons with energy equal to or higher than the required energy will be absorbed. However, when using more different materials, more of the incoming photons can be absorbed and thus the efficiency of converting sunlight into electricity is increased. These multi-junction cells are in fact piled-up single-junction cells with the required energy to free the electron decreasing from top to bottom (Knier, 2002). The theoretical maximum efficiency of crystalline silicon (single-junction) is 29,05% (Kerr, 2002), whereas for multi-junction PV-cells the record efficiencies are crossing the 40%, see Figure 9 (Wikipedia, 2011).

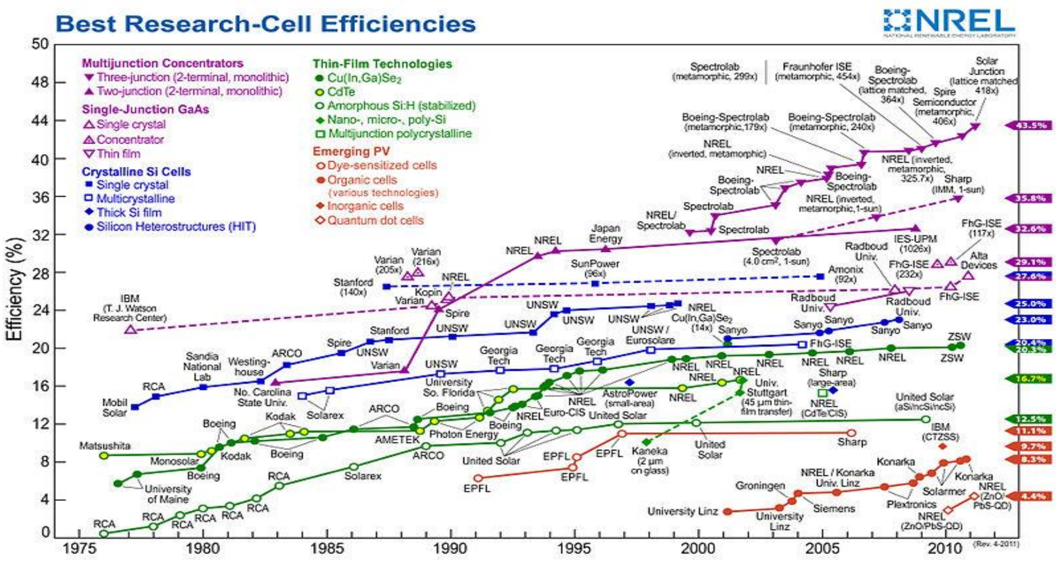



**Figure 9** **PV-cells efficiencies (Wikipedia, 2011)**

### *Concentrated Solar Power*

The other type solar energy technology is Concentrated Solar Power (CSP), which can be roughly divided in so-called concentrated solar thermal (CST) systems and High Concentrated Photo Voltaic (HCPV). Both technologies use the idea of reflecting sunlight with mirroring surfaces and directing it all, 'concentrating it', to one point.

HCPV works the same as normal PV, but now the quality and efficiency of the cells is higher. The solar cells need to withstand way higher temperatures and should produce large amounts of electricity. This makes these cells more costly, but since a smaller area is needed to be covered by them, this can remain economically viable. The mirrors surrounding the cells are cheaper than the normally used solar cells and thus decrease the investment and use of materials (Angel, 2010).

The other type of CSP is the Concentrated Solar Thermal (CST). Mirrors reflect light and concentrate it at specific heat exchangers. Due to high reflectivity, outdoor durability, and low cost, glass mirrors are preferred above lenses, which could do the same. The heath exchangers transfer the energy of the sunlight to a heat transfer liquid (Pitz-Paal, 2008). Now the obtained heat can be used in a power cycle directly if the transfer liquid is water or gas, or it might be used indirectly if there is an intermediate secondary cycle with transfer liquids like thermal oil or molten salt. This indirect use requires a second heat transfer to the power cycle (Pitz-Paal, 2008). In the power cycle it is just like in normal power plants. The thermal energy is converted into electric energy, using turbines and generators to produce electricity (Blok, 2007). The higher the temperature, the better the thermal energy can be converted to mechanical energy. However, for higher temperatures the efficiency of a collector/heat exchanger drops due to higher heat losses. This implies a maximum efficiency can be found depending on the used materials and their characteristics (Blok, 2007). This should be taken into account when arranging the CST.

Types of CST can thus be distinguished further by their arrangement. Either they are line-focusing systems requiring only single-axis tracking of the sun to concentrate the solar radiation onto the convertor tube. Alternatively, they are point-focusing systems, requiring of each mirror independent double axis tracking of the sun to focus the solar radiation to a specific receiver on a tower. The advantage is that the reached concentration factor and thus heat is far higher than for the line focusing systems (Pitz-Paal, 2008).

The most important feature and advantage compared to PV is the fact that the heat obtained can be stored and used later on. This means that a transfer liquid e.g. molten salt, can be heated during the day and converted into electricity when it is cloudy or after sunset. It thus circumvents the setback of intermittency that most RET's encounter (Pitz-Paal, 2008).

### 5.2 Installed capacity and production solar energy

The installed capacity of solar energy, PV and CSP together, has not increased for South Africa during the period 2002-2008 according to the UN Data (2011), see Figure 10. The series started with 0 MW installed in 2001, rising to an estimated capacity installed of 6 MW in 2002 and afterwards this number has not been adjusted in the consecutive years. The total solar energy produced followed the same path rising from 0 GWh in 2001 to 21 GWh in 2002. The production only increased in the year 2008 to 22 GWh. Likely the series started being measured or taken into the UN database in 2002, therefore the graphs are starting in 2002. The main conclusion is that the use of solar energy in South Africa is low compared to the goals of 10000GWh renewable produced electricity in 2013 (White Paper, 2003).

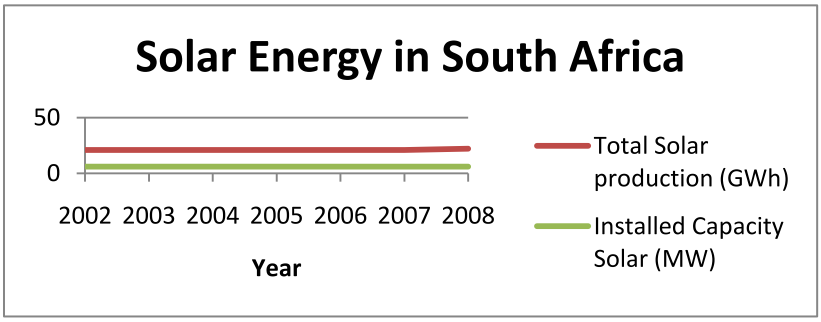



**Figure 10** **Solar Energy in South Africa (UN Data, 2011)**

## 5.3 Technology of Wind Energy

Just as for solar energy, there are different types of electricity production technologies that use wind power. However, the technology behind the types remains the same. Whether the technology is applied on land or at sea, the way the underlying technology works is the same. An overview of the worldwide development of the wind energy system is available in Appendix B.

Ever since ancient times, humans used wind energy and converted it in mechanical energy. Sailing ships or mills used the kinetic energy in wind and converted it into a desired motion, mechanical energy. Current wind turbines do the same (US DoE, 2010). Wind flowing past a wind turbine's blades causes the rotor and the shaft to turn round. The horizontal motion of wind is now turned into a rotational motion at the centre of the windmills blades. An axis (shaft) connected to this rotating rotor drives a generator which produces electricity.

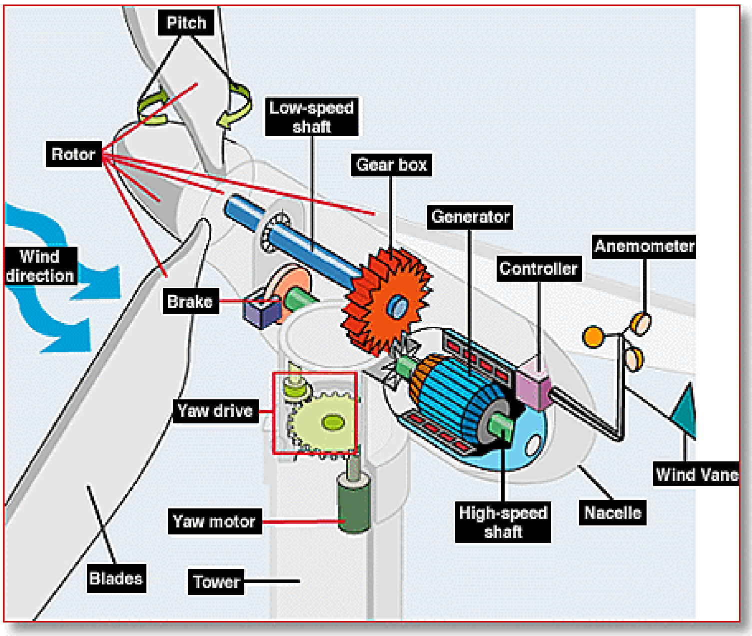



Figure 11 **The inside of a wind turbine (US DoE, 2010)**

There are generally two types of wind turbines, the Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine (VAWT) (US DoE, 2010). The HAWTs are most common for commercial electricity production (Riegler, 2003), they have there rotor and shaft in a horizontal line and normally also the generator is in the top of the wind turbine. For typical wind turbines the tower heights range from 25 – 75 meters and the rotor diameter can go up to 80meters. The blades normally rotate at constant speed with 10-30 revolutions per minute, though more machines are getting able to operate at variable speeds (BWEA, 2010). Nowadays, the capacity of new installed commercial wind turbines ranges from 1,3 – 1,85MW.

VAWTs have their rotor and shaft in a vertical line, they are rotational movement is around a vertical axis. This implies that the generator can be at the ground. There are many different types of VAWTs, but they all use the same vertical rotation-axis principle.

A setback of wind energy is its intermittency. Most wind turbines will only produce electricity when the wind speed is between 4m/s and 15m/s (BWEA, 2010). Despite the availability of current wind turbines of 98%, the efficiency of wind turbines is approximately 30%. This does not mean the wind turbine works 30% of the time. Wind turbines can be expected to generate electricity 70 – 85% of the time, however not at full capacity. With wind speeds of 4-5m/s a turbine will generate way less energy than with winds speeds of 15m/s, since a doubling in wind speed leads to a eight times higher output (BWEA, 2010; Blok, 2007). Further, the intermittency does not have to be a problem to the grid. Demand and supply are constantly matched every minute. Fluctuations in supply by wind energy are not causing problems until they are generating 20% of the total electricity production (BWEA, 2010).

### 5.4 Installed capacity and production Wind energy

The installed capacity of wind energy has increased for South Africa during the period 2002-2008 according to the UN Data (2011), see Figure 12. Again, the series starts in 2001 with 0 MW installed capacity and rose to an estimated 10 MW installed capacity in 2002. Later on the installed capacity increased from an estimated 10 MW in 2003 to 17 MW in 2004. The total wind energy production followed a similar start of the series rising from 0 GWh in 2001 to 32 GWh in 2002. Likely, the series started being measured or taken into the UN database in 2002, therefore the graphs are starting in 2002. The production of electricity from wind did not increase in line with the installed capacity increase from 2003 to 2004. This implies that the estimation of installed capacity in 2002 and 2003 is likely to be wrong, unless during the last 5 years of the series the wind resources declined or installed capacity was not in use. The main conclusion is that the use of wind energy is a bit higher than the use of solar energy in South Africa, but that it is still low compared to the goals of 10000GWh renewable produced electricity in 2013 (DME, 2003).

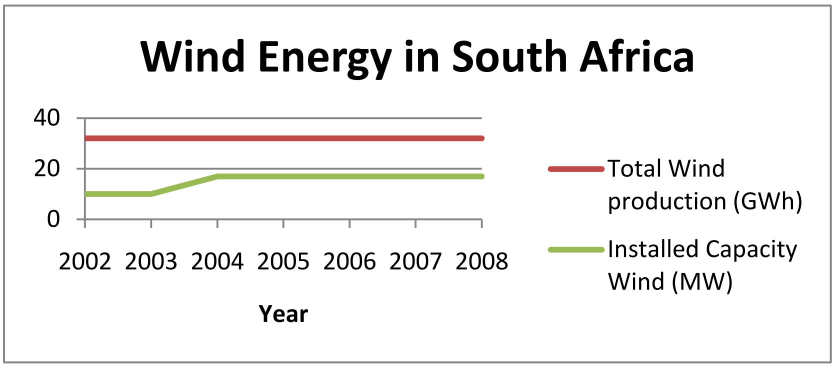



**Figure 12 Wind Energy in South Africa (UN Data, 2011)**

# 6. Results

## 6.1 Case-study of the solar energy system for electricity production in South Africa

This chapter will show the narrative of solar energy in South Africa. All the important events that are related to the solar energy sector and its development are taken into account. The narrative is displayed in chronological order making use of periods of time. The periods are divided according to major key events that occurred and that had a large influence during a specific time period. However, these key events occurred irregular and thus the periods are not of equal length. The functions are referred to with F1-F7 and their full name. At the same time, at the end of every time period, the feedback to theory is made.

### *1994-1997 Electrification and Technology Transfer*

The first period starts in 1994 when there were elections in South Africa. In this context the African National Congress (ANC) handed out a manifest 'the Reconstruction and Development Programme (RDP)', to gain popularity among the poor. This RDP included the idea of electrification in South Africa and can be seen as a start for policy guiding principles for electrification (Tinto and Banda, 2005). This electrification programme (INEP) brought many opportunities to the development of solar technology in South Africa. Several remote areas had no connection to the national grid and were not near to the grid. The new government of South Africa tried to increase access to electricity for the people and thus partly directed at decentralized renewable energy technologies for these far off areas. Their commitment to electrification was shown by several events like e.g. buying solar panels to broadcast the elections (Pendleton, 1994), the creation of the organization REFSA (Renewable Energy for South Africa) after they won the elections (DE, 1995), and plans to supply schools, medical centers and houses with solar energy (DE, 1995; Energy Newsletter, 1996). However, now also non-governmental organizations like SELF and the Independent Development Trust accommodated several places with Solar 'Home' Systems (Costantini, 1995; DE, 1995). As can be identified, the practical guidance by the government (F4, Figure 13) caused an increase in resources available for solar technology (F6, Figure 16).

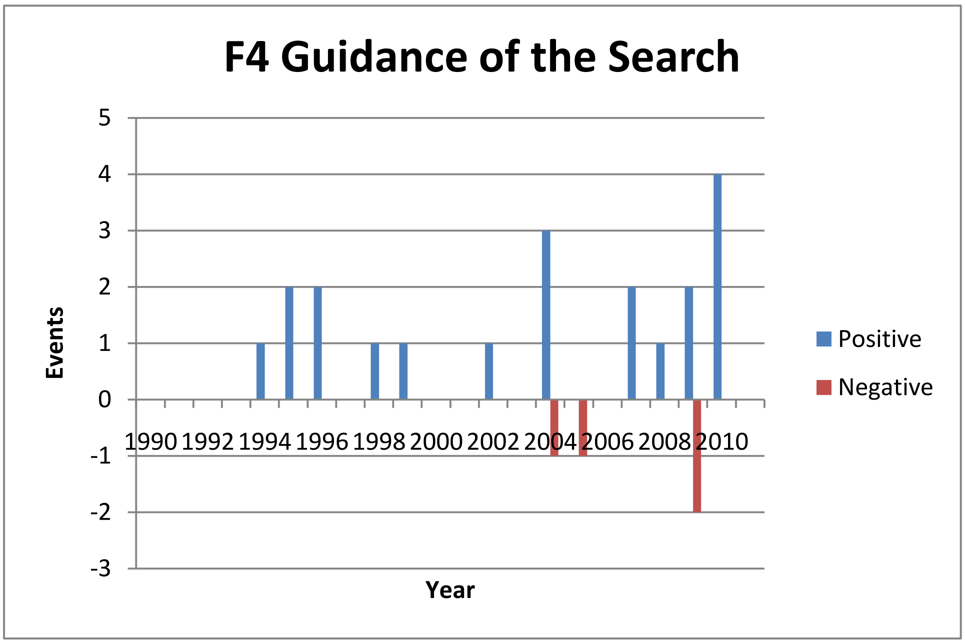



**Figure 13** Guidance of the Search for Solar Energy

Besides the governmental and NGO projects that started, some entrepreneurial activity (F1, Figure 14) was going on. Spire Corp, with help of the US DoE, opened a PV module factory near Johannesburg (Loveless, 1995; Energy Conservation News, 1995). In combination with this plant, they provided the knowledge and technology using demonstration modules and other components, while at the same time providing training (Energy Conservation News, 1995). The transfer of technology can be seen as knowledge development for the country (F2) and the training is diffusion of the knowledge (F3).

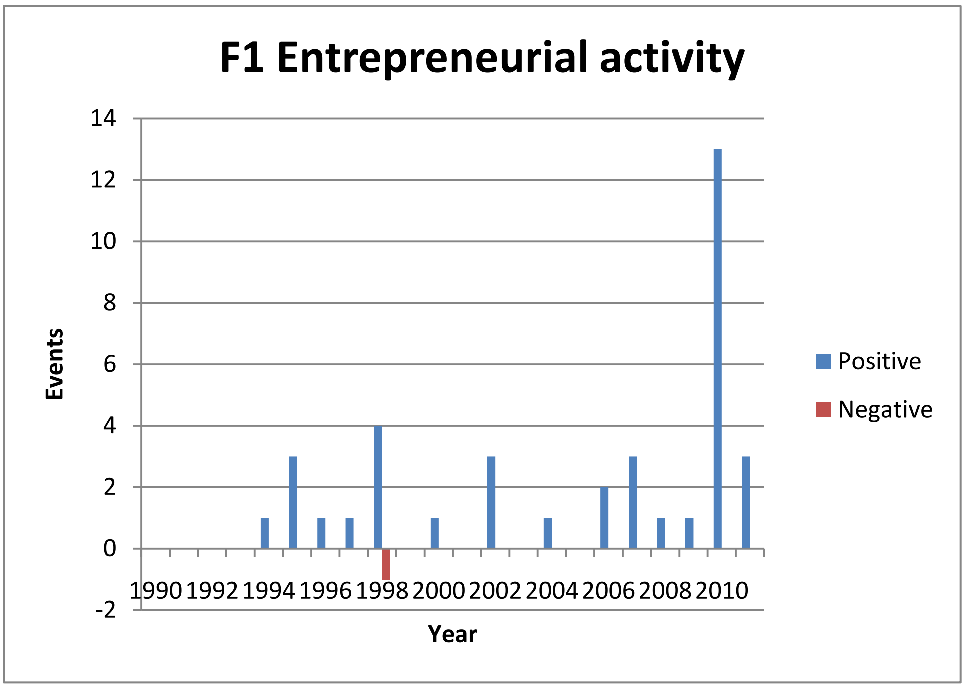



**Figure 14** Entrepreneurial Activity in Solar Energy

Although this is a small example existing of not too many events, it shows already some linkages and the presence of the five functions, F1, F2 and F3, F4 and F6, that are important for the STP-motor according to Suurs (2009). Some relations are identified and it has the functions required for a STP-motor, however, in this period it seems more internationally and national guidance driven. The following years 1996 and 1997 show a decreasing amount of events in all functions. This may well be caused due to a lack of knowledge development and diffusion (F2, Figure 15; F3, Figure 17).

### *1998-2001 A second try*

In 1998, an increase in events can be seen again after the low activity of previous years. In 1998 the 'White Paper on the Energy Policy of the Republic of South Africa' (1998) is presented, an important governmental paper that lays out the plans for the energy sector for the coming years. It describes the energy sector and the place of renewable energy technologies in the future energy sector in South Africa. The guidance of the South African government again seems to influence the availability of resources and the increase in efforts. As a consequence again some new projects started and renewed entrepreneurial activity started (Pearce, 1998; DE, 1998) (F1, Figure 14) and knowledge diffusion increased (F3, Figure 17). An example is the development of a financing system by Shell Solar and Conlog (Pty) Ltd. that enables users to pay if they want to use solar systems (DE, 1998). Further, more lobby activities related to the solar system arise in South Africa; NGOs show positive expectations, an International Energy Conference is held in Cape Town and for example Nelson Mandela opens a rural solar electrification project (DE, 1998; The Economist, 1998; National Journal's Daily Energy Briefing, 1999). In 1999, due to a government initiative scientific research to solar chimneys was started, though this could not deliver results in short term. All these events have a positive influence on the development of the solar system, but are counteracted by a lack of further R&D programmes (F2, Figure 15) and a lack of successful stimulation programs (F5, Figure 18) (Energy economist, 1998; Africa Energy and Mining, 1999). A setback in the White Paper is the demise of the Renewable Energy for South Africa organization; the Department of Mineral and Energy (DME) took their tasks back into the DME to gain more control (Energy economist, 1998). Further, the focus for renewable energy technologies remains at supplying rural and remote areas. The technology is considered as a solution for access problems and not as a centralized grid-connected power supply technology. Organizations like SELF and Shell both try to deliver this gap in access to remote areas by supporting, financing, and investing in new projects (Electrical Business, 1998; Pearce, 1998).

Later on in this period, foreign parties are visible. Again in accordance to South African governmental aims, the US DoE has a long running program in South Africa on supplying energy to remote areas and by 2000 they have provided 100s of rural schools, clinics and houses with solar energy (Federal Document Clearing House Congressional Testimony, 2000). In 2001, investments were announced for South Africa by Solar Development Capital, an external source to South Africa (Braunschweig, 2001).

Again, the functions F1, F2 and F3, F4 and F6 were partly present. There were even events that can be allocated to legitimization and lobbying (F7). A starting STP-motor is visible, but a lack of market for the entrepreneurs slowed the further development. In fact, there does not seem to be a market in South Africa except for the NGO, governmental INEP and Shell Solar programs. Giving access to people that are not connected to the grid is the market for solar energy, but there seems to be no demand by either individual customers or energy producing companies like ESKOM or IPPs to do so.

There is no real market, and there are no market stimulations or supporting measures (-F5). The demand is dependent on the charity projects. Again, national and international guidance (F4) seemed to drive the motor instead of knowledge developed within the country. The second barrier is still the lack of knowledge development (-F2) on the PV and CSP technology itself and on institutions and regulations of these technologies. The main driver and a key event in the development of the solar-system is the White Paper (F4). It is an incentive to the market, providing clarity on the future of energy in South Africa.

### *2002-2008 White Paper on Renewable Energy*

In 2002 new small scale projects start (Africa News, 2002) that are either demonstration projects or from individual green entrepreneurs (Agence France Presse, 2002). These demonstration plants and entrepreneurial activity show an increasing trust and believe in the technology. Organizations like the state-owned company Eskom and the World Bank also invest money and start a project (SAPA, 2002c).

This positive stance seems to be an anticipation to the 'White Paper on Renewable Energy' of the DME of South Africa (2003), caused by positive expectations on this White Paper. The paper, available in 2003, states that it is important to switch to more sustainable resources and to be less dependent on the conventional resources that have the costs to cover the caused damage not internalized in the current price. Goals are set at 10 000GWh renewable energy for final energy consumption in 2013, roughly 4% of the expected energy demand. It proposes the introduction and facilitation of Independent Power Producers (IPPs) to increase competition and investments in renewable energy technologies, while it at the same time allows for diversification of electricity sources and enables further market formation. However, they still see solar energy applied in the context of mini-grid or hybrid systems in remote areas. This might partly be due to their acceptance on the centralized and monopolistic characteristics of their current national energy system.

As a consequence of this important guidance report, many functions show an increased activity. Knowledge started to develop and diffuse over South Africa (F2, Figure 15; F3, Figure 17). The government started research on a large scale solar energy plant in the Northern coast(Ball, 2004) and started a feasibility study for a 100 MW solar plant in Upington (Liquid Africa, 2004; Singh, 2005), besides they planned to set up the NERI (National Energy Research Institute) (Liquid Africa, 2004). CEF established the Energy Development Corporation, which is to investigate RE opportunities and support the viable business cases (Liquid Africa, 2004) and demonstration projects were established in the Eastern coast (Liquid Africa, 2004). Besides, the University of Johannesburg developed a new more efficient type of solar cells, the Thin Film CIGS (Africa News, 2006a; UPI Energy, 2008) and Eskom studied the potential of solar power (Enslin-Payne, 2007d). The public sector in South Africa was getting involved more in the knowledge development and diffusion of solar technology.

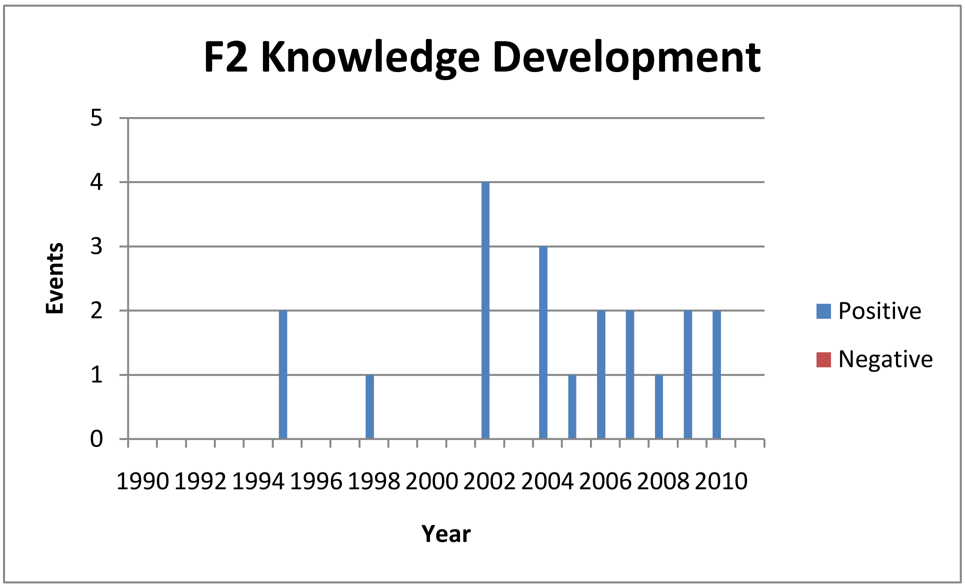



Figure 15 **Knowledge development for Solar Energy**

As can be seen in the knowledge development projects, the public sector clearly showed some intention to support renewable energy technologies. Whereas these activities already can be seen as guidance and example to the market, the government also investigated how they could create incentive schemes for renewable energy project developers or even renewable energy certificates (Liquid Africa, 2004). The minister of Science and Technology stated the importance of renewable energy sources in the lowering of the high carbon emissions in South Africa (Africa News, 2005b) and the environmental department started limiting the amount of $CO_2$ that companies can emit (Barry, 2005). This shows guidance of the government towards solar energy and other RETs. However, they resented to buy solar technology and tended mainly towards cheaper hydro energy (Akoko, 2004). However, the development in costs for solar energy is expected to decline to about 16c/KWh in 2050. A promising number since the price of coal-sourced electricity is expected to rise to 25c/KWh for new base load coal energy (Enslin-Payne, 2007b).

Meanwhile, more resources come available, since Eskom, the energy producer in South Africa, and Network BBDO also start to invest in the technology (Singh, 2005; Lunsche, 2006; Ritchie, 2007; Enslin-Payne, 2007c)(F6, Figure 16).

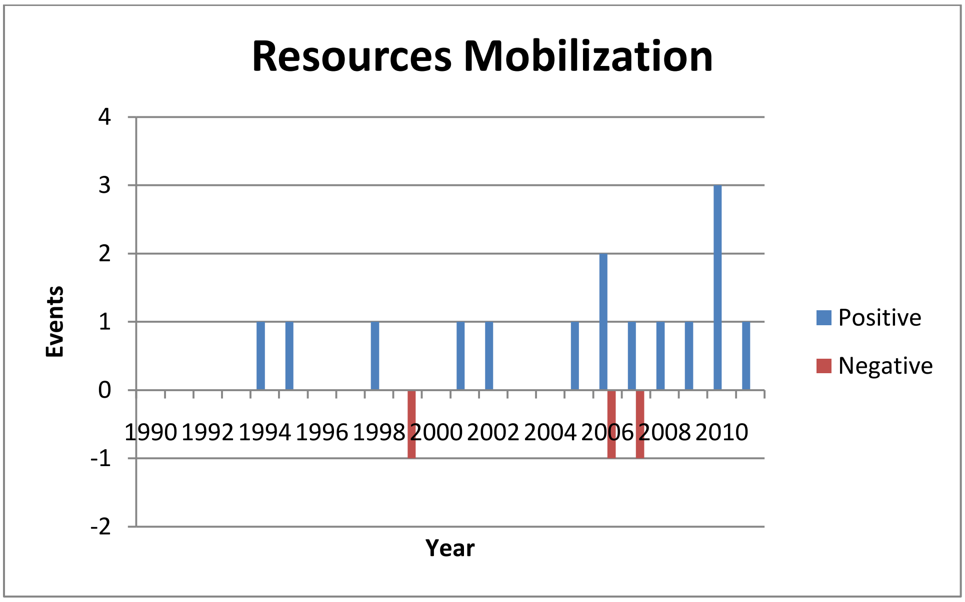



**Figure 16** **Resource Mobilization for Solar Energy**

Still, there are some barriers that prevent further investments. Entrepreneurs and investors do not like to have too much risk (Haw, 2011). Though the White Paper on Renewable Energy (DME, 2003) clearly showed a way forward for PV and CSP, the actions of the government were not in accordance to their guidance. No supporting measures were undertaken and no favorable tax regimes were created. The government has a positive view on the technology, but they did not create a successful regulatory framework to enable IPPs to enter the market easily. Meanwhile, despite Eskom's actions they were not too enthusiastic either, for it would mean they had to buy electricity from their competitors. Risk-aversion, uncertain income and difficulties with getting access to the grid of Eskom kept entrepreneurs from a more active role (F1) and kept investors from larger investments (F6) (Marquard, 2011).

On top of this regulatory uncertainty, there was the uncertain future. Lobbying groups chased after cheap energy for the big energy intensive companies (Marquard, 2011; Haw, 2011). Together with the aimed for reductions of approximately 0.8 Mtoe in GHG emissions and the quick rise in energy demand, the option of nuclear energy gained legitimacy (Heinzl, 2005; Kenny, 2007). The lobby for renewable energy also increased (Pretoria News, 2008), but the centralized option of nuclear energy fits better in the centralized energy system of Eskom and helps the state-owned company to stay in control (Marquard, 2011). Lobbying of opponent groups (F7) slowed the development of renewable energy technologies like PV and CSP further down (F7, Figure 19)

In January 2008 there occurred a new key event; there were large outages in South Africa (DME, 2008; Du Preez, 2008; Pretoria News, 2008; Rabobank, 2008). Large parts of South Africa and many companies have been without electricity for days. A growing public debate started about what should be done to solve the problems of the tense electricity market. More capacity is required, but what are the technologies to be used for this growth? Nuclear power already was considered for a long time, but that potential new power plant was temporarily put on hold, because of lack of financial resources due to the worldwide credit crunch (Power, Finance and Risk, 2008) and is alone not enough so close the gap (DME, 2008). Newspapers, individuals, NGOs and politicians all lobbied for their favorite technology; coal, nuclear or renewable (Cape Argus, 2008; The Star, 2008;

Smetherham, 2008; Bateman, 2008). This disruptive event opens up new opportunities. Whatever happens, the outages caused a decreasing trust in Eskom, because of their mismanagement. They caused an opening for private companies. The government is more inclined to privatize the production of electricity, since Eskom cannot be expected to solely solve the problems and build the required capacity (DME, 2008).

This time period ends with a midterm assessment of the period described in the energy white paper of 2003. The goals described in that paper were aimed at 2013, so in 2008 the current development and situation had to be assessed. Clearly, the previous described events, but also the re-assessment in 2008 showed a request for more energy capacity, a growing demand and obligation to invest (Donohoe, 2009). Further, Eskom requested an electricity price increase of approximately 18-20% per year (Enslin-Payne, 2007d; Naidu, 2008). This will make the cheap coal electricity more expensive. In the meantime, costs per KWh renewable energy are expected to decline.

The energy crisis is an opportunity to stimulate the renewable energy market, but it is as well a pitfall if many conventional power plants are build that will be operational and that will be competitors to renewable energy technologies the next decades.

For this period, the functions of the STP-motor, F1 with new small scale projects, F2 and F3 by universities and research institutes, F4 by means of the government mitigation strategies and aims, and F6 by more public investments, show themselves more clearly. However, it was initiated by governmental guidance (F4), and thus the push of science and technology needs to be reconsidered as initiators of the start of technological development in developing countries. In this period the TIS even tends to be at the edge of transition to the Entrepreneurial motor, while some legitimization (F7) takes place and the search for new installed capacity will likely lead to market formation actions by the government (F5). However, the barriers are not yet outweighed by right structural conditions, e.g. strong lobby and market formation actions.

### *2009-2011 REFIT programme*

The national pressure on the government to solve the energy crisis and the international pressure to aim for low carbon technologies showed to have their effect on the energy policy. The South African government shows itself to have been guided by international policy cases and advise like from Germany and Spain. Although, the national pressure to come up with short-term solutions and NGOs lobbying for cleaner energy also added to their slow turn to renewable energy. The main event supporting an upcoming interest in solar energy was the introduction of REFIT (Renewable Energy Feed-In Tariff) (The star, 2009; DPE, 2009). At least, during the second phase (ADP News, 2009), because PV was excluded in the first REFIT list, which caused a lobby from the industry and organizations like SESSA, to include the technology (Foss, 2009; Tendersinfo, 2009a; Schneider, 2009a). This supporting of the market by fixed feed-in tariffs at levels interesting for projects increased the attention of both national and international investors and entrepreneurs (Salgado, 2010; ADP news, 2010; Africa Today, 2010). Companies such as Yingli green, Sasol, Energy Investments Inc. and Tenesol were willing to invest and started planning solar equipment production or solar projects (CN&I, 2009; Tendersinfo, 2010a; Tendersinfo, 2010e; Tendersinfo, 2010f). Concentrix even clearly stated they started their solar project, because the REFIT tariff was comparable to Germany and Spain and thus high enough for investments in RETs (Salgado, 2010). The market formation initiative REFIT and guidance together achieved a mobilization of resources towards the system and increased the entrepreneurial activity. This indicates that function F5 becomes part of the system, which thus shows characteristics of the Entrepreneurial Motor.

Meanwhile, also the development and diffusion of knowledge increased (F2, Figure 15; F3, Figure 17). The University of Johannesburg has a known research group that also developed Thin Film Solar Technology (TFST), which will decrease the costs of solar cells (Schneider, 2009b). Small projects started as demonstration or testing projects and reports analyzing the potential for South Africa showed huge opportunities (M2 Presswire, 2010; Tendersinfo, 2010c; Businesswire, 2009; PR Newswire, 2009). One of the lacking features of previous periods, knowledge development, is now well underway. Universities have departments dedicated to the technology development or research to policies (Marquard, 2011; Meyer, 2011). They are able to transfer the knowledge into practice, giving advice for the REFIT tariffs and getting a TFST plant to South Africa (Tendersinfo, 2009d).

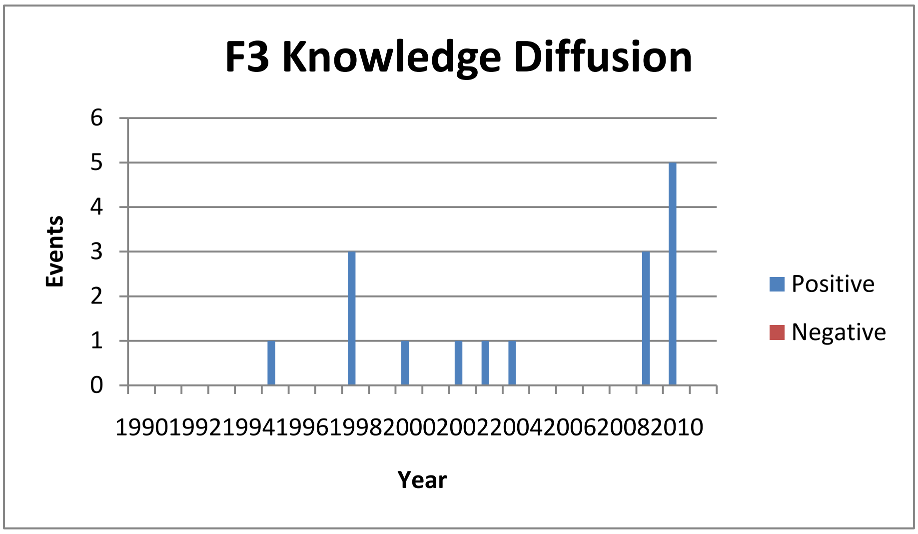



Figure 17 **Knowledge Diffusion for Solar Energy**

This shows a pretty optimistic view of the PV system in South Africa; however, the number of events is still low. It might do so to investors and entrepreneurs as well, but despite the intention displayed by the REFIT program subsidies only are not enough. A regulatory framework is still missing in South Africa for the buy-in and licensing of Independent Power Producers (IPPs) (Kelly, 2010; Rycroft, 201; Beukes, 2010). There are two major problems; one is becoming an IPP, the other is getting a Power Purchasing Agreement (PPA). For both regulations are lacking. If one wants to produce electricity on relatively large scale and feed it to the national transmission grid, a license to be an IPP is required. To get one can be difficult, because there are not yet clear regulations and requirements for this license. The next step for larger IPP licensees is that the electricity needs to be sold. As Eskom is the owner of the transmission grid and a monopolistic party to sell electricity to the people, often this PPA needs to be an agreement with Eskom. Eskom then has to pay the prescribed REFIT tariffs (DPE, 2009) and incorporate it in their electricity price. Eskom, however, already asked for a tariff increase for selling electricity of 25% per year (Meyer, 2011) for their current delivered energy, which mainly comes from coal-fired power plants. This money is needed to invest in new to-be-installed capacity. They are in a split. Eskom needs to choose whether they move towards paying for renewable sources and hoping to increase their capacity by that, or building new centralized power plants as nuclear and coal power plants.

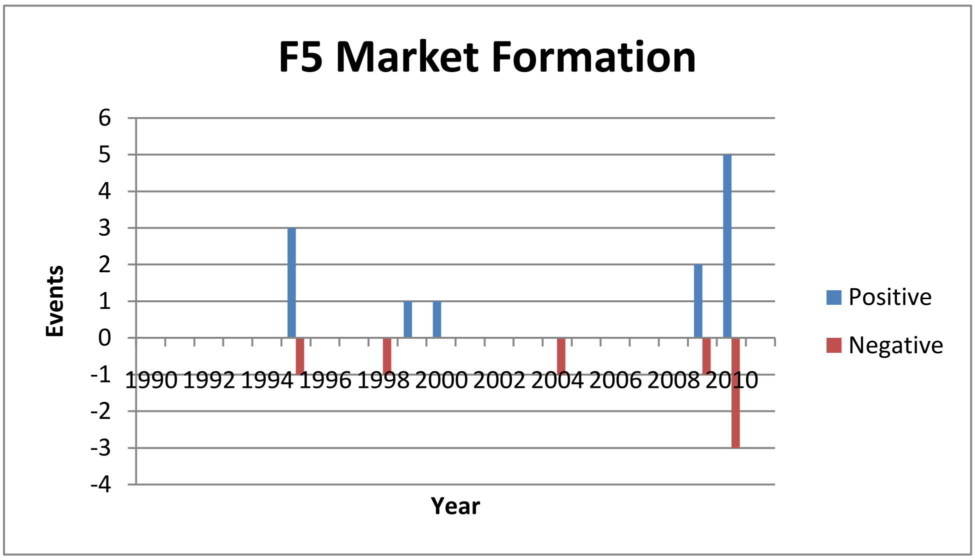



**Figure 18** **Market Formation for Solar Energy**

The lobby for renewable energy and regulations went on (F7, Figure 19) due to groups like Greenpeace, the EPIA, SAPVIA (Gosling, 2010), Earthlife Africa (Thompson, 2010) and SESSA (Schneider, 2009a). This lobby was mainly aimed at the government or NERSA to come up with more technologies in their REFIT scheme, to provide regulations to create a market by ensuring IPPs to be licensed more easily or at least according to clear rules and to have Eskom sign PPAs.

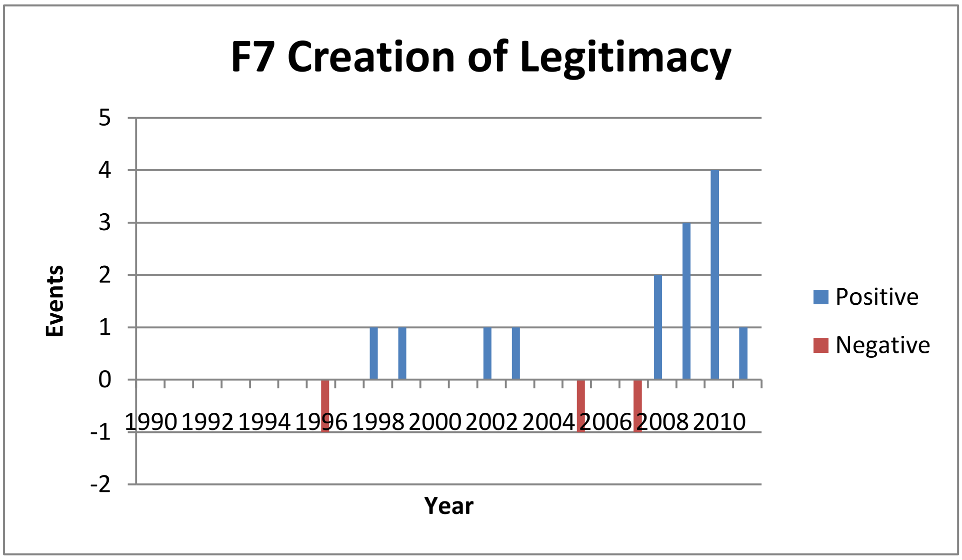



**Figure 19** **Creation of Legitimacy for Solar Energy**

Another major event that cannot be left out is the financial crisis. Remarkably, there has not been much reaction regarding this worldwide event. In none of the events there was a reference to the financial crises except for two articles that stated that the crisis did not seem to have so much influence on the renewable energy sector in developing countries (The Star, 2009) or they were at least already showing recovery (Tendersinfo, 2009c). However, this remains difficult to assess, since one never knows what could have been achieved otherwise.

This period shows increasing entrepreneurial activity (F1) caused by the REFIT tariff, which is a clear market formation (F5) program that increased the attention of investors and thereby caused a resource mobilization (F6). Lobby activities (F7) partly initiated by industry had their influence on the government and NERSA to adjust the tariffs and to come up with tariffs for PV as well (F5). Thereby, it indirectly caused an increase in resources available from project investors. The knowledge development and diffusion (F2, F3) also have become more present and influential, although it needs to be said that many reports had an international background and were incorporating South Africa. Together this shows characteristics and relations as found in the Entrepreneurial motor, and though due to lacking functions and regulations the motor does not run very smoothly, it can be seen as an Entrepreneurial motor.

Major barriers that are upholding the transition towards more extended successive motors are the lacking regulations for the IPPs and PPAs. Eskom is still in a split although they postponed building the nuclear power utility, because of a lack of money. Investments need often to come from abroad, making these processes difficult and time-consuming. In addition, the lobby against renewable energy and the NIMBY effect are barriers to overcome. EIA procedures, in which the people have many opportunities to oppose to the project, need to be overcome. Lobby for nuclear energy increased uncertainty around the legitimacy and place for renewable energy in the future. Another important issue is that up to now there are almost no existing projects. Many projects are in planning, but need to be realized within the next years (Marquard, 2011). Except for the extraordinary case of the Darling Wind Farm, which was not created under similar conditions of REFIT, and government intentions, there are no examples of successful projects. Learning from such projects is thus not yet possible.

### *Preliminary Conclusions*

Considering the solar energy TIS in South Africa some preliminary conclusions about barriers can be drawn, see Table 2. The view on solar energy, of being a technology for decentralized energy production and at small scale, has, after being a driver at first, long been a barrier to further development and growth of the solar system as its assumed non-applicability for large-scale electricity supply made it irrelevant in larger energy supply activities.

Secondly, no real market was present. Poor people just got PV-cells during the electrification programme, but they themselves did not have enough money or an incentive to buy solar cells. On top, there is also no market for produced solar energy. A lack of willingness to pay for more expensive renewable energy is a barrier to the development of the solar-system. That however, is no surprise in a developing and emerging country searching for economic growth. Especially not since South Africa is known to have really cheap electricity, due to the abundance of cheap coal and the depreciated power plants. Another threat related to this is the lobby and tendency of the government towards nuclear energy, which can produce electricity for low cost (Haw, 2011). For a long time a proper stimulating program for solar energy lacked and so no protected market was formated. The conclusion is that the market should be helped by mechanisms that level out the higher price of the solar energy.

Thirdly, Eskom has financial problems. The energy supplier of South Africa lacks financial resources to invest heavily in required new installed capacity, though it is necessary. They requested an increase in price for electricity at NERSA, to raise more money for investment, however for now they seem to be stuck. This is a large barrier since Eskom is practically the only grid connected energy supplier in South Africa.

Fourthly, the major barrier of getting an IPP license and a PPA with Eskom is blocking the continuation of many projects. The lack of regulations for IPP and PPA causes uncertainty and sometimes more clearly just blocks the realization of projects. An independent regulatory organization should solve the problems of lacking regulations and of Eskom's conflicts of interest. However, up to now the conclusion is that the government lacks in regulation and stimulation efforts for getting PV-systems installed.

Fifthly, the case on solar energy showed in several occasions a lack of knowledge developed, not on the technology itself, but on the side issues, institutions and regulations. This requires more attention. It might even shed light on and reduce the NIMBY effect if more on the effects is known. This however can be difficult, since there are except for the small and remote solar projects no clear examples and projects that can be analyzed and learned from.

The drivers for the TIS of solar energy are also presented in Table 2. The most important insights among those drivers is the role that international and national pressure and guidance has played. The White Papers, REFIT, NGO's and governmental programs were important in the development of solar energy system in South Africa.

To conclude this case, no continues entrepreneurial motor emerged due to lack regulations and market stimulating programmes. Despite the space and a request for extra installed capacity, the market is not accessible. Getting an IPP license and a PPA is so difficult that it hampers the entrepreneurial activities.

| ***Solar energy system*** | |
|---|---|
| **Barriers** | **Drivers** |
| **Minigrid, off-grid application** | Mini-grid/off-grid application |
| **No market available** | International pressure and Guidance |
| **Electricity price/Coal** | NGO/government support programs |
| **Lobby for nuclear** | White Papers (National Guidance) |
| **Eskom finances** | Outages |
| **IPP and PPA** | REFIT |
| **Knowledge on institutions and regulations** | Electricity price increases |
| **NIMBY** | |
| **Learning of successful projects** | |

**Table 2 Barriers and Drivers to the solar energy system**

### 6.2 Case-study of Wind energy in South Africa

This chapter will show the narrative of wind energy in South Africa. All the important events that are related to the Wind-sector and its development are taken into account. The narrative is displayed in chronological order making use of periods. The periods are divided according to major key events that occurred and that had a large influence on the TIS during a specific time period. However, these key events occurred irregular and thus the periods are not of equal length. The functions are referred to with F1-F7 and their full names. At the end of every time period, the feedback to theory is made.

#### *1990-1993*

In this first period, there was no attention for wind energy in South Africa. Almost no important issues or events related to this RET were identified in this first period. South Africa had an abundance of energy and installed capacity (DME, 2008) and therefore had not an incentive to change their electricity supply. However, there are already positive expectations (F4) of wind energy in South Africa by anti-nuclear groups (Koch, 1990) and by scientists like prof. Eberhard (Koch, 1990).

#### *1994-1997 Positive expectations*

With the elections of 1994 in mind the ANC produced a manifest called 'the Reconstruction and Development Programme'. This is seen as the start of policy guiding principles in energy and electrification (Tinto and Banda, 2005). The new government of South Africa tried to increase access to electricity for all the people and thus partly directed at decentralized renewable energy technologies for these far off areas. Despite this electrification programme INEP and the opportunities for applying wind energy decentralized, the new government and the creation of the REFSA no increase in in-country activities besides some positive guidance can be seen for South Africa. The positive expectations present were often in combination with foreign country's RET developing programs to provide people in remote areas with electricity access, like e.g. from the US and Canada (NPR, 1994; Federal Document Clearing House Congressional Testimony, 1994; Agence France Presse, 1995; Dayton Daily News, 1997).

With a lack in activities for many functions, clearly no motor of change can be identified. The positive expectations and international guidance show that there is some potential in South Africa, but no real incentive to do something with these opportunities is present. After the elections in 1994 the new government had probably more important issues to address and the electrification scheme for remote areas focused more on solar energy to provide in electricity.

#### *1998-2001 The White Paper*

In 1998, the 'White Paper on the Energy Policy of the Republic of South Africa' (DME, 1998) was presented and envisioned the future on energy in South Africa and the place of RETs. As described in the case of solar energy, RETs were identified to be applied in remote areas were grid connections is not an option. According to NGOs like Earthlife Africa the government was not taking renewable energy production serious enough, and they started to lobby for RETs (F7, Figure 20) (Petroleum Economist, 1998; SAPA, 1999a; Africa News, 2000).

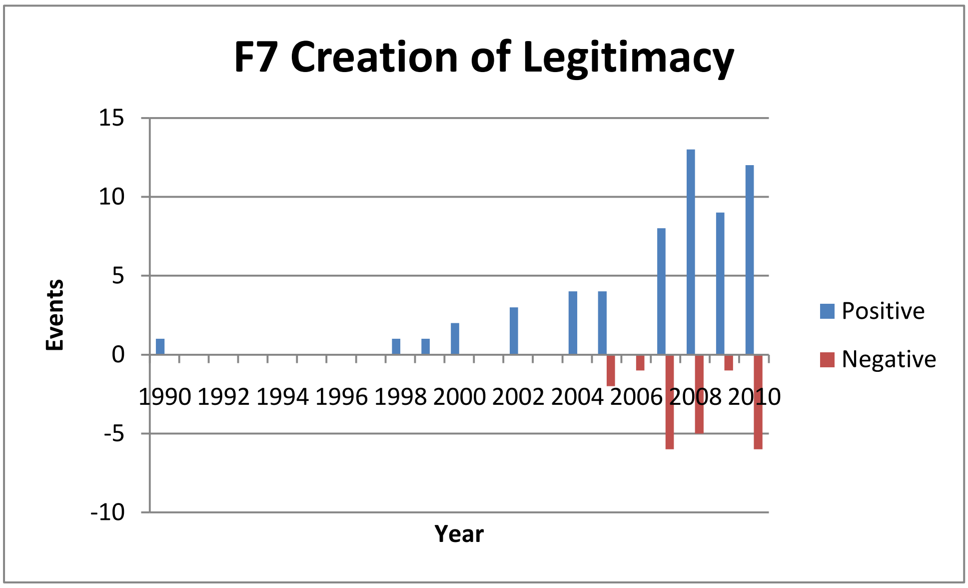



Figure 20 **Creation of Legitimacy for Wind Energy**

Many other potential energy producers applied for an IPP license (SAPA, 1999b); however, the government only approved the Oelsner Group to start their wind farm project (SAPA, 1999c). No clear market regulation on entering the energy production system was available, so Eskom remains the energy producer for South Africa. In 2000, the government pledged that within ten years all communities would have access to electricity. Part of this plan was to make use of off-grid technologies, among these wind power (Chalmers, 2000).

Later, in this period Eskom started to think about a project near Cape Town. This caused them to identify public opinion, to do an Environmental Impact Assessment (EIA) and they researched costs of various turbines, performance data and reliable locations for wind farms (SAPA, 2001). For the project, they also tried to find private sector partners for investing in the demonstration project (SAPA, 2001). This can be considered remarkable since Eskom announced that South Africa will have to invest €10billion in new generation capacity the next 25 years and they are a state-owned company (Africa News, 2001). Eskom thus seems to have more trust in private investments than in support from the government. The actual place of wind energy and RETs more in general, can be set in perspective by looking at the government, who says to be willing to make use of RETs, spending 50 million Euros for feasibility studies to a speculative nuclear energy project (Africa News, 2000) and not spending on wind energy.

Still no motor of sustainable innovation is visible. Although some guidance (F4) occurred by means of the White Paper, this was not followed up by many projects, even not in an off-grid and remote area context. The entrepreneurial activity (F1) by Eskom was having difficulties in raising resources (F6), so the knowledge development as part of this demonstration project also can be expected to slow down (F2) and due to a lack of regulations (F5) many potential IPPs are still not starting new projects (F1). Besides, the feasibility study to nuclear energy pointed out that the expected potential for RETs might decline for the future.  Together, there were many barriers to the development of wind energy is South Africa during this period.

### *2002-2006 Research and Guidance*

An increased amount of activities is noted in 2002. This increase is due to development of the Darling Wind Farm and Cape Town's stance towards it (Africa News, 2002a). The CSIR and the University of Cape Town were joining the project and funding has been obtained from Denmark (Africa News, 2002). Further, a Power Purchase Agreement was signed with the city of Cape Town (The Indian Ocean Newsletter, 2003). However, some more demonstration projects following the lobby from the earlier period were taking off. Eskom tried to develop a 10MW demonstration wind farm and the Koega Energy Company tried to develop a 7MW wind farm (Africa News, 2002b).

Further, international pressure (Haw, 2011) and lobby by Earthlife, SECCP and Greenpeace was going on pushing the government towards renewable energy sources (Africa News, 2002c; SAPA, 2002a; Agence France Presse, 2002) (F7, Figure 20). Research and funding for projects came available; €5.16million for a demonstration plant at Klipheuvel (Africa News, 2002d), and for research €7.54million in total by Eskom (SAPA, 2002b).

This starting business (F1) can be seen as positive expectations of upcoming governmental guidance (F4). In 2002 already, South Africa joined a platform of a partnership that tries to increase EU's energy efficiency activities in the developing world (Xinhua General News Service, 2002). The government also embarked on possible goals for decreasing emissions and growing the industry of renewable energy technologies (Africa News SAPA, 2002d). The mentioned goal of 10000GWh renewable produced electricity shows that some people already knew what was more or less coming up in the 'White Paper on Renewable Energy' (DME, 2003). The start of this period, because of increased activity in 2002, could well be a consequence of positive expectations by the actors in the system (F4, Figure 21). They anticipated to the expected statements of the government in the White Paper (DME, 2003).

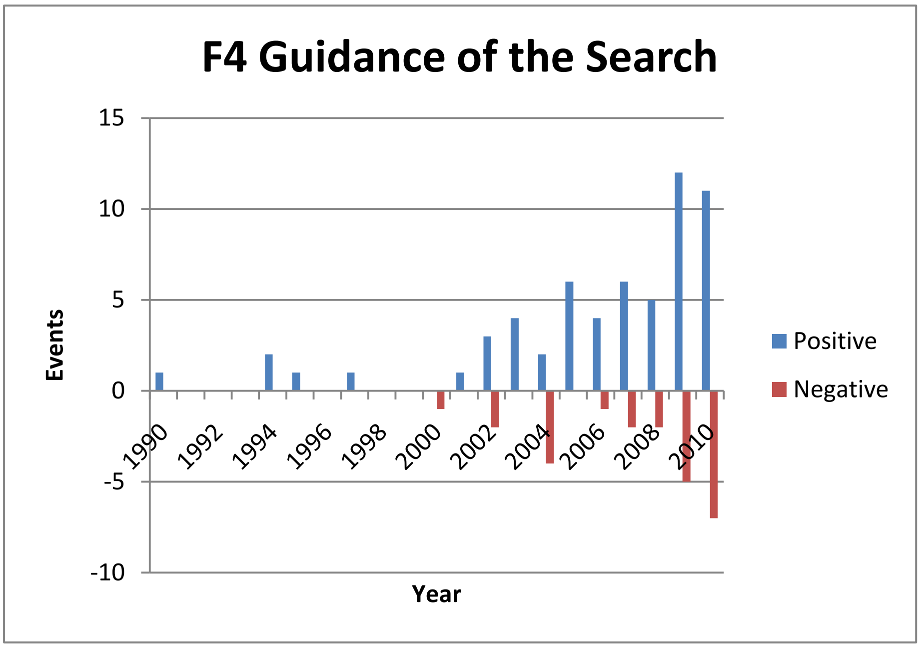



**Figure 21 Guidance of the Search for Wind Energy**

Continuing in this period, the testing plant of Eskom at Klipheuvel started (SAPA, 2003). The two projects, Darling wind farm and Klipheuvel, attracted quite a lot attention; the opening of Klipheuvel was attended by two ministers and the Darling Wind Farm has been recognized as national demonstration project (SAPA, 2003; Scott, 2003; The Indian Ocean Newsletter, 2002). The knowledge development and entrepreneurial activity together lead to an increased attention for the wind energy system and thereby caused guidance and positive expectations of the government. Radebe, Minister of Public Enterprises, predicted a drop in costs for wind energy (SAPA, 2003) and Cape Town included renewable energy sources in its strategy to achieve sustainability (Africa News, 2003a). Further, the government stated that wind energy should play an important role in South Africa's economic and sustainable development (Africa News, 2003b, Bennett, 2003a). These positive expressions and opinions could well have added to the White Paper on Renewable Energy. This further guidance of the energy market aimed to have at least 4% of the final energy consumption to be produced by RETs. However, the share for wind energy has not been stated (Africa News, 2003c).

The motor went on with the government launching a research institute (Bennett, 2003b), providing resources to set up the South African Wind Energy Programme (Africa News, 2003b), setting up the National Energy Research Institute (Liquid Africa, 2004) and doing research to RETs in general (Ball, 2004)(F2, Figure 22).

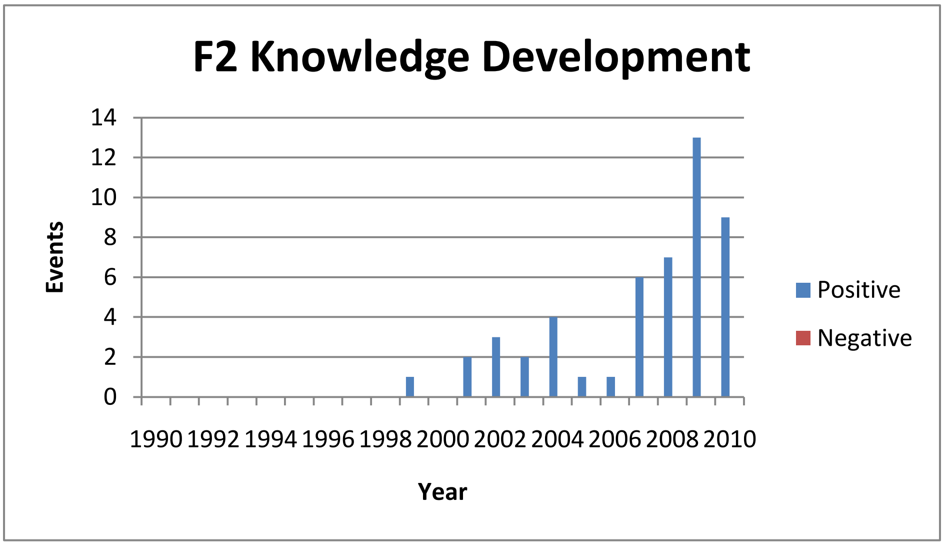



**Figure 22 Knowledge Development for Wind Energy**

Besides knowledge development, the diffusion of knowledge started with help from abroad (F3, Figure 23); the World Wind Energy Conference in Cape Town (Energy Management News, 2003) and the newly created global renewable energy information pool (World Markets Analysis, 2003). The conferences like in Cape Town and in Bonn (Liquid Africa, 2004) (F3) both led to more guidance by getting the government willing to set up research institutes and new and more ambitious goals (F4).

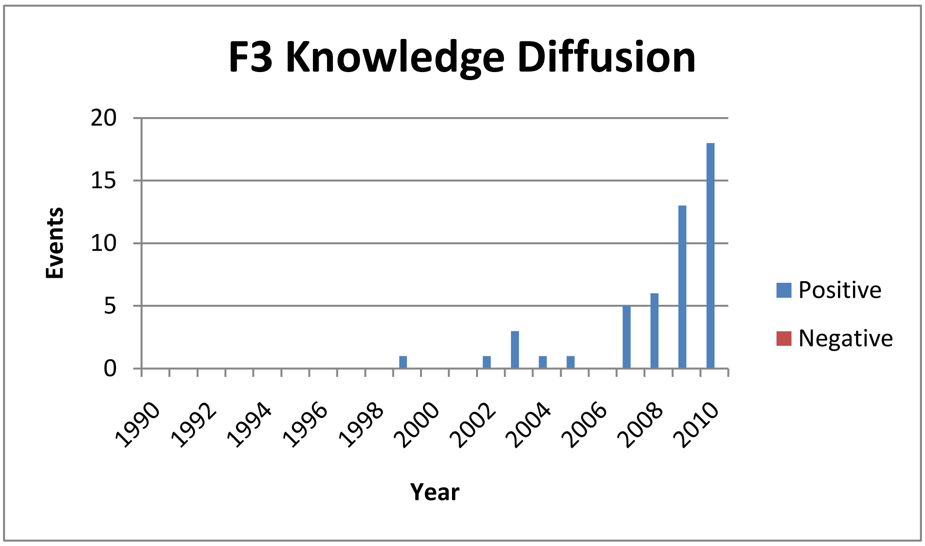



Figure 23 **Knowledge Diffusion for Wind Energy**

The Darling wind farm could despite these positive developments not develop as it wanted to do. Due to a law case against the wind farm and the provincial environmental minister Gelderbloem, the development was blocked (Sunday Times, 2004). Besides, the delays caused by the slow court process threatened the availability of the Danish grant funding (Sunday Times, 2004). The government did not show positive guidance in this case. Further, the government by means of the minister of Minerals and Energy stated again that nuclear energy should deliver larger parts of the energy needs in the future (Nuclear Engineering International, 2004). The option is a way to diversify the energy mix and increase the security of supply. Though she stated that the government aim still was to produce the earlier proposed amount of RE in 2013, it is a weakened guidance by the government. The year 2004 can be seen as a small setback or slow-down for the development of wind energy.

Following up on the law case, the minister Van Schalkwyk approved the initial proposal and thereby gave green light to further the development of the Darling Wind Farm (Africa News, 2005a). On top of that, the minister of Science and Technology indicated the importance of renewable energy sources in the battle against the high carbon emissions in South Africa (Africa News, 2005b) and the environmental department started limiting the amount of $CO_2$ companies can emit (Barry, 2005). The government showed a clear guidance towards wind energy and other RETs. More positive expectations came from other actors in the wind energy system. Oelsner, the developer of the wind farm and head of the African Wind Energy Association, said an 'awakening of consciousnesses was underway (Indo-Asian News Service, 2005) and Earthlife lobbied for wind energy and expected that the wind turbines could be build locally (Moore, 2005).

Consequence of the guidance and positive attention for wind energy was an increased entrepreneurial activity in 2006 (F1, Figure 24) (Singh, 2006). The building of four wind turbines, the Darling Wind Farm, started (Pearmain, 2006). Cape Town's major had approved to purchase power from the wind farm, thereby stimulating the project (Africa News, 2006b). More stimulation and regulations was expected to be available soon, because the government was investigating how to introduce private investors to the energy system. These IPPs were aimed to produce up to 30% of the electricity within ten years (Africa News, 2006c). Entrepreneurial activity became visible in consortia like Lereko Energy Consortium, Thermo-Rec and Enercon India, a 100 percent subsidiary of EIL South

Africa Power Development (Pty) Ltd that was succeeded in bidding for a project to implement among other technologies wind farms (Africa News, 2006c) and in organizations like Suzlon gaining access to South Africa by acquiring the South African gear making company Hansen Transmissions (Hindustan Times, 2006).

This period clearly shows a motor of sustainable innovation going from demonstration and knowledge projects (F2, F3) and positive expectations (F4) to increased attention and guidance by government towards RETs and specifically wind energy (F4). This increased available funding for new research (F4, F6 and F2 again). Opening a new test project, Klipheuvel, and efforts and successes in the Darling Wind Farm, caused a renewed and increasing commitment of the government. Though the year 2004 was a setback with guidance towards nuclear energy and the slow-down of the Darling Wind Farm, the government afterwards continued to put emphasis on wind energy and other renewable energy technology. The guidance and positive expectations caused entrepreneurial activity and research again to rise.

Having the functions F2 and F3 influencing F4 and consequently having resources, F6, available for more research and thereby causing an increasing amount of entrepreneurial activity, clearly indicates a Science and Technology Push motor. The barriers in this period were mainly the lack of effective lobbying (F7), the lack of stimulation and regulation programs (F5) and the threat of nuclear energy. Especially the difficulty of really being allowed to build a wind park is a major barrier, as was visible in the Darling Wind Farm case. The transition towards the Entrepreneurial motor was thus halted by the lack of lobby (-F7) and the lacking follow-up on market formation (-F5), what should lead to further mobilization of resources (-F6) besides mobilization initiated by guidance.

### *2007-2010*

This period took off with serious power cuts, because of unforeseen maintenance and excessively low reserve capacity (Oberholzer, 2007; Associated Press Worldstream, 2007; DME, 2008; Du Preez, 2008; Pretoria News, 2008; Rabobank, 2008). The South African society was afraid for more outages during the winter and a search for additional capacity started. Although it is an external event to the wind energy system, it might be clear that there are opportunities for developing renewable energy technologies, besides coal and nuclear, to solve the issue. It is a disruptive event that is important for the possible breakthrough of new energy technologies.

The Western Cape continued the guidance seen in the last period 2002-2006 by committing to a 15% renewable energy by 2015 target (Africa News, 2007a). Their Western Cape Integrated Energy Strategy started with workshops for actors in the field of RETs and called for wind farm proposals (Africa News, 2007a). The response was enormous and worldwide actors were interested in the Western Cape region. In this period there are loads of organizations willing to invest in this emerging market in South Africa. Money was invested by organizations like Transnet, Tchenguiz's Consensus Business Group, the World Bank (Armbruster, 2007; Northedge, 2007).

An increasing amount of entrepreneurial activities shows even better the development of the wind energy sector in South Africa (F1, Figure 24). There are responses from all over the world, companies are interested in South Africa’s wind energy sector (Africa News, 2007a); Siemens SA securing orders for offshore wind parks in England (Africa News, 2007b) Theolia has an option to acquire a 5MW project (AFX International Focus, 2007) and Eskom calling for interest of turbine makers in a

€113.9million wind farm on the West coast (Enslin-Payne, 2007a) are just a few examples of the increasing entrepreneurial interest and activity in 2007.

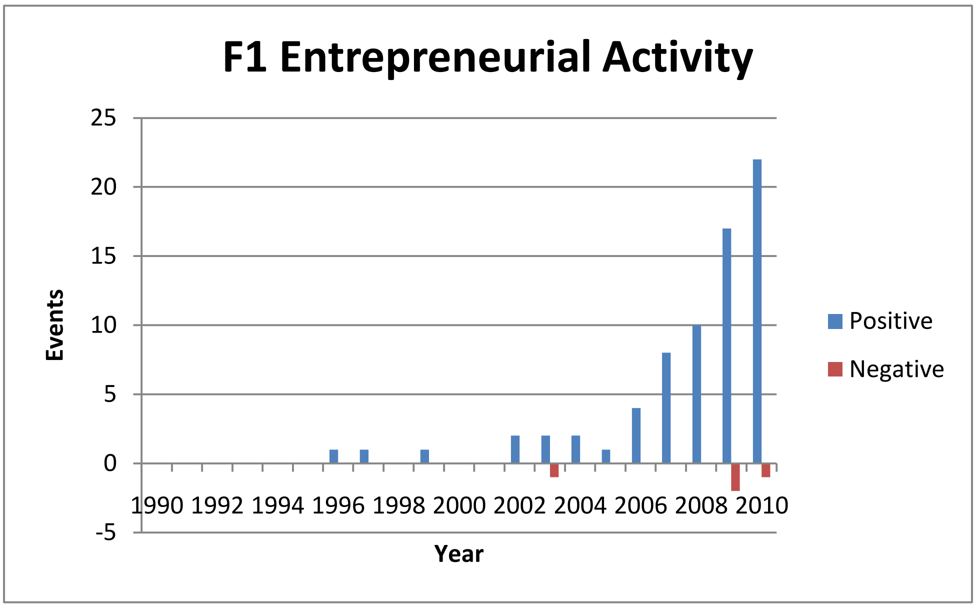



**Figure 24 Entrepreneurial Activity in Wind Energy system**

The projects planned and proposed by the entrepreneurs produced and diffused knowledge. Eskom participated in making the 'wind atlas' and produced an EIA that is publicly available (Africa News, 2007d). These EIAs have to be done for every proposed site for wind farm projects, e.g. the Koega wind farm's EIA (Cull, 2008) and the Hopefield wind farm's EIA (Pearmain, 2009). Other potential IPPs conduct feasibility studies (Africa News, 2008d). This development and diffusion of knowledge mainly aims at side issues. Further, knowledge develops at universities like the University of Cape Town, and the Nelson Mandela Metropolitan University (Carnie, 2009; Africa News, 2008b; Marsh, 2008; Njobeni, 2009), Stellenbosch (Muhwezi-Bonge, 2007) and at organizations like Saneri (Sunday Tribune, 2007) and CSIR (Africa News, 2007d), see Figure 22. Knowledge diffusion was addressed by a number of conferences like the business conference (Agence France Presse, 2007), the Generation conference (Smillie, 2008) the Renewable Energy conference (Africa News, 2008c) and the international wind energy seminar in Pretoria (Carnie, 2009), see Figure 17.

In this period the guidance also continued (F4, Figure 21); besides government guidance, more influence from entrepreneurs and investing organizations was visible. The Central Energy Fund (CEF) stated that on short to medium turn renewable energy could provide 5% of the energy needs (Africa News, 2008b; Africa News, 2008a). At the opening of the Darling Wind Farm actors speculated that soon tenders for other wind farms would be issued by Eskom (Naidu, 2008). University of Cape Town professor Eberhard said renewable energy options might become cheaper than conventional sources, because of increasing prices for fossil fuels (Terreblanche, 2008). Besides, these examples the government stayed guiding the search by agreements with Denmark (Carnie, 2009) and by introducing REFIT tariffs (Mpofu, 2009; DPE, 2009).

Lobbying in this period has been divided into two subjects. One was on getting a subsidy scheme, the REFIT, in place, because it is seen as an important means to push investors and entrepreneurs to starting projects (Africa News, 2007c; Sunday Tribune, 2007; Peters, 2008; Africa News, 2009). The other topic was caused by the ongoing uncertainty on the nuclear energy project of the government. Proponents lobbied for nuclear energy and against investing in renewable energy technologies like wind energy (De Boer, 2007; Cape Argus, 2007; Cape Times, 2007; Kenny, 2007). Opponents lobbied for the wind energy and pointed at the costs and dangers of nuclear energy (De Boer, 2007; The Mercury, 2007; Foss, 2008). Remarkable is that part of the lobbying is done by writing letters to the newspapers that write on these topics. This lobbying thus seems to have an individual character and tries to influence the larger public, though the recurring writers often are connected to either nuclear or environmental institutes.

With mentioning the REFIT tariffs, this case study arrives at its major problems with enabling potential power producers to actually produce power and sell it on the grid. The entrepreneurial activity increased even more after the REFIT program was announced. The Hopefield wind farm was announced (Gosling, 2009), Suzlon entered the market (India Business Insight, 2009), in the Coega zone a wind farm project was announced (The Herald, 2009) and the Adventure Power facility was established (Schneider, 2009c). These are a few of the projects started due to the stimulation program.

Again this incurred research by organizations like SAWEP (Schneider, 2009d), CSIR (Comins, 2010), the Durban University on Technology (Terreblanche, 2009) and other private project developers and caused a spread of knowledge by reports and using the acquired knowledge in the projects. For this research funding was available (F6, Figure 25) from the South African, German and Danish government (Schneider, 2008; Lewis, 2009; Schneider, 2009d). Other types of funding, both private and public, were available for the development of projects. For example, Setsolar invested R40million (Hartley, 2008), Evolution one raised R400million (Daily News, 2008), a French agency loaned 120million Euros (Tendersinfo, 2009b) and the GEEREF committed 10million (Tendersinfo, 2010a).

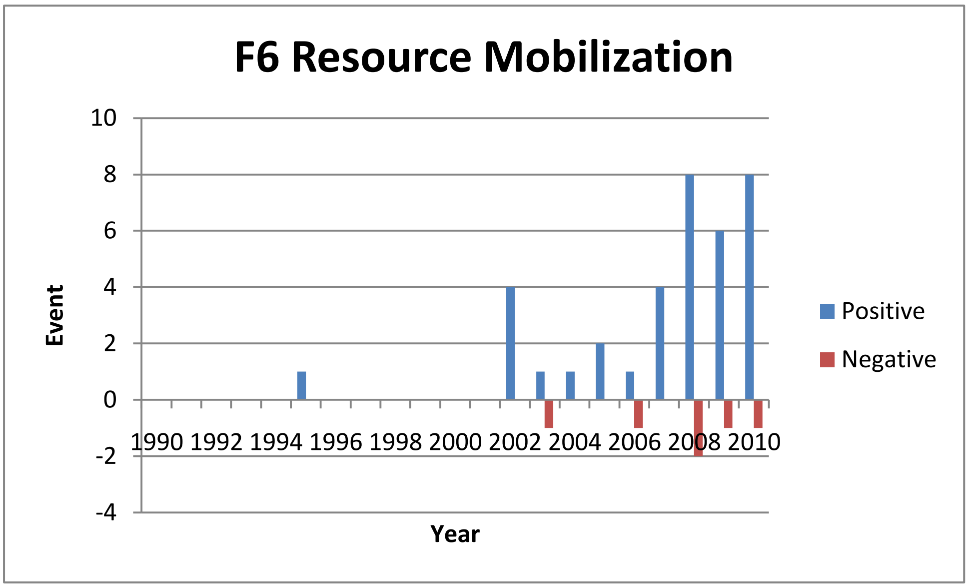



**Figure 25** Resource Mobilization for Wind Energy

However, entrepreneurial activity does not mean actual realization of wind parks. Despite the stimulation program REFIT and the presence of nearly all functions in the system, there remain a few barriers that are really blocking the application and mitigation strategies in South Africa.

Wind farms are only to be build, if it is sure where the energy will go. To be allowed to produce energy an owner of a project requires an IPP license. This already is quite difficult to get and many actors point at this lack of market regulations (F5, Figure 26) (Tendersinfo, 2009e; Tendersinfo, 2010d), even Eskom does point at this lacking regulation (Tendersinfo, 2010b). However, besides this IPP license, a Power Purchase Agreement (PPA) is required. This can freely be agreed upon with buying actors as long as it is outside, or with permission on, the national transmission grid, for example like the Darling Wind Farm agreed on a PPA with the City of Cape Town. In normal cases the PPA needs to be made with Eskom the owner of the national transmission grid and the only big seller of electricity in South Africa. Eskom than has to pay the REFIT tariffs for energy from wind farms, which conflicts with their own production of energy. Due to lacking regulations they are not obliged to buy the energy from 'competitors', so this is the main bottleneck in the development of wind energy in South Africa (Oberholster and De Jong, 2010; Foss, 2010).

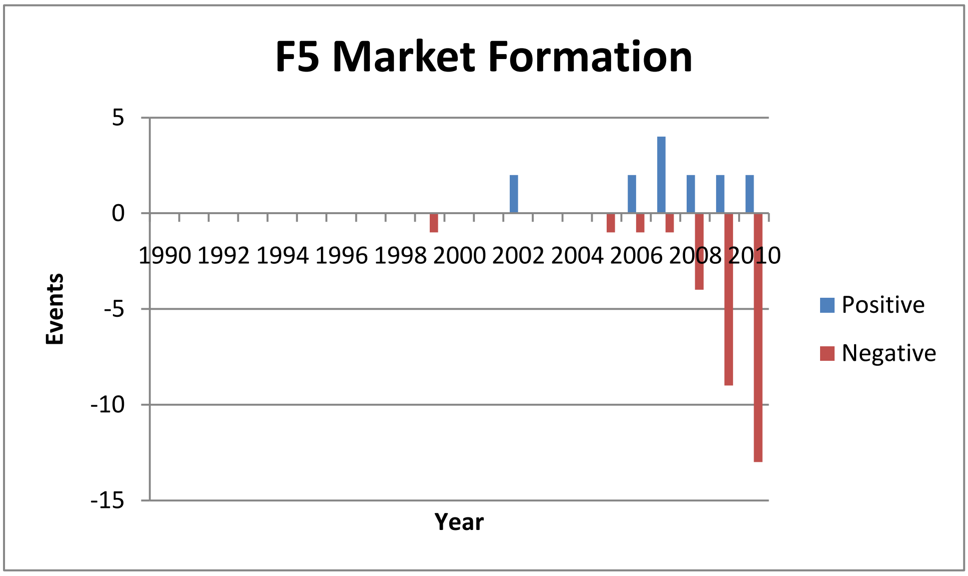



**Figure 26** **Market Formation for Wind Energy**

Meanwhile, the Hopefield project is on hold waiting for regulations (Tendersinfo, 2010d), Mainstream Renewable Energy SA's wind farm project near Jeffrey's Bay is on hold waiting for regulations (Njobeni, 2010) and ACED and Umoya Energy could start as soon as proper regulation on PPAs is in place (Schneider, 2010). The next issue will than probably be the actual grid connection, even when projects are licensed IPPs and have proper PPAs connecting them to the grid is expected to be difficult and take a while (Oberholster and De Jong, 2010).

This period shows a lot of positive activities on all functions, but to a lesser extend for function 5, the market formation (Figure 26). Clearly, a System Building motor is visible; important in this is that the market stimulation program REFIT has enabled more resources (F6). However, the market for wind energy and the market formation strategies as IPP licenses and PPAs are not yet developed well enough to cause direct influence from market formation (F5) on entrepreneurial activity (F1), such as visible in the Market motor (Figure 5). So, the current motor is the System Building motor.

## *Preliminary Conclusions*

Some preliminary conclusions on barriers can be derived for the wind energy case in South Africa as well; see Table 3. At first, the view on wind energy technologies applicable on large scale prevented it from a large uptake in the early electrification programs. Consequently, the wind energy sector for application within South Africa lacked a bit compared to solar energy. It lacked the non-competitive development that was be caused by these programs.

Secondly, the threat of nuclear energy decreased the expected potential for wind energy. The market was less certain and risks seemed to be higher. The conclusion is that this threat slowed down the entrepreneurial activity and thus slowed the development of the wind energy system. The lack of effective lobbying and the lobby of the pro-nuclear groups have a major influence, added to the strength and plausibility of this threat increasing the uncertainty and decreasing the expected potential of wind energy even further. This lack of effective lobby is thus a barrier to the development as well.

Thirdly, Eskom has a conflict of interest. They are an energy producing company, but at the same time they own the grid and are the only supplier and seller of electricity, at least when the national grid is concerned. There incentive to invest in energy technologies that are likely less profitably might be limited. Further, along the same line of argumentation, their incentive to buy electricity from other independent producers, which is more expensive than their own cheap coal-produced electricity, would also make them less profitable. Both ways forward are counterintuitive to Eskom in their current financial dire state. Related to that, Eskom might not be capable to supply and support new independent producers with actual access to their grid, if in larger numbers requested. This will raise a new barrier even if the next barrier is solved.

Fourthly, the difficulties surrounding an IPP license and a PPA are blocking the continuation of many projects. The lack of regulations for IPP and PPA causes uncertainty and sometimes more clearly just blocks the realization of projects.

An independent regulatory organization should solve the problems of lacking regulations and of Eskom's conflicts of interest. However, up to now the conclusion is that the government lacks in regulation and stimulation efforts for getting solar energy systems installed.

The drivers for the TIS of wind energy are also presented in Table 3. The most important insights among those drivers is the role that international and national pressure and guidance has played. The White Papers, REFIT, and knowledge diffusion from abroad were important in the development of the wind energy system in South Africa.

| ***Wind energy system*** | |
|---|---|
| **Barriers** | **Drivers** |
| **Not off-grid/remote applicable** | Large scale application |
| **Lobby for nuclear/ against RETs** | White Papers |
| **Conflict of interest Eskom** | National Guidance |
| **Regulations, IPP, PPA, grid connection.** | REFIT |
| **Low electricity/coal price** | Electricity price increases |
| | Outages |
| | Expectations |

| | |
|---|---|
| | Demonstration/Test projects |
| | International community pressure and support |
| | (International) resources |
| | Diffusion of knowledge from abroad |

**Table 3 Barriers and Drivers to the wind energy system**

## 6.3 Comparison of TIS PV and TIS Wind in South Africa

This study considers two different technological innovation systems in the same country and during the same period. This opens up the possibility to compare the two and see what their similarities and difference are. What causes differences between them and what can be concluded from the differences and similarities?

### *Starting Position and technology characteristics*

The two different systems solar and wind had an equal starting point. Both technologies were considered for supplying electricity in remote areas in the electrification programs after the 1994 elections that were won by the ANC. However, due to the off/on-grid characteristics of the technologies more solar system projects took off and started earlier, it thus had an advantage, see Figure 27. Help came from SELF (Solar Electric Light Fund) and Shell Solar that saw the possibilities in applying solar technology decentralized in household-size projects. These kinds of support organization or companies were lacking for the wind energy technology, probably because small wind projects for households are more difficult to realize and the remote areas were not close to the windy area near the coast. The first incentive for renewable energy technologies thus had characteristics that fitted better to solar energy than to wind energy. That caused a small lead in development for the solar energy system. A major difference thus was the availability of public resources and stimulation programs for the solar energy system. However, these publicly subsidized programs seem to imply more than there actually is in the development system. No real demand except for the aims of the electrification program and the efforts to give everyone access to electricity was available. The people themselves did not have the resources to buy electricity let alone the more expensive solar cells and energy. There was no further system development since the solar cells were often imported from abroad. In fact it lead to a view of solar energy being a small-size off-grid application, what later on became a barrier to be overcome. The other way around, the view on wind energy of being a more large-scale applicable technology was a barrier in the first period, but turned to being an advantage later on, see the last part of Figure 27.

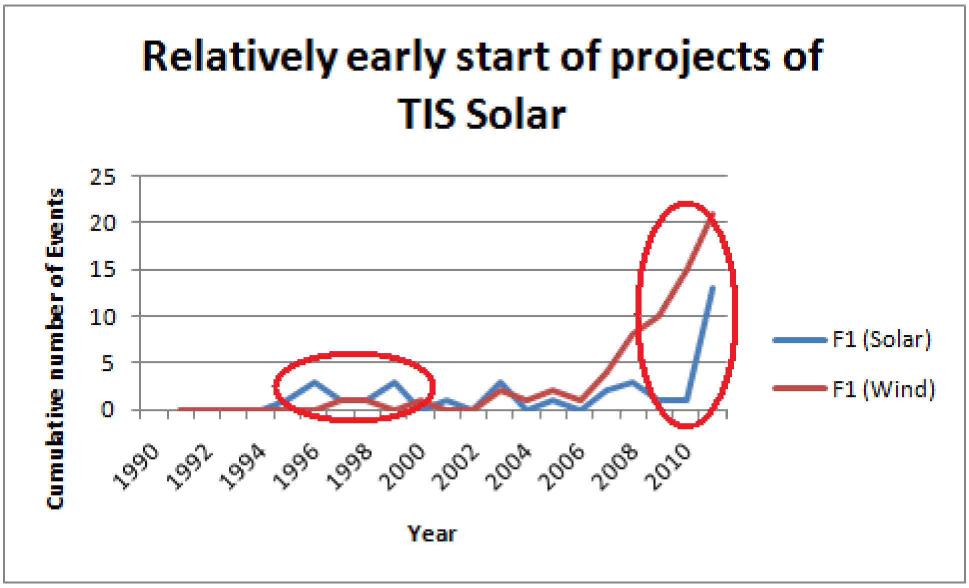



**Figure 27** The relative early start of projects of TIS Solar

In the context of South Africa there is more to say on the characteristics of the technologies themselves. As described in chapter 4, South Africa is strong in knowledge extensive production. Natural resources and mechanical products (motor parts/vehicles) are strong sectors in South Africa. The knowledge for research into PV-cells and CSP is just as for wind energy available within the country. However, producing PV-cells is knowledge intensive and does not fit so well to South Africa as the large steel wind turbines. Steel production is one of the large industries in South Africa and uses coal that is available in abundance in South Africa (CIA, 2011) and the mechanical sector of South Africa fits with the turbines of the windmills. Therefore, there is hope that the production chain can be realized local (Meyer, 2011). The precision requiring production of solar cells can be expected to have more difficulties developing a local production chain. What happens now is that the assembly of pre-manufactured PV-cells into modules takes place in South Africa. The larger part of these imported cells, (95%) is exported again as modules (Meyer, 2011).

### *National vs. International Guidance*

The government of South Africa felt pressure from the international community to come up with mitigation strategies and thus was led to renewable energy technologies (Haw, 2011). This stimulated both technologies in their start-up. Further, international support, by means of finance, knowledge and lobby, strengthened both TISs all in the early stages as well as later on in the development.

Both technologies were spurred by governmental White Papers (1998; 2003) and the guidance and envisioned future that was displayed by these papers. Reactions to these papers were visible in the form of an increase in entrepreneurial activity and knowledge development for both technologies. However, wind energy was the cheaper technology, an important issue especially in South Africa; a developing country used to cheap electricity from coal fired power plants. Further, it was considered more an on-grid applicable technology than the more expensive solar energy. In this context, especially Eskom had some influence; the main electricity producer in South Africa started research into wind energy and started building wind parks, but lacked doing so for solar energy.

Besides the White Papers, the government introduced a market formation regulation, REFIT (DPE, 2009), and thus stimulates entrepreneurs and investors. However, in the first REFIT phase, wind energy was included, but for solar energy only CSP with 6 hours storage was included (Greyling, 2009). This caused an increased lobby for the solar energy technologies and therefore CSP and large-scale PV were included in phase two of REFIT half a year later, what shows that lobby indeed is important in developing a technology. However, the delay for the stimulation of the solar energy technologies caused the wind energy system to catch up with its initial delay and take over the solar energy system (Meyer, 2011).

### *Exploitation vs. Exploration*

The described issue on including different types of solar energy shows another difference between the two innovation systems. For wind energy, the focus for research and development is clear. In fact, it can mainly aim at researching efficiency of try-out wind turbines and developing wind parks (Meyer, 2011). The solar energy system however, has several quite different technologies involved that each may form their own technological innovation system on a more disaggregated level. CSP with or without storage, PV applied at small- or large-scale and concentrated or not are all different options requiring other costs and thus different REFIT tariffs. It also caused difficulties in and lobby for identifying what the total and per technology envisioned installed capacity has to be (Marais, 2010). The preference now seems to go out to CSP (IRP, 2010), for it requires mainly mirrors instead of more expensive PV-cells. Further, it potentially enables storage of heat that can be converted to electricity when there is no solar radiation (night). Solar energy thus requires more technical development research into the technologies instead of measuring output. As a consequence of this uncertainty on what the dominant technology is going to be, the risk for entrepreneurs and investors in the solar energy system is larger and thus is probably the reason for the lower entrepreneurial activity.

Furthermore, the requests for regulations and institutions surrounding the technology are similar in both TISs. Besides the technological research, working out IPP and PPA regulations, as well as technical, financial and timing details of connecting IPPs to the grid are required(Salgado, 2010). Up to now, these are major barriers for both cases to actually having projects build and delivering electricity. There is thus no difference visible regarding starting point of knowledge development and diffusion in the two TISs. Figure 28 only clearly identifies the cumulative advantage of the wind energy system in the last years, identifying a relative advantage for this TIS.

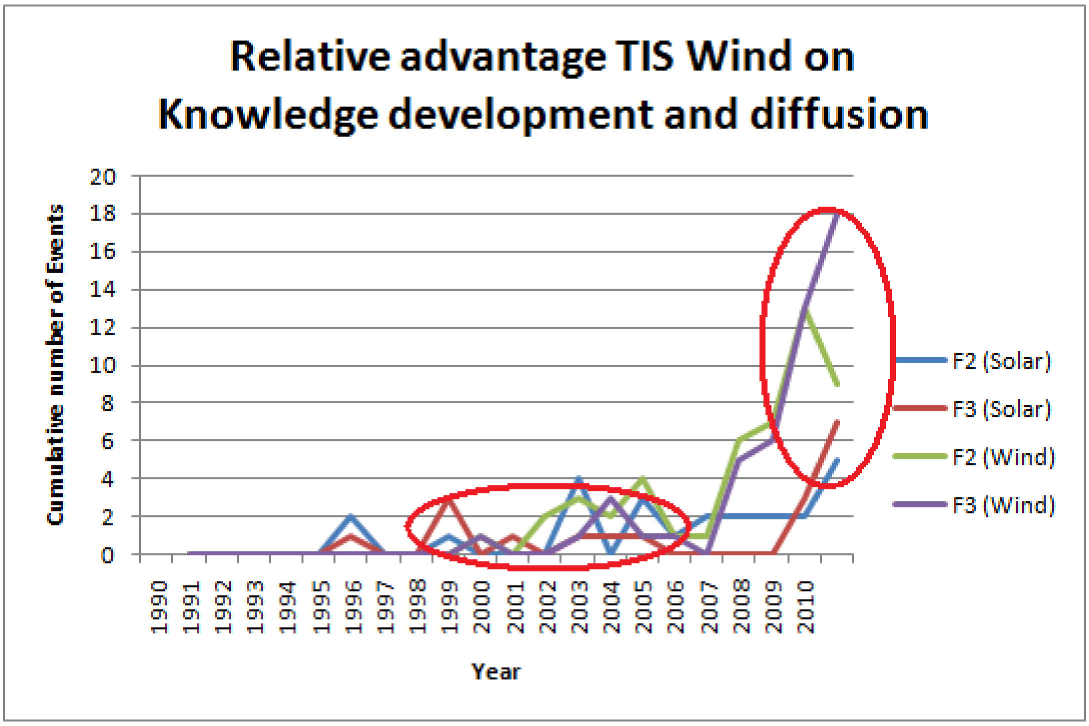



**Figure 28 Relative advantage of TIS Wind on Knowledge development and diffusion**

## *Financial Resources*

The financial resources available for both innovation systems can be divided in resources available in South Africa and resources from abroad. The resources from within South Africa are spent in both energy systems on research within the universities and governmental organization that are actors in the systems. Further, Eskom invests money in the renewable energy technologies. Starting with wind turbine tests and planning for wind parks before 2003, Eskom preferred the wind energy systems.

After the discussed White Paper (2003), Eskom also started investing in research and development of plans for solar energy. In-country investments by the most important energy producer of South Africa and by Lereko Energy Consortium clearly started earlier with investment in the wind energy system giving it an advantage and lead over the solar energy system.

Financial resources from abroad mainly come from large industrial players in the field of renewable energy technologies (Suzlon, Vestas), private investment funds (Investec) or from the development funds (GEF and EIB) and aid from other countries, Denmark (Africa News, 2002) and France (Gulf Daily News, 2008).This is similar for both innovation systems. Besides the electrification programs that were subsidized by foreign development aid, again the first period of sponsoring of a commercial energy production from RETs was for a wind park. The Darling Wind Farm started developing in 1998 with practical help and funds provided by the Danish government. Later on around 2005-2006 the first private investments were noticed for wind energy (Figure 29) by Suzlon, Thermo-Rec and Enercon India, a 100 percent subsidiary of EIL South Africa Power Development (Pty) Ltd. The first serious investment from the private sector for solar energy occurred after the REFIT introduction (last years of Figure 29). Companies like Yingli green, Energy Investments Inc., Concentrix and Tenesol invested only after this stimulating measure was implemented. However, the REFIT also increased the resources available for the wind energy system by investments of Setsolar (Hartley, 2008), Evolution One Fund (Daily News, 2008), a French agency loan (Tendersinfo, 2009b) and the GEEREF (Tendersinfo, 2010a).

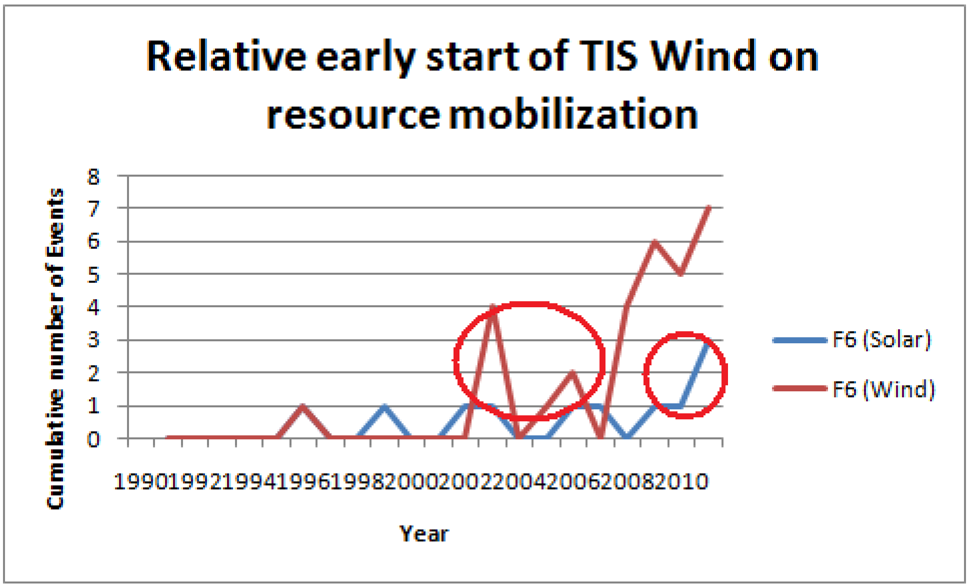



Figure 29 **Relatively early start of TIS Wind on resource mobilization**

The main difference between the two systems is thus that REFIT was really required for the solar energy system to get investments, whereas guidance by the government already initiated investments for the wind energy system.

### *Lobby for Renewable Energy Technologies*

In this respect, the two systems seem to have similarities or to overlap. For the lobby was mainly about general issues of getting RETs on the agenda and focused on getting a REFIT program. Instead of technology specific issues the lobby often collectively addressed wind and solar energy together.

The same is the case for addressing the threat of nuclear energy. Nuclear energy diminishes the potential for the renewable energy technologies in general and proponents often lobby against RETs in general lowering their legitimacy (Haw, 2011). This caused the dip for both technologies as can be seen in Figure 30 Starting point and dip (2007) in Lobby for both TISs. Again lobbying for both technologies together is thus well possible for there is a common goal. However, since the reserved amount of capacity for wind and for solar energy is being proposed in the Integrated Resource Plan (IRP, 2011), there might be started two separate lobbies for gaining a larger share of the envisioned installed renewable capacity.

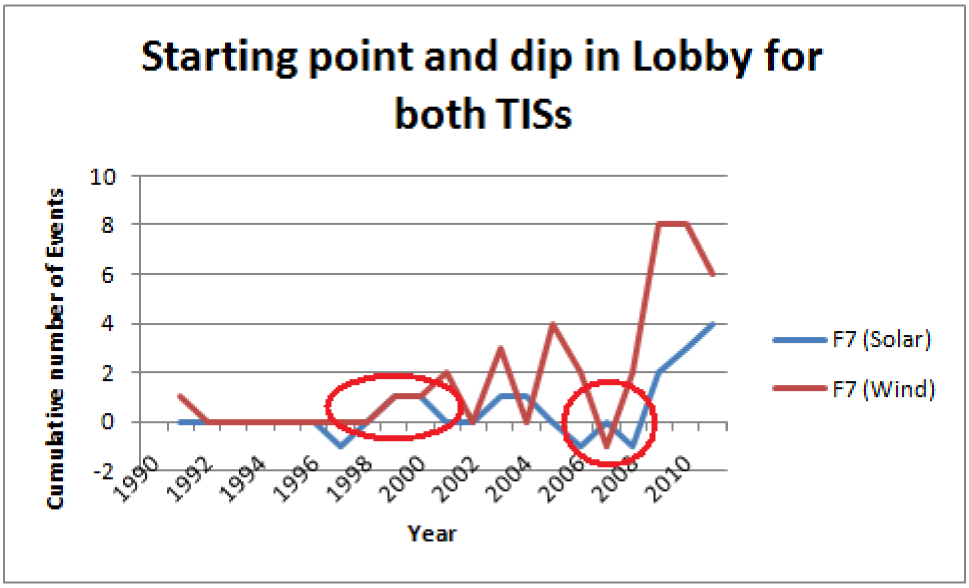



**Figure 30 Starting point and dip (2007) in Lobby for both TISs**

## *Preliminary Conclusions*

The main similarities are the usefulness of governmental and international guidance and support by means of knowledge diffusion and financial support, the White Papers, the REFIT, the lobby and the required knowledge development on side issues. The main differences are the technical characteristics of both technologies, and how that influenced the perspective of Eskom and other investors. These started investing first in wind energy and only after the White Paper on Renewable Energy Technologies (DME, 2003) solar energy was invested in. Further main differences are the starting date of the REFIT, solar was only incorporated half a year later due to intense lobbying, and the envisioned use of the technologies in the IRP (2011). The wind energy systems now is further developed, due to more extended funding, support and envisioned installed capacity.

# 7. Theoretical reflection of application of TIS in a developing country context

Having assessed the development of solar and wind energy in South Africa while using the TIS approach supported by an event history analysis and the theory on ‘motors of change’ gives way to reconsidering the TIS approach and the ‘motors of change’ since it is used in a developing country context, or better said; a non-developed country context.

## 7.1 Functions of the TIS in a Developing Country context

The previous chapters described the different functions of the TIS in a developing country context. Both cases provide insight in the use of TIS in South Africa and thereby came up with characteristics and processes that might come forward in a developing country context.

With respect to entrepreneurial activity in developing country context, it is important to consider that RETs are in the electricity sector. In many of these countries, a single energy company controls this sector (SAPP, 2008). The entrepreneurial function thus might encounter barriers regarding the access to the market for independent producers of energy. However, many of these countries do see the need to privatize the energy market (Zhang et al, 2005), which gives some space to entrepreneurs willing to work in developing countries. Further, a large part, roughly 40% of the population in developing countries, lives without access to electricity and further supply will become a problem since the demand for electricity in these countries is expected to increase faster than the production and grid expansion (HTC, n/a). However, the lack of access to electricity severely limits socio-economic development (HTC, n/a) and thus electricity reliability, access and production is a governmental responsibility. This responsibility is recognized (Zhang et al, 2005) together with the rising awareness of climate change and the need to produce energy sustainably (Haw, 2011). However, as the case of South Africa shows as well, due to a lack of financial resources in these developing countries (UNEP, 2011a), it will be difficult to replace and expand the current electricity grid and production, let alone by means of the slightly more expensive RETs. Entrepreneurs are expected to fill this gap and thus there are major opportunities for them. To do so while using renewable technologies requires extra lobby for government permission and support, since the government is often the owner of the poor performing incumbent electricity firms (Zhang et al, 2005) and, as can be seen in the cases, does not easily license IPPs. Further, the government will probably represent the only demand for renewable energy if they have mitigation goals at least; renewable energy demand by inhabitants of developing countries can be assumed low if they are grid connected. So entrepreneurial activity is desired and possible, but getting grid-connected as an entrepreneur is difficult in a developing country context and thus the entrepreneurial activity in developing countries can be expected to be fairly low.

With regard to knowledge development and diffusion, there are more insights for what is required in developing countries. As described in the introduction, the UNFCCC, just as well as the IEA and OECD, considers technology transfer as a means to achieve the development of RETs in developing countries (IEA/OECD, 2001). This points at a lack of knowledge development and diffusion in and towards developing countries and is an incentive to take the international context of knowledge into account in the TIS framework. For South Africa experts stated that the level of knowledge development was quite high (Meyer, 2011; Marquard, 2011), this can be due to the dual character of South Africa (US Department of States, 2011), but in general knowledge development in these countries can be expected to be low (Van Alphen, 2008). Nonetheless, even South Africa has used knowledge from abroad; the technology is mainly developed in other countries, but they participated in some important development and knowledge diffusion programs (ICTDS, 2009) with the US (Energy Conservation News, 1995; NPR, 1994; Klar, 1994; Agence France Presse, 1995; Dayton Daily News, 1997), Denmark (Carnie, 2009) and France (Tendersinfo, 2009b), to gain capacity to deal with those new technologies. This importance of knowledge assimilation is confirmed by Ockwell et al. (2008). At the same time however, the cases of wind and solar energy in South Africa showed that further knowledge development and diffusion within the country is required and has a positive influence on the development of the innovation system. In this respect, the functions knowledge development and knowledge diffusion are important in developing countries and can be analyzed using the TIS framework. However, the diffusion of knowledge by means of international knowledge and technology transfer for creation of adaptive capacity and starting the cycle should be emphasized. These can well be used as specific indicators to allocate events to the functions 2 and 3. Furthermore, assuming the developing countries have a time lag compared to developed countries, there is no need to start reinventing the technology. The technology can be assumed to be out of the first laboratory and R&D phase, this implies that knowledge development and diffusion should be even more focused on side issues like regulations and institution, instead of on technical development (Haw, 2011). The development of knowledge and diffusion of knowledge creates a larger adaptive capacity within a country and that is required for more successful technology transfer, it decreases the cognitive distance between what is known and what is to be adapted to (Nooteboom, 2000). The functions knowledge development and knowledge diffusion from the TIS are applicable and important to analyze in a developing country context.

The fourth function is 'Guidance of the Search' and it plays according to the cases a rather important role in the innovation system in developing countries. As already indicated in the analysis and in the description of functions two and three, guidance of the search seems to be the start of the cycle instead of the invention of a new technology followed by science and technology push as described by Suurs (2008). The technology is as described not new in general, but new to the country. The uptake of the technology in the national system will thus be dependent on willingness to use it. In the cases described guidance was mainly dependent on the governments' view and expectations and their willingness to live up to mitigation actions requested and pressured for by international climate change conventions (UNEP, 2011b). The international context plays an important role. Guidance by international organizations like the GEF, UNEP, UNDP, UNIDO, the World Bank, FAO and UNICEF enables and supports the developing countries with capacity building, financial assistance and technology transfer (Van Alphen, 2008; UNEP, 2011a). As Van Alphen (2008) shows developing country projects are highly dependent on international support programs. He however points out that these programs should have particular attention for entrepreneurial activity to assure the follow-up on projects. Guidance of the Search is thus an important function in the technological innovation system in developing countries, both international and national guidance require attention and analyzing and tracking them enables to capture better the process of development of TISs in developing countries.

The fifth function is market formation and this seemed to be a real bottleneck in the cases described. South Africa encounters difficulties due to the availability of cheap coal-produced energy, one single government owned company that produced the energy, and the low demand for renewable energy (Haw, 2011; Marquard, 2011). Other developing countries are likely to encounter difficulties as well if they have an energy monopoly by a single company (SAPP, 2008), at least they have had difficulties implementing RETs (Stapleton, 2008). Stapleton (2008) points out the importance of a regulatory framework and the importance for the industry to work closely with government and international donors to develop a market and let the renewable energy technology develop in developing countries. The mentioning of 'industry' implicitly means a market with competitors when the market is created; it also implies that if there is a single energy company it would have to share the market with competitors. However, there is more to say on market formation. As inhabitants of developing countries by definition do not have much money to buy more expensive renewable energy, there is also no demand-side on the market for these types of energy, as can be seen in South Africa. This can be solved by leveling the electricity price of different electricity sources. Paying a feed-in tariff to support power producers with their renewable energy technology business and selling it at normal prices on the grid can solve the market demand problem in developing countries (Moner-Girona, 2009). South Africa has a similar system called REFIT, which could probably work well if they can solve the difficulties with creating an authorized organization that can buy all energy from all IPPs, including the embedded energy company, level the price and wholesale it to the market. This shows that market formation plays a useful and applicable function from a researching developing countries perspective. Analyzing it and following the development might give good insights in the barriers or drivers in the specific developing country. Solving the price issues by subsidies is however in the case of electricity production not enough. There should be regulatory and institutional framework to care after the transmission, licenses and purchase agreements (Stapleton, 2008). Exactly that, what is often considered as lacking in developing countries (Van Alphen, 2008; Worrell et al, 2009). Whereas much international focus is at technology transfer and knowledge or adaptive capacity creation around the technology, this research shows a gap in transfer of market formation regulations, institutions and frameworks that should be addressed at an international level. Helping developing countries on how to create a protected market will enable better implementation of RETs, examples might be support for and diffusion of knowledge concerning IPPs, PPAs, grid connections and control of intermittent supply sources.

Mobilization of resources in developing countries plays an important, but slightly different role. According to theory, it covers the financial and human capital flows into the system (Hekkert et al, 2007; Negro, 2007). As described for knowledge development and diffusion, and guidance there is an international component in these functions. Financial resources and knowledge can come from abroad as well as from within the country as the cases in South Africa show (Schneider, 2008; Lewis, 2009; Schneider, 2009d; Tendersinfo, 2009b; Africa News, 2002). This is similar to developed countries cases (Negro, 2007; Suurs, 2009) and thus a relatively small difference to TIS in developed countries. However, the availability of resource available by the government or by in-country investors might be limited in developing countries what causes a relative focus on foreign investor groups and companies as can be seen in the wind and solar cases in South Africa. Further, the cases show that, besides private investors, international development funds can play an important role in mobilizing resources for and in developing countries. To the normally difficult to track flows of resources (Hekkert et al., 2007) another element is added. However, these development funds are often inclined to publish their investments as the newspaper articles used in the South African cases show; this makes these flows easier to identify. From the developing country perspective mobilization of resources, but mainly international mobilization of resources is important, and since no large differences are found that could disturb the analysis or tracking of these resources themselves the function mobilization of resources can well be used in a developing country context.

Legitimating the technologies within the TIS is important in developing countries. As described, guidance was mainly dependent on the government view and expectations and their willingness to live up to mitigation actions requested by international climate change conventions. Lobby of international players or organizations like Greenpeace (Africa News, 14-8-2002; SAPA, 2002a; Agence France Presse, 2002) and Earth life (Petroleum Economist, 1998; SAPA, 1999; Africa News, 2000) play in this context an important role. They strengthened the will to live up to international conventions on climate change issues in the cases described, despite the importance of cheap energy to the development and economic growth of the country. International lobby thus adds to the pressure on the national governments. As described under entrepreneurial activity and guidance of the search, there is no market yet in many of the developing countries. The theoretical described formation of advocacy coalition of actors (Negro, 2007) might be difficult. In the early stages of the TIS within these countries, the main lobby can be expected to come from abroad. This lobby can be expected to support a wide range of renewable energy technologies and might be best described as selectors (Suurs, 2009; Garud and Ahlstrom, 1997). Only after settling of several actors e.g. entrepreneurs and investors, the formation of in-country and technology specific coalitions for lobbying can be expected and these are best described as enactors (Suurs, 2009; Garud and Ahlstrom, 1997). The function creation of legitimacy played an important role in making room for renewable energy technologies in South Africa. It likely will have a similar role in other developing countries, but when analyzing this function of the TIS, one needs to take in account the different types of lobby, international and in-country.

## 7.2 Motors of Change

As identified in the narratives of the case studies in South Africa the technology likely already evolved to more mature levels in developed countries. However, the system did not emerge out of nothing; there must have been some incentives. As noted in the narratives as well as in the description of TIS in developing countries, guidance of the search plays a particular and important role in developing countries.

As can be seen in the South African cases the international pressure for low emission technologies in the light of climate change, the national pressure (F4) for technologies that can replace the current energy system and expand electricity access to all inhabitants, and the pressure to live up to international required emission abatement strongly guided the search in the energy systems. This guidance (F4), mainly the positive expectations, caused availability of national and international resources (F6) for spreading RETs in remote areas (F1) and thereby diffusing knowledge towards the developing country South Africa (F3). Both lead to increased positive expectations and thus positively influence renewed guidance (F4). The cases thus show two small cycles that occur; one is F4 => F6 => F1 => F4 as the started projects are part of the cycle, and the other one goes via knowledge diffusion from abroad and thus becomes F4 => F6 => F3 => F4. Though, for the first cycle it should be noted that these first entrepreneurial activities could be projects started by NGOs or governmental institutes. In that context the relation between F1 and F3 is clearly visible, the test and demonstration projects also spread knowledge.

In the South African cases and for developing countries described above, the international lobby seems to influence the national guidance of the search and thus F7 positively influences the in-country guidance that is required to make resources available and start projects. This relation, 'international' F7 => F4 'in-country', is in fact the starting point of the development of the technology in the South African case, but can be expected to be true for other developing countries as well. South Africa had an extra in-country incentive in the form of the stated electrification of all people. This focus on energy access and reliability is however nowadays propagated as well at international level, by the ESMAP, the UNDP, the UN Millennium Project, and the World Bank (Modi et al., 2005)(UN, 2002).

To finish this starting motor of sustainable innovation as it was present in South Africa and might occur in other developing countries, the knowledge development function is added separately from knowledge diffusion and it requires some special attention. Whereas in South Africa the knowledge development at universities and institutes is considered to be quite good (Marquard, 2011; Meyer, 2011) this may not be the case for other developing countries (Van Alphen, 2008). Due to this possible context difference caution is needed for drawing conclusions from these South African cases. Instead of developing knowledge on the technology itself, it is more important to develop knowledge about the innovation system that supports the technology (Stapleton, 2008). Some knowledge was gained early on in South Africa, e.g. the importance of White Papers and providing envisioned futures (1998, 2003). However, though South Africa is considered having a good knowledge development system (Marquard, 2011), they lacked development and implementation of knowledge on institutions and regulations that can support a market. The 'international' knowledge diffusion positively influences the required building up of adaptive capacity that can be seen from an in-country perspective as knowledge development. This developed knowledge is likely to positively influence guidance of the search as it did in the South African cases as far as this barrier was overcome. The positive relation thus becomes F3 => F2 => F4.

Altogether, the starting cycle for developing countries is shown in Figure 31. It shows large similarities with the STP-motor, but has clearly a different focus; it is lobby and guidance driven. The differences are shown in Figure 31 by yellow lines. F7, lobby from an international perspective is added to the starting motor, and diffusion and development of knowledge are separated, due to the specific role the international diffusion of knowledge plays. From here on the development of the technology will likely follow the other 'motors of change', since all prerequisites for transition towards the entrepreneurial motor are fulfilled. However, the success of further development cycles of the technologies could not be properly tested in South Africa since it is not yet a successful case that can be used to analyze all 'motors of change'. Regarding that, more research is required, but it might be difficult to identify developing countries with an extensive and far developed TIS for renewable energy technologies. However, the international component remains important in these more extended 'motors of sustainable innovation'. Market formation is dependent on diffused knowledge and on raised adaptive capacity to create regulations and institutions. Further, the in-country lobby will take a more important role compared to the international pressure as the system develops. This also was indentified in the case studies.

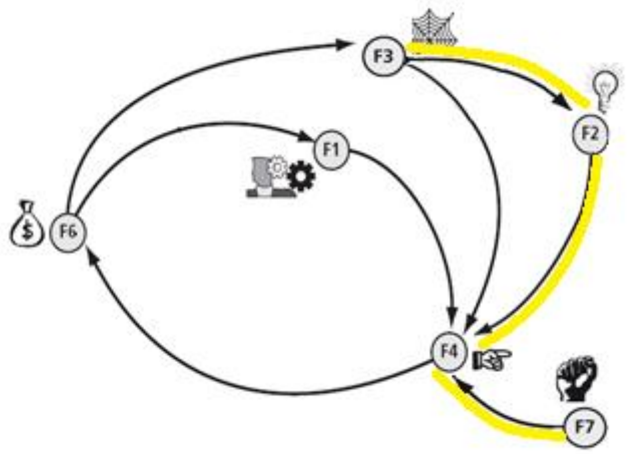



**Figure 31** **The Guidance-Lobby motor**

## *Concluding*

The TIS approach can be used in a developing country context as long as this developing background is acknowledged and taken into account. The international component has a larger influence on the in-country TIS compared to developed country systems. Legitimizing the technology and guiding the developing country innovation system starts at an international level. Resources are at the start also provided by international investment funds or foreign governments. The diffusion of knowledge both from abroad into the country and within the country plays an important role in the development. Whereas diffusion is closely linked to development of knowledge in developed countries (Suurs, 2009; Bergek et al., 2008) in this developing country context it clearly has a separate, but important function. Further, the NGOs or government-supported projects add to both entrepreneurial activity and knowledge diffusion in the start-up phase and overcome the barrier of a missing market. There are no large changes to be made to the TIS theory before applying it to developing countries. However, the international flow of knowledge and the creation of adaptive capacity should be included in the knowledge development function as indicators. Further it is important to focus on international ties and events for the functions in order not to miss essential processes. The TIS can thus be used to analyze the development of RETs in developing countries. Regarding motors of sustainable innovation there is a large alteration in the form of the new starting motor of sustainable innovation focusing on international lobby and national guidance. However, there are no other barriers that prevent the use of motors in a developing country context.

Further research, incorporating case studies in developing countries, is required. At first, to increase the body of knowledge available on the use of TIS in a developing country context and secondly, to further identify the motors of sustainable innovation that are present in such a context.

## 8. Recommendations for removing barriers

Table 2 and Table 3 showed an overview on the barriers and drivers in both renewable energy cases. Many points are similar (Table 4), but a few differ as well (Table 5). Therefore, an integrated approach to mitigation strategies should be feasible due to the similarities and prevents different recommendations on the technologies to cancel each other out.

| *Overlapping Barriers* | *Overlapping Drivers* |
|---|---|
| **Lobby for nuclear energy/against RETs** | the White Papers |
| **Eskom finances and conflict of interest** | REFIT |
| **Regulations and institutions, IPP and PPA** | Outages |
| **Low electricity/coal price, market availability** | International community pressure and support. |
| | International resources |

Table 4 **Overlapping Barriers and Drivers**

| *Non-overlapping Drivers* | *Non-overlapping Barriers* |
|---|---|
| **Large scale application (wind)** | Not off-grid applicability (wind *past*) |
| **Expectations (wind)** | Off grid application (Solar) |
| **Demonstration and test projects (wind)** | NIMBY (Wind) |
| **Diffusion of resources from abroad** | Lack of learning from successful projects (Solar) |
| **Off-grid application (Solar *past*)** | |

Table 5 **Non-overlapping Drivers and Barriers**

Most important in accelerating the mitigation strategies and causing a succession of motors is the need to overcome the overlapping barriers. The pro-nuclear lobby seems to diminish the legitimacy of renewable energy technologies in general. Not having this 'competitive' technology would probably leave a bigger market share available for the renewable energy technologies, but they might not be up to cover the total gap. More important is to show their joint application. The energy gap needs to be filled, to diminish the emissions of greenhouse gasses, both nuclear and renewable energy technologies can add. The nuclear technology might even serve as the base load required to secure safe and reliable energy supply when renewable energy technologies supply larger shares of the total energy production. At least take care that the nuclear energy lobby does not become also an anti-RETs lobby. Present the two technologies side by side and communicate clearly to both sides that support and development for one technology does not decrease the support and development that the other technology receives.

The position of Eskom raised another barrier to the development of both RETs. Eskom has produced energy really cheap, since the available coal was cheap and their plants depreciated, and is owner of the grid. They need to invest in installed capacity to replace the current power plants and to add extra capacity to be able to handle the increase in use of electricity. However, due to the low energy prices within the country (Marquard, 2011; Meyer, 2011; Haw, 2011), what is still controlled by the government, there are not enough resources to invest much in the energy sector. They even requested an increase of energy prices between 18-20%. The energy produced in the REFIT program is thus unlikely to be bought by them, because they are not obliged to do so and it will lower their profitability even more. Further, they cannot easily free capacities or are not very willing to support new grid connection. The solution would be to separate the grid-division from Eskom and to create an independent system operator. Grid connections to new IPPs, and the licensing of new IPPs, are then taken care of by this organization, which does not produce energy itself and thus is not a competitor to the IPPs; Eskom becomes an IPP that delivers electricity to the grid as well. Zhang et al. (2005) confirms that this creates a higher energy generation and delivers higher capacity. This action will strengthen the position and activity of entrepreneurs and will partly overcome the barrier on Market formation that holds the transition towards the system building motor and market motor.

This solution can be further extended to also cover the barriers on Power Purchase Agreements. Both cases showed it was difficult for the IPPs to get a buyer to supply to besides a license to produce. Eskom as described had a low incentive and supplying independently of the grid to buyers is difficult. The independent system operator should thus also take care of the market. This Independent System and Market Operator (ISMO) should buy the electricity from all IPPs paying whatever the NERSA or the REFIT prescribes. Subsequently, they can wholesale this energy by selling all energy at leveled prices, which allows NERSA and the government still to control the energy price. This also circumvents the low availability of demand for more expensive renewable energy technologies. However, market demand can be expected to change in the future. The ISMO can make different premium packages of energy, e.g. with higher shares of green or nuclear energy. This enables users to freely choose their required type of energy, although the market is small for now. It will enable companies to show Corporate Social Responsibility, what can increase their popularity and competitive advantage. Further, an ISMO can better focus on the grid expansion and development towards a smart-grid in the future, than Eskom, which also has to produce energy and invest in more installed capacity. Some first ideas on the ISMO are already mentioned in South Africa, but no decisions have been made yet. However, this paper shows that the earlier this ISMO is created the better it is for the development of renewable energy technologies, since some projects are really blocked by lack of PPAs, IPP licenses or grid connections. Again this recommendation aims at solving the difficulties surrounding the function of market formation and tries to trigger succession to the next motor of sustainable innovation in both cases.

The technology specific drivers provide room for learning of successes of the technology and can come up with recommendations for the development and acceleration of the other technology. It has been noticed that wind energy improved a bit more, because it was regarded an on-grid and larger scale applicable technology. However, its potential is often still assumed small. Strengthening the view that wind turbines can supply in large amounts to the produced energy is important. Further, for nuclear energy the modular characteristic of the new PBMR is considered a huge advantage, this feature of wind energy should get more attention as well. Together this will raise the expectations, which is another important feature for the development of RETs in South Africa. A similar strategy should thus be applied to solar energy; it is modular and large scale applicable as well, thereby immediately overcoming the barrier of view on solar energy of being only a small-scale and off-grid technology. However, that is also an advantage of solar energy technology and should be used to promote the use of PV-cells in residential areas.

The realized projects, which can be seen as test and demonstration projects, in the wind energy case influenced to opinion of the government, entrepreneurs and investors. Expectations raised and confidence that such projects can work and can be implemented in South Africa also increased. This should be stimulated further by setting up other examples of wind energy projects; this will keep knowledge development, the source of positive expectations, running. At the same time, it can be noticed that these typical projects are missing in the solar energy system. For the same reasons, but even more important in this case, there is a need for test and demonstration projects. Setting-up such a project, in order to be able to show how the implementation of these projects works and to learn from these test-projects will increase the expectations and will likely overcome the 'lack of learning from successful projects' barrier in the solar energy system. It will trigger and enable the development of the Entrepreneurial motor and later on add to the transition to the system building motor.

Regarding the overlapping drivers of the TISs their importance and action to undertake is clear. However, the 'outages' have been a path dependent event, and though it was a driver it should not be stimulated. The same applies to the influence of off-grid (solar)/on-grid (wind) characteristics of the technologies in the past, these cannot be changed. However, for the other drivers, there presence should be stimulated and supported. One extra recommendation regarding the drivers can however be found concerning the REFIT. Since technologies and their costs change over the years, it is important to keep the tariffs up-to-date. To pursue on the old tariffs will cost a lot of money whereas lower tariffs can do the job as well, as long as they are high enough. Monitoring the cost-curves of the technologies would be useful to solve these issues. However, due to the relatively high early-on investment costs of renewable energy technologies, entrepreneurs and investors should be sure what the REFIT tariff for their project is in the coming years. The solution is to take the tariff of the year of investment as fixed to the project, thereby reducing uncertainty. This also is an incentive to start projects faster, since the returns will be higher if it can be started before the tariff changes. For both cases this recommendation will influence the direct link between market formation (F5) and entrepreneurial activity (F1) and will likely raise the available resources (F6). The identified barrier of market formation can be overcome and likely the successive system building motor and later on the market motor will occur.

The recommendations described above should enable the development and realization of solar and wind energy in South Africa. They enable the transition to successive motors of sustainable innovation. Thereby, it should enable South Africa to produce more renewable energy and thus to accelerate mitigation actions in order to achieve the goals aimed for in their White Papers.

## 9. Discussion

As noted in the introduction and theoretical framework, the TIS approach has mainly been used for a developed country context. Van Alphen (2008) attempted to use the TIS approach to analyze a technology in a developing country, in the context of Small Island Developing States (SIDS) like the Maldives, while changing some of the functions (F2 and F4). The current debate on technology transfer and frameworks to develop technologies within the developing countries justifies further analysis of the applicability of TISs in the developing country context. Since no prior research is available, besides Van Alphen (2008), the original set of functions (Hekkert et al., 2007) with integrated relevant lessons of Van Alphen (2008) is applied to identify the applicability of the TIS approach in a developing country context. For the developing country South Africa, the TIS approach delivered useful insights and enabled to formulate recommendations for the acceleration of mitigation strategies. There are no clear indications found that avert the use of TIS in this context. The lack of strict geographical boundaries of a TIS proved essential for analyzing innovation systems in this specific context. The outcomes regarding the TIS approach can be generalized and likely applied to other developing countries.

This new application is as well the case for the use of the theory on 'Motors of sustainable innovation' (Suurs, 2009). This theory is used to check the case study results produced with the TIS approach. The similarities that occurred for several interactions between functions and similarities in patterns of change between the results and theory both strengthened the results and justified the theory of TIS and of motors of sustainable innovation. Differences surrounded mainly the start of the development of the TIS; science and technology are not likely to push the development since the technology, by the time it will be used in developing countries, is not in laboratories and early R&D programs anymore. However, these difficulties are likely due to the knowledge lag of developing countries and the rest of the results justify the assumption of motors of sustainable innovation. The insights from the theory of motors of sustainable innovation are applicable in a developing country context. A new 'Guidance-Lobby motor' is thus proposed as it is identified in the two cases and based on insight from theory (Suurs, 2009). This new 'Guidance-Lobby motor' and the proposed drivers of it, international lobby and national guidance, requires further research to confirm the results.

Regarding the used methodology in analyzing the TIS, there are some remarks. Due to the point of view that especially solar energy can be a decentralized and remote area technology, identifying events in developing countries newspapers can be more difficult. Smaller projects often get less or less detailed attention in the media, and local newspapers in developing countries are difficult to get access to, might they exist. In this research, indeed the events available for solar energy are much lower in number than those present in the wind energy case. However, quantity does not enable better research or analysis. Not the accumulation of events per function is important per se, though it can add to insights in the system, but their effect and influence on other functions. However, both cases incorporate enough events to do a proper analysis for at least the latter periods. Besides, having interviews with in-country experts, added to the reliability of the analysis. Here, it might be useful to note that being at location will likely increase access to actors in the system and thereby enable more personal communication. However, the amount of interviews for this research has not limited the results and has increased the reliability and generalizibility.

To continue on that, the research methodology is partly based on individual identification and allocation of events. However, the interviews added to the analysis of the narratives and assured that no (important) events were missing. An interview protocol (Appendix C – In-country Interview) was used to assure that all topics were covered, thereby strongly increasing the reliability of the research without detailed crosschecking of the allocation of events to indicators. Following the proposed methodology, applying the same operationalization for the functions, searching for events and allocating them to the different event categories, would enable the research to come up with similar results. On top, the analysis is based on the complete narrative combined with the graphical representations of the development of the functions. Being assured that no large and important events are missed the outcome of a similar research is not likely to differ if a new small event is identified. Due to the clear framework, this research can be compared to other research of TISs in a developing country context.

## 10. Conclusion

The main question in this research was 'How can mitigation strategies of South Africa be accelerated?'. The research concludes that, with abidance of the developing country context, there are several measures that can accelerate the mitigation strategies in South Africa. These strategies were partly based on the use of renewable energy technologies that produce electricity sustainable and thereby increase the abatement of greenhouse gas. The recommendations for acceleration of solar and wind energy technologies are proposed in chapter 8.

The most important recommendations is the creation of an Independent System and Market Operator (ISMO), an authorized organization that will manage the national grid, license Independent Power Producers (IPPs), buy in energy via Power Purchase Agreements (PPAs) and wholesale all the energy to the market, will structure the energy system. Besides that, there is a need for stimulating and supporting knowledge diffusion and development in the international context with bilateral agreements with foreign countries and organizations and via national learning of realized test and demonstration projects. Further, the REFIT is already in place as an important driver, but needs to create more stability and certainty for participating projects and needs to stimulate implementation of new projects. Therefore, the tariffs need an update in line with the cost-curve decline every year.

These measures will enable the development of the TISs of solar and wind energy in South Africa and thereby accelerate the mitigation strategies. It increases the chances of realizing 10000GWh renewable produced energy in 2013.

With respect to the underlying question of this research, the conclusion is that there are no indications of difficulties that might hamper the use of the TIS approach in a developing country context. The theory is able to analyze technological innovation system in such a context and is able to identify drivers and barriers to the development of the system with help from the 'motors of sustainable innovation' theory. These drivers and barriers can be used to provide recommendations in order to accelerate the implementation of renewable energy technologies. The TIS theory is thus applicable in developing countries.

This research further identifies that the start of the technological innovation systems likely comes from international pressure for mitigation activities and national guidance of the search within the country. These important outcomes led to the proposed 'Guidance-Lobby Motor' representing the identified and theoretically supported cycles that lead to the start-up of at least renewable energy technologies in developing countries.

If South Africa is able to implement these recommendations and to overcome the barrier of market formation, than the now waiting entrepreneurs are able to realize a large part of the aimed for 10000GWh of renewable produced energy.

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## *Personal Communication - Interviews*

Marquard, A.; Senior Researcher in the Energy, Environment and Climate Change research group, University of Cape Town. June 2011.

Meyer, I.; Research Engineer at the Centre for Renewable and Sustainable Energy Studies, Department of Mechanical and Mechatronic Engineering, Stellenbosch University, 15th of July 2011.

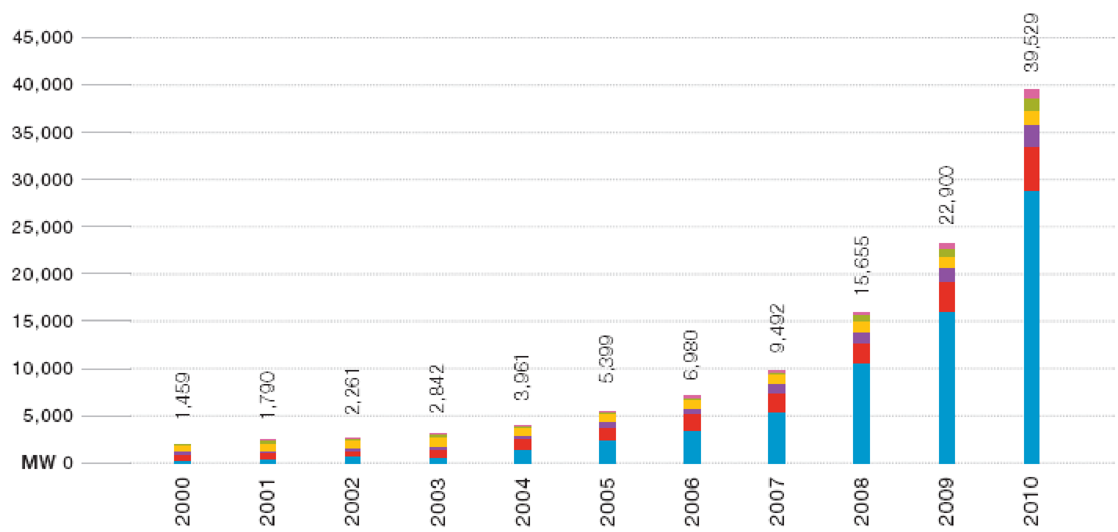
Haw, C.; Chairman SAPVIA and Core member in the team from Aurora Power Solutions (Pty) Ltd, 10th of August 2011.

## Appendix A - Solar Energy

### -Trends in Solar energy capacity-

Around 1960 NASA started to apply PV in their spaceships and on satellites (Knier, 2002) for PV is able to produce electricity in airless space and in non-gravity environments in contradiction to other technologies. CST was first commercially applied in the California Mojave desert in the late 1980's. However, long time no other projects were started. The next projects started in Spain and the USA during 2007 (Pitz-Paal, 2008).

Due to the global quest for renewable energy, new incentive schemes induce the development of new solar energy projects. This lead to an increasing production capacity of solar energy, mainly PV. It came from nearly 1,5GW installed capacity in 2000 and went up to 39,5GW installed capacity in 2010, producing approximately 50TWh electricity; see Figure 32 (EPIA, 2011a). This is a growth rate of approximately 40% per year. Of this 39,5GW installed capacity, slightly more than 29GW, that is 74%, is housed in the EU. South Africa is shared under 'Rest of the world', which together have 1,8GW installed capacity.

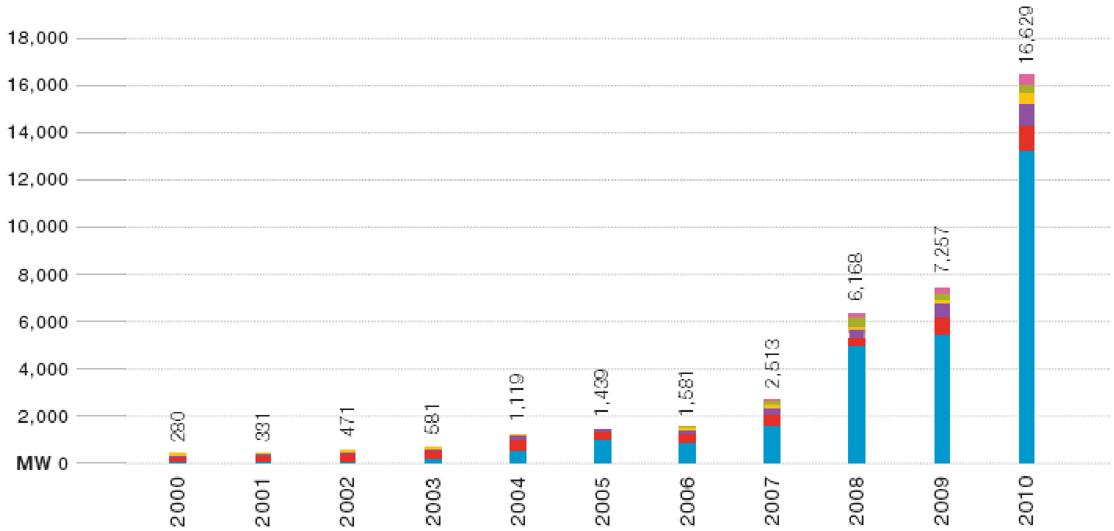



| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| China | 19 | 30 | 45 | 55 | 64 | 68 | 80 | 100 | 145 | 373 | 893 |
| APEC | 38 | 43 | 49 | 57 | 66 | 80 | 112 | 170 | 466 | 718 | 1,191 |
| Rest of the world | 758 | 814 | 894 | 971 | 1,000 | 1,010 | 1,128 | 1,190 | 1,303 | 1,427 | 1,844 |
| North America | 146 | 177 | 222 | 287 | 379 | 496 | 645 | 856 | 1,205 | 1,744 | 2,727 |
| Japan | 318 | 452 | 637 | 860 | 1,132 | 1,422 | 1,708 | 1,919 | 2,149 | 2,632 | 3,622 |
| EU | 181 | 275 | 414 | 613 | 1,319 | 2,324 | 3,307 | 5,257 | 10,387 | 16,006 | 29,252 |
| **Total** | 1,459 | 1,790 | 2,261 | 2,842 | 3,961 | 5,399 | 6,980 | 9,492 | 15,655 | 22,900 | 39,529 |

Figure 32 **Installed Capacity Worldwide (EPIA, 2011a)**

Further, the annual growth numbers can give more insight in the industry. A growing trend has been noticed since 2000, although Figure 33 shows clearly the decrease in growth of installed capacity in 2009. This in contradiction to the more than doubling of new installed capacity in 2010 compared to 2009, respectively 16,6GW and 7,3GW. The major part of new installed capacity came from Germany and Italy, respectively 7,4GW and 2,3GW. Germany thus installed in 2010 more new capacity than the whole world did in 2009. In fact, in 2009, there was 22,9GW installed capacity and with the 16,6GW added in 2010, the total installed capacity grew 72%. This grow is also typical for the group

‘Rest of the world’, although this does not state something specifically about South Africa. From the numbers it is clear that the solar energy industry is growing rapidly and shows a larger potential.

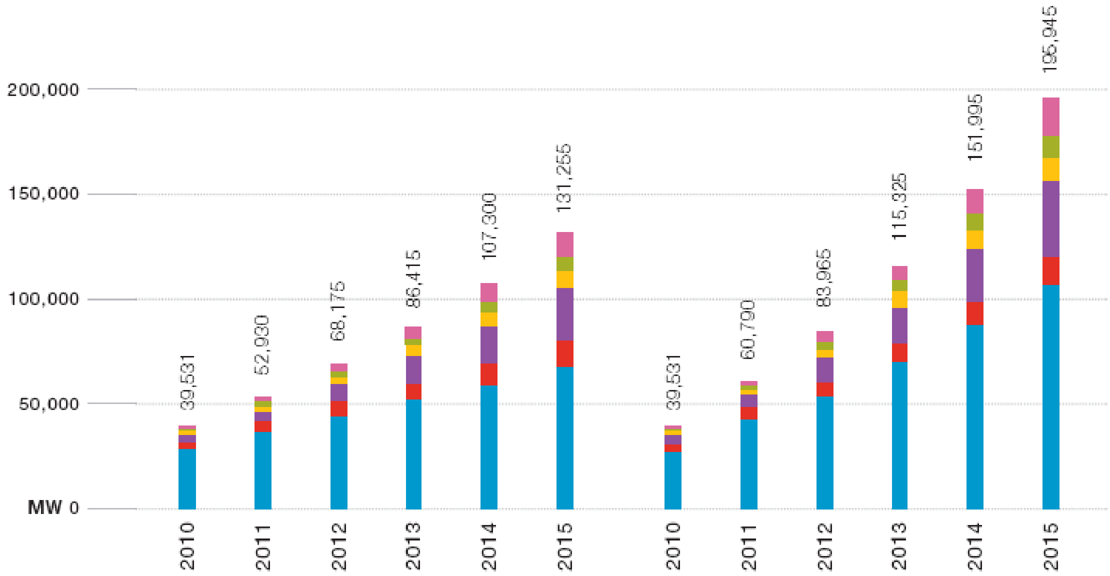



| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| China | 0 | 11 | 15 | 10 | 9 | 4 | 12 | 20 | 45 | 228 | 520 |
| APEC | 5 | 5 | 7 | 8 | 10 | 13 | 33 | 59 | 300 | 258 | 473 |
| Rest of the world | 88 | 56 | 80 | 77 | 29 | 10 | 118 | 63 | 115 | 130 | 417 |
| North America | 23 | 31 | 46 | 65 | 92 | 117 | 149 | 212 | 349 | 539 | 983 |
| Japan | 112 | 135 | 185 | 223 | 272 | 290 | 287 | 210 | 230 | 483 | 990 |
| EU | 52 | 94 | 139 | 199 | 707 | 1,005 | 983 | 1,950 | 5,130 | 5,619 | 13,246 |
| **Total** | 280 | 331 | 471 | 581 | 1,119 | 1,439 | 1,581 | 2,513 | 6,168 | 7,257 | 16,629 |

Figure 33 **Annual installed capacity Worldwide (EPIA, 2011a)**

## -Future Markets-

The expectations for the future can be divided into forecasts until 2015 and those until 2030. Starting with the forecast up to 2015 there is a difference between the EU and the rest of the world. The EU growth is expected to be low or even negative, whereas non-EU countries are expected to keep the global PV market growing until 2015. It is important to notice that the market still is an incentive driven market and that political support is required (EPIA, 2011a). The EPIA has produced two scenarios, one moderate scenario and one policy driven scenario. The expected installed capacity in 2015 ranges respectively between 131GW and 196GW, depending on the scenarios, Figure 34.




| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| China | 893 | 1,643 | 3,143 | 5,143 | 7,643 | 10,643 | 893 | 1,893 | 3,893 | 6,893 | 11,393 | 18,393 |
| APEC | 1,191 | 1,605 | 2,347 | 3,274 | 4,577 | 6,089 | 1,191 | 1,858 | 3,189 | 4,918 | 7,076 | 9,480 |
| Rest of the world | 1,844 | 2,644 | 4,144 | 6,144 | 8,144 | 10,144 | 1,844 | 2,844 | 4,644 | 7,144 | 9,644 | 12,144 |
| North America | 2,727 | 4,477 | 7,827 | 12,227 | 17,677 | 24,177 | 2,727 | 6,227 | 10,927 | 17,727 | 25,627 | 35,627 |
| Japan | 3,622 | 4,672 | 5,922 | 7,422 | 9,172 | 11,172 | 3,622 | 4,872 | 6,372 | 8,122 | 10,122 | 12,622 |
| EU | 29,252 | 37,817 | 44,812 | 52,222 | 60,072 | 68,992 | 29,252 | 42,977 | 54,802 | 70,382 | 87,992 | 107,492 |
| **Total** | **39,531** | **52,930** | **68,175** | **86,415** | **107,300** | **131,255** | **39,531** | **60,790** | **83,965** | **115,325** | **151,995** | **195,945** |
| | **EPIA Moderate (cumulative)** | | | | | | **EPIA Policy-Driven (cumulative)** | | | | | |

Figure 34 **Future outlook installed solar capacity worldwide (EPIA, 2011a)**

On the longer term, the potential of non-EU countries might become an important factor. The 'sunbelt' regions, near the equator, clearly have more potential for growth and it is economically and environmentally a sustainable option to fulfill their growing energy needs. China and India are expected to show the largest growth. Together the potential of the 'sunbelt' for 2020 is somewhere between 60GW and 250GW, and for 2030 this is even up to 260GW to 1100GW (EPIA, 2011a). Although South Africa, or a region including it, is not mentioned or appointed in this Global Market Outlook report, it comes forward as an opportunity in 'Unlocking the Sunbelt potential of photovoltaics', (EPIA, 2011b). Assuming three different scenarios', the moderate, advanced and paradigm shift, the forecasted potentials for South Africa range from 1,6GW to 5,5GW in 2020 and from 6,0GW to 19,9GW in 2030.

# Appendix B - Wind Energy

## -Trends in Wind Energy Capacity-

The Global Wind Energy Council (GWEC) provides information on the global development of wind energy. According to their Global Wind Report (2011), the global cumulative installed capacity has been rising during the last one and a half decade, see Figure 35. However, due to the financial crisis annual installations went down compared to 2009, Figure 36. The annual market has shrunk 0,5% to 38.3GW. Despite a decrease in installment of capacity in 2010 a 24,1% increase in total installed capacity was realized.

GLOBAL CUMULATIVE INSTALLED WIND CAPACITY 1996-2010

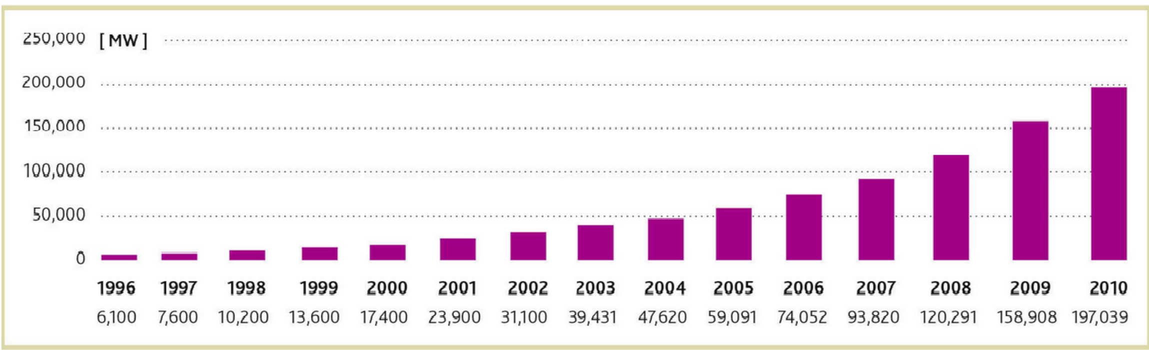



**Figure 35** **Global cumulative installed wind capacity 1996-2010 (GWEC, 2011)**

GLOBAL ANNUAL INSTALLED WIND CAPACITY 1996-2010

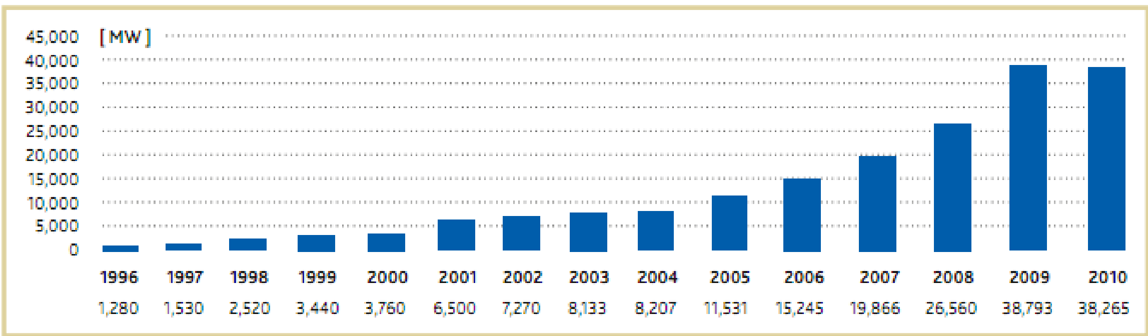



**Figure 36** **Global annual installed wind capacity 1996-2010 (GWEC, 2011)**

As can be seen in Figure 37 the annual installed capacity used to rise last years in the biggest wind energy producing regions Europe, North America and Asia. However, the financial crisis caused a sharp decline in North America. Almost 50% less new installed capacity was realized. For Europe, the decline was 7,5%, despite a 50% increase in offshore activities. Asia and Europe produced the largest part of new installed capacity, but most remarkable is the position of China. With a new 18.9GW installed capacity in 2010, they had a share of almost 50% in the absolute growth in 2010. Further, the regions Latin America and South America are developing, reaching a cumulative growth of 53% in 2010 (GWEC, 2011).

ANNUAL INSTALLED CAPACITY BY REGION 2003-2010

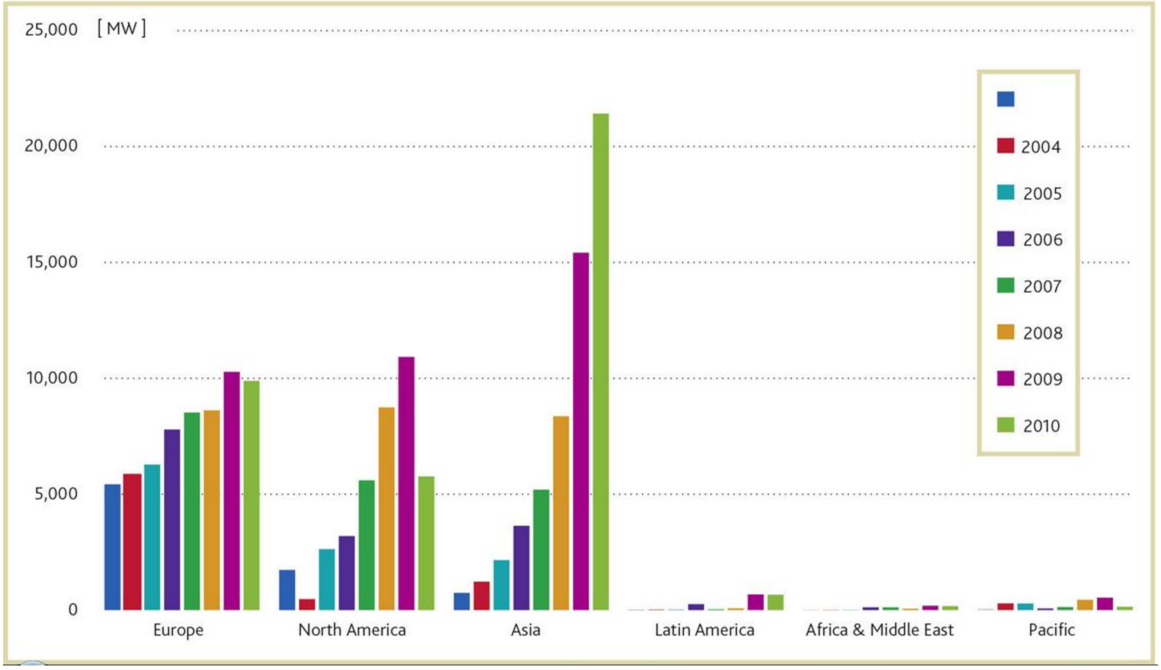



**Figure 37 Annual installed capacity by region 2003-2010 (GWEC, 2011)**

The African region also shows a growth, but at a different scale. The total capacity of Africa and the Middle East is slightly more than 1GW. Egypt leads this region with a cumulative 550MW installed capacity of which 120MW was installed during 2010. South Africa is placed under the category 'other' having only 8MW installed capacity. However, it is mentioned as a promising country, where 'wind project development is slowly yet firmly underway' (GWEC, 2011, pp17).

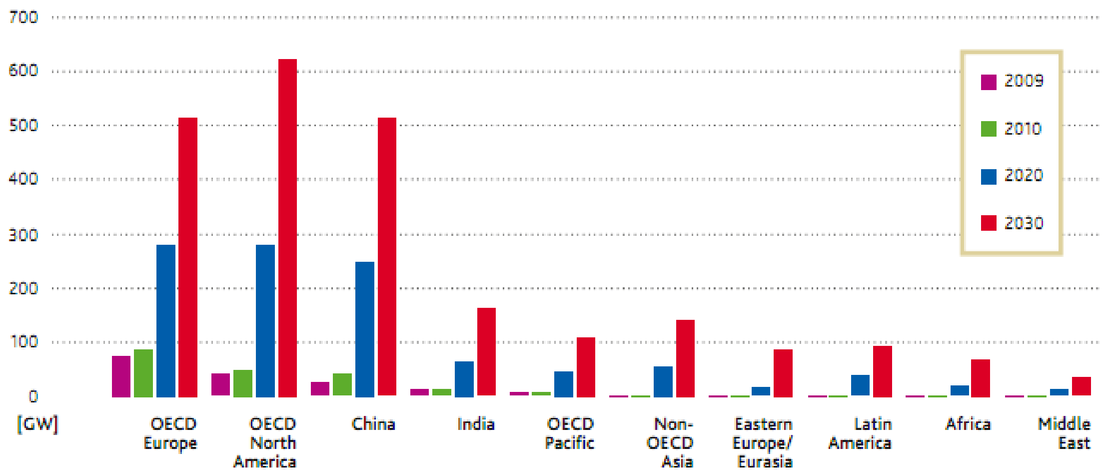
### -Future Markets-

The development of the wind energy market is important. Wind energy is considered to have a large share in the 'renewable' energy production in many countries. The developed countries use wind energy to reach goals for renewable energy production they agreed upon. To developing countries, there are economic, supply security and environmental drivers for this technology. However, the political will remains very important, complemented by financial support, incentive schemes and grid infrastructure (GWEC, 2011).

In the future, the wind energy market is expected to grow, Figure 38. Starting in the near future, the order books were filled again in 2010 resulting in promising growth of installed capacity during 2011 and 2012.

The emerging economies are expected to gain share of worldwide installed wind power capacity. By 2020, regions like Asia, Latin America, Africa and the Middle East are forecasted to have over 40% of the installed capacity instead of 31% nowadays. However, the largest part of that share will be due to the installed capacity of China.

REGIONAL BREAKDOWN: ADVANCED SCENARIO (GWEO 2010)




| | OECD Europe | OECD North America | China | India | OECD Pacific | Non-OECD Asia | Eastern Europe/ Eurasia | Latin America | Africa | Middle East |
|---|---|---|---|---|---|---|---|---|---|---|
| **2009** | 76 | 39 | 26 | 11 | 5 | 0.5 | 0.5 | 1 | 0.8 | 0.1 |
| **2010** | 87 | 50 | 41 | 13 | 6 | 0.7 | 0.9 | 2 | 1 | 0.1 |
| **2020** | 279 | 279 | 250 | 65 | 48 | 55 | 16 | 37 | 19 | 11 |
| **2030** | 515 | 622 | 513 | 161 | 109 | 140 | 87 | 93 | 67 | 34 |

Figure 38 **Regional breakdown: advanced scenario (GWEC, 2011)**

With respect to South Africa, there are not extended forecasts on wind energy. However, the renewable energy technologies should add to the required 40GW new generating capacity required in 2025. The SAWEA (South African Wind Energy Association) estimates that due to the abundant wind resources and South Africa's long coastline, wind power potential could provide up to 20% of the country's energy demand. This is equivalent to 30000MW of installed capacity. Further, they state that already 7000MW is under development, waiting for Power Purchase Agreements and grid connection allowance (GWEC, 2011).

# Appendix C – In-country Interview

## Introduction

This interview is conducted for a research enabled by the Utrecht University. The aim of that research is to identify the main barriers and drivers of the development of renewable energy technologies (RETs) in South Africa. These insights can help to accelerate mitigation strategies for South Africa.

For this research the Technological Innovation System (TIS) approach is used. The innovation system accounts for all components influencing RET like industry, consumers, education, government, NGO's, and financial structures. The interaction between the functions of the TISs of solar and wind energy is analyzed to see if they fulfill conditions needed for development. In the end, from the patterns of interaction barriers and drivers can be identified. However, since this theory is mainly used in developed countries, its applicability in developing countries or emerging economies should be considered part of this research as well.

With this interview I hope to gain more insights in the (renewable) energy sector of South Africa. Further, I hope to identify important events and I hope to identify issues missed in earlier research.

## Start

1. **Do you have concerns against the recording and publication of this interview?**
2. **Individual information**
    - Name
    - Function
    - Organization
    - …
3. **Phase of the RETs in South Africa. (See figure 1)**
    - In which phase of development is RET in South Africa now? (See figure 1)

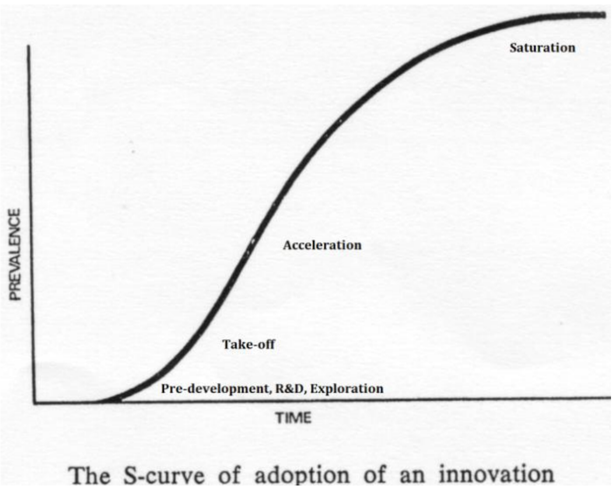



Figure 1

## Innovation Systems

**4. Components of the Innovation System (See figure 2)**

- For every block: Which actors or institutions are involved with RET?
- What are the most important actors, and what is missing according to you?

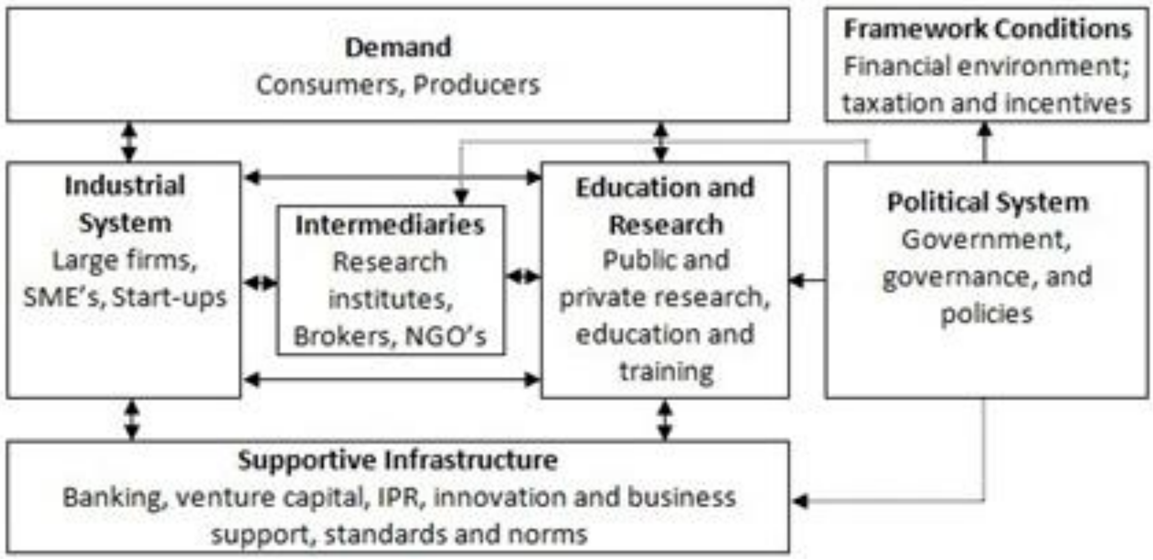



Figure 2

## Events

**5. Events that occurred.**

- Can you tell about projects started or stopped involved in RET in South Africa?
- Where these projects successful or are there projects that stopped? When? Who?
- Can you tell me about workshops/ conferences on RET? When? Who?
- Can you tell me about government regulations/ visions on RET? When? + or -?
- Can you tell me about the mayor investments in RET? When? Who?
- Have there been any protests against or in favor of RET?

## System Functions

| # | Name |
|---|---|
| F1 | Entrepreneurial Activity |
| F2 | Knowledge Development |
| F3 | Knowledge Diffusion |
| F4 | Guidance of the Search |
| F5 | Market Formation |
| F6 | Resource Allocation |
| F7 | Legitimation |

Table 1

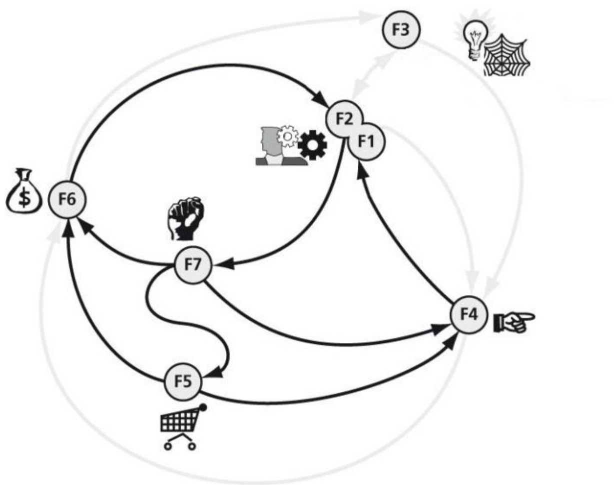


Figure 3

## Functions of the Technological Innovation System

**6. Entrepreneurial activity**

- Are there enough organizations involved in RET in South Africa according to you?
- Are there enough entrepreneurs involved in RET in South Africa according to you? Type/Foreign
- To what extend do they experiment?
- Is there an increase or decrease of firms involved in RET?
- Are there new entrants involved in RET or are it only the incumbent firms?

**7. Knowledge development and diffusion**

- Is there enough knowledge in SA to absorb RET?
- Who has this knowledge?
- Is knowledge development taking place on RET within SA?
- Who finances this?
- What is the quality of knowledge compared with abroad?
- Does technology get special attention in national programs?
- How is knowledge gained from users?
- Does the level of technological knowledge hampers the development of RET in SA?

- For knowledge diffusion: are there strong links/networks to stimulate this? Who?
- Are there opportunities/occasions/events to exchange knowledge?
- Is there use of licenses, patents, or other property rights? What is the impact?
- Does knowledge development and diffusion hamper the development of RET in SA?

**8. Guidance of the Search**

- Does the government have clear goals? Is this activating?
- Are goals supported by policy?
- Are these goals visibly supported by important actors?
- What are the technological expectations of RET in SA?
- Does this influence the process of change do you think?
- Does laws or rules have to be changed to stimulate the development of RET?
- Are there negative views on RET in SA? Who supports these views?

**9. Market Formation**

- Who are the users/consumers?
- What is the size of the market?
- Which institutional factors influence market formation most? Or what is done to stimulate the market for RET in SA (rules, taxes, campaigns)? How much?
- Are these regulations and licence procedures adequate?
- Is the market for RET increasing?
- Are main users public or private?

**10. Resource Allocation**

- Are there enough resources available for the transition to RET? In which areas?
    - Specialized human resources
    - Financial resources
    - Venture capital
    - Manufacturing capacity
    - Logistic capacity (vessels, ports)
    - Technological development
- How is the money divided in terms of research vs. project implementation?
- Are resources made available by the government? Which? How?
- Can firms make enough resources available? Where is the money coming from?

– Is there lack of trained personnel regarding RET? How are people educated?

– How are these resources used?

- R&D
- Pilot projects
- Education
- Market implementation

**11. Creation of legitimacy**

– Is an investment in RET regarded as a legitimate investment decision?

– Is there resistance to change? How does this look like?

– Who resist?

– Is there formation of coalitions to counteract this resistance?

– Is there formation of coalitions to lobby for RET at the government?

## Final Issues

**12. Motors of Change**

– Are there positive feedback-loops present within the system do you think?

– Why? Why not?

**13. Advice/recommendations**

– What do you think that needs to be done to make RET a success in SA?

– Do you think I missed important aspects in the development of RET in SA?

**14. Thanks for time and participation in the interview.**

– Would you like to get the final research?